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Special Article

SPECIAL ARTICLE

Global Tracheostomy Collaborative: data-driven improvements in patient safety through multidisciplinary teamwork, standardisation, education, and patient partnership

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Summary

There is growing recognition of the need for a coordinated, systematic approach to caring for patients with a tracheostomy. Tracheostomy-related adverse events remain a pervasive global problem, accounting for half of all airway-related deaths and hypoxic brain damage in critical care units. The Global Tracheostomy Collaborative (GTC) was formed in 2012 to improve patient safety and quality of care, emphasising knowledge, skills, teamwork, and patient-centred approaches. Inspired by quality improvement leads in Australia, the UK, and the USA, the GTC implements and disseminates best practices across hospitals and healthcare trusts. Its database collects patient-level information on quality, safety, and organisational efficiencies. The GTC provides an organising structure for quality improvement efforts, promoting safety of paediatric and adult patients. Successful implementation requires instituting key drivers for change that include effective training for health professionals; multidisciplinary team collaboration; engagement and involvement of patients, their families, and carers; and data collection that allows tracking of outcomes. We report the history of the collaborative, its database infrastructure and analytics, and patient outcomes from more than 6500 patients globally. We characterise this patient population for the first time at such scale, reporting predictors of adverse events, mortality, and length of stay indexed to patient characteristics, co-morbidities, risk factors, and context. In one example, the database allowed identification of a previously unrecognised association between bleeding and mortality, reflecting ability to uncover latent risks and promote safety. The GTC provides the foundation for future risk-adjusted benchmarking and a learning community that drives ongoing quality improvement efforts worldwide.

Keywords: adverse events; length of stay; patient safety; quality improvement; standardised care; tracheostomy

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Editor's key points

- The authors describe the development and implementation of a global quality improvement collaborative to improve patient-centred tracheostomy care.
- The Global Tracheostomy Collaborative created new partnerships to disseminate knowledge through webinars and international forums.
- The characteristics of the 6500 global patient database are described, reporting predictors of adverse events, mortality, and length of stay indexed to patient characteristics, co-morbidities, risk factors, and context.
- This provides the foundation for future risk-adjusted benchmarking and a learning community that drives ongoing quality improvement efforts worldwide.

Tracheostomy is one of the oldest surgical procedures, with descriptions carved on ancient Egyptian clay tablets dating back to 3600 Before the Common Era (BCE)[1,2] and instruction in the surgical technique found from 2000 BCE.[3–5] Alexander the Great, legend has it, performed a surgical tracheostomy in the fourth century BCE, using the tip of his sword to open the windpipe of a choking soldier.[6] Indications for tracheostomy have evolved in both adult and paediatric practice; the most common indication for tracheostomy currently is to facilitate ventilation in critically ill patients (70%), in contrast to the classical indication of threatened or actual airway obstruction enduring for the minority.[7–12]

The number of tracheostomies performed annually in resource-rich countries is estimated at 250 000, with approximately 10% performed in children.[13–17] Fewer procedures are performed in low- and middle-income countries, although such data are limited.[18–20] Patients with tracheostomy have increasingly complex needs, managed in diverse settings by multiple staff, and have needs that cross traditional working boundaries.[21] The need for placement of a tracheostomy is indicative of significant airway or respiratory pathology. Mortality rates in patients requiring tracheostomy are 10–60%, depending on co-morbidities.[17] Whilst many patients who undergo tracheostomy are critically ill and may succumb to underlying disease, there is also significant permanent harm or mortality that is directly attributable to having a tracheostomy. In many instances, such harm relates to inadequate care and is preventable.[22,23]

Several critical knowledge gaps exist pertaining to tracheostomy care. These gaps include the epidemiological characteristics of patients, clinical course, and predictors of adverse outcomes. Adding the patient voice directs healthcare staff to address deficits in quality of care,[24] particularly around vocalisation,[25] communication,[26] and enteral intake.[27] We report on the development of the Global Tracheostomy (Quality Improvement) Collaborative, an international partnership to improve the safety and quality of tracheostomy care, describing the origins, key drivers, outcomes, and impact to date, derived from patient-level data. The results of a 3 yr implementation in UK hospitals are reported in an accompanying paper.[28]

Scale and impact of tracheostomy-related adverse events

Recurrent reports highlight consistent themes from global hospitals and systems describing inadequacies in tracheostomy care.[29–32] Detailed reports from the UK have identified adverse events occurring in 20–30% of all hospitalised patients managed with a tracheostomy.[15,16,22] Rates varied depending on location, and although incidents were less frequent in critical care units, here, tracheostomy incidents accounted for up to half of all airway-related deaths and hypoxic brain damage.[33] Clinicians who perform tracheostomies include anaesthetists, intensivists, surgeons, and pulmonologists using a variety of percutaneous, open surgical, or hybrid techniques. Whilst insertion incidents occur, the vast majority of adverse events occur post-procedure, with reports dominated by tube obstruction and displacement.[34–36] Analysis affords a major opportunity for quality improvement (QI), as events overwhelmingly occur in the absence of systems that could have prevented harm.

Strategies to improve care

Analogous to landmark work with central venous catheter bundles,[37–39] improvements in the safety and quality of tracheostomy care cannot be realised solely through education.[40] Eradicating preventable morbidity and mortality requires systems that ensure comprehensive training and technical skills, staffing, equipment provision, and appropriate organisational support structures.[41–49] Furthermore, such systems should provide clinical decision support, human-factors engineering, and infrastructure that ensures expertise is available in an emergency.[31,50–54] Comprehensive tracheostomy care requires traditional clinical boundaries to be crossed and efforts to improve care to date have typically been speciality-specific, limiting the impact. Similarly, data collection has been siloed, or restricted to a particular part of the patient journey (such as surgery). The Global Tracheostomy Collaborative (GTC) aimed to take a whole-systems approach to improving care by combining successful approaches across disciplines.

In the past two decades, two hospitals with very different populations on different continents independently implemented institution-wide approaches for transforming tracheostomy care, reducing adverse events 10-fold.[55] The approach at St Mary's, London, UK was bundle based and reminiscent of the keystone central line initiative, whilst the strategy at Austin Healthcare, Melbourne, Australia involved an itinerate tracheostomy review and management service spearheaded by speech-language pathologists with multidisciplinary engagement.[25] In addition to reducing adverse events, reductions in length of stay (LOS) and total tracheostomy time were realised, associated with improvements in the quality of patients' lives, allowing communication and vocalisation much earlier.[25] Despite fundamentally divergent structures, these two positive outliers evolved surprisingly similar core elements to drive QI, serving as pillars for scalable strategies. In the USA, Johns Hopkins Medicine further innovated by initiating dedicated multidisciplinary engagement before tracheostomy.[56,57]

These bright spots[58] inspired the development of a global quality improvement collaborative (QIC). QICs drive

improvements in diverse areas, including door to balloon time in myocardial infarction,[59–61] central line infections,[62–65] falls prevention,[66] and paediatric disease.[67–70] Originally developed by the Institute for Healthcare Improvement,[71] QICs promote rapid dissemination of proven mechanisms from exemplars to enhance outcomes. QICs range from organ specific to contextual, and range in scope from small local coalitions to global endeavours, with participating institutions standardising approaches and tracking patient-level data to evaluate the impact of interventions.[72] Within the QIC structure, the member healthcare trusts designate champions leading the QI roll-out, introducing clearly defined interventions that catalyse progress towards the improvement objectives. The QIC model is highly conducive to implementing the complex set of interventions required to improve tracheostomy care.

Methods

Development of the Global Tracheostomy (quality improvement) collaborative

The growing body of evidence regarding preventable harm served as the impetus for change. Twenty-one international multidisciplinary experts in tracheostomy and QI convened in Glasgow, Scotland in 2012 to develop a strategy for improving tracheostomy care globally.[31] This leadership team discussed mission, guiding principles, and structure for the initiative, resulting in the incorporation of the GTC as a non-profit organisation in the USA. Governance and committee structures were established to support QI and dissemination of best practices, with the steering committee representing several early adopter charter hospitals.

After the development of an international privacy-law-compliant database, the GTC began holding kick-off meetings and enrolling hospital members in 2014. These member institutions are the pillars of the GTC, catalysing system-wide change. Hospital members orchestrate multidisciplinary teams that include medical, nursing, allied health professional staff, patients, and carers.[25,55,57,73,74] Teams prioritise interventions based on published evidence, the successes of others within the Collaborative, and changes proposed by their own expert team.[75] The impact of these interventions was then tracked using GTC reports describing patient data, anonymously benchmarked over time against other GTC member sites.

Individual patients, family members, or healthcare professionals can join the GTC, and they may do so without incurring the cost of institutional membership. As of December 2019, more than 3700 healthcare professionals and more than 175 patient/carer members had joined the GTC. All forms of membership allow access to webinars (www.globaltrach.org) and to the growing learning community. A network of patients, carers, clinicians, and corporate partners is growing and collaborating with the shared aim of improving the quality and safety of care of these patients.

Key drivers for tracheostomy QI

Whilst each healthcare environment faces unique challenges and opportunities, five common elements, or 'key drivers', were developed by expert consensus as the foundation for the GTC's QI efforts[75] (Supplementary Fig. S1).

Multidisciplinary team-based care

Multidisciplinary tracheostomy team replacing siloed care, meeting face to face to coordinate and plan care, overcoming barriers to effective communication between providers.[76–79] Team-based care has been shown to reduce adverse events, LOS, and time to decannulation; increase speaking valve use; and facilitate patient communication.[25,57,80–84]

Standardisation of care

Standardised care protocols provide consistency in care, environment, equipment, and patient and provider expectations.[80,85–87] Instituting such pathways and procedures promotes coordinated care, increases efficiency, and improves outcomes in airway emergencies.

Broad staff education

Hospitals develop strategies to educate staff and assure that patients with tracheostomy are cared for by trained providers.[88,89] As few as 2% of clinicians report being confident in managing tracheostomy emergencies.[90] Simulation[91–94] and related educational interventions markedly improve knowledge and confidence with in- and outpatient tracheostomy care.[51,95–99]

Patient and family involvement

Patients, family, and carers are engaged in tracheostomy education and QI.[100] Prioritising patient-centred care identifies key clinical outcomes, performance measures, and improvement areas that may otherwise not have been recognised.[101–105]

Patient-level data

Hospitals track outcomes using a prospective database with detailed patient-level data captured for each tracheostomy admission. Global Tracheostomy Collaborative-generated analytics allow the multidisciplinary team to benchmark their outcomes over time and anonymously with peers within the Collaborative to assess the impact of initiatives.

These elements are resourced by the GTC, and member sites are supported in implementation by GTC (and other) resources, webinars, publications, and peer support from within the Collaborative.

Amplifying the voice of patient, family, and carers

Partnership with patients and carers was a key catalyst for driving positive change in tracheostomy care. The patient advocacy motto, 'Nothing about us without us', captures the ethos of patient engagement that pervades GTC culture. Member institutions include a patient, their family, or carer as stakeholders within multidisciplinary tracheostomy teams. Boston Children's Hospital described how adding a family member to their team prompted identification and addressing of previously unrecognised challenges.[31] Furthermore, patients and families often describe very different performance metrics to those that would seem important to healthcare providers.[106]

The patient and family committee has multidisciplinary professional and international patient representation. A family member was present at our very first organisational

meeting. The Collaborative's board of directors has included the mother of a child with tracheostomy and an adult patient with tracheostomy and his spouse, ensuring patient/family input for all significant decisions. Early in the GTC, the committee leveraged social media platforms to gather input and perspectives from patients and families around the world. Data from this audience revealed that only half of respondents benefited from the opportunity to meet another patient with a tracheostomy before surgery. Only a minority felt prepared to handle tracheostomy care at discharge.[102] Capturing these perspectives helps clinicians understand and respond to the needs of patients.[24,107]

Dedicated family/caregiver sessions are integral to International Tracheostomy Symposia. The late Stephen Hawking, a theoretical physicist and cosmologist, shared his experiences of a 'full and active life' at the European launch of the GTC in 2014, describing his journey with a tracheostomy and laryngectomy. During the Baltimore international symposium in 2016, Orenthial J. Brigance, a former American national football player, described his experiences of how a tracheostomy helped him survive amyotrophic lateral sclerosis. Jennifer Arnold, a neonatologist and a star for *The Little Couple*, an American reality television series, highlighted the importance of using mannikins to educate patients in managing accidental tracheostomy displacement at the 2018 symposium in Dallas, TX, USA. In addition, some GTC member hospitals (such as Austin Health, Melbourne, Australia) host 'family forums', where patients and providers learn together. The GTC webinar, 'The voice of patients and families in tracheostomy care', demonstrated how virtual forums can enhance patient engagement and stimulate involvement of patient and family/carer advocates in QI.[108] Through periodic newsletters, e-mail, and social media channels, the GTC communicates with members and the public. The GTC has a presence on platforms, such as Facebook, Twitter, LinkedIn, and Instagram with the purpose of sharing the work of the GTC widely amongst the patient and family audience.

Strategic use of technology that engages the patient and family can be highly effective in disseminating knowledge. The National Tracheostomy Safety Project in the UK partnered with patients and families to develop educational videos. A targeted social media campaign generated 629 270 social media impressions over a 12 week campaign.[109] Part of the explanation for this viral response was the effectiveness of disseminating educational content into an already-vibrant online community.[110] Patients and carers, thus, share their perspectives with each other and with medical professionals involved in their care. These data highlight the immense potential of social media for improving tracheostomy safety.

Data capture and analytics

Development of the GTC database

The GTC database was developed by clinicians from nine disciplines, QI specialists, health information technology experts, and legal counsel, ensuring compliance with relevant global data privacy laws. The database was launched in June 2014, allowing member hospitals worldwide to enter patient-level data. It uses a password-protected privacy-compliant web-based software platform, Research Electronic Data Capture (REDCap), offering an intuitive interface for data capture with audit trails.[111,112]

The database captures patient characteristics, reason for tracheostomy, co-morbidities, LOS, ICU utilisation, tracheostomy duration, decannulation rates, adverse events, and mortality. It requires 15 min of data entry per patient.[8] The database currently holds more than 6500 tracheostomy admissions from 62 institutions and six countries, 4595 of which were analysed (Supplementary Table S2). Primary admissions were defined as episodes where a new tracheostomy was inserted, with secondary admissions involving an existing tracheostomy. This report concerns primary admissions admitted on or before December 31, 2018. Analysis was conducted in September 2019, allowing 8 months to capture completed episodes and clean data. We excluded hospitals without regular accrual, defined as <20 admissions entered (Supplementary Fig. S2).

The Center for Applied Pediatric Quality Analytics provides analytic support and identifies missing, inconsistent, or inaccurate data. Annual comparative reports allow member hospitals to monitor outcomes, prioritise interventions, and compare against other member hospitals. Additionally, hospitals can export from REDCap and analyse their own data.

Analytical methods

De-identified data analysis was conducted with methodology registered with the University of Michigan Institutional Review Board (Study eResearch ID: HUM00174895). Descriptive statistics with mean (standard deviation) or median (interquartile range) values are reported as appropriate. Kruskal–Wallis test compared non-parametric continuous variables and $\chi 2$ test compared categorical variables. Unadjusted logistic regression models examined univariate predictors of tracheostomy outcomes (extended LOS, mortality, and adverse events) using generalised estimating equations to account for correlation within sites. Results are presented as forest plots with odds ratios and 95% confidence intervals. Analyses were performed using SAS software (version 9.4; SAS Institute Inc., Cary, NC, USA).

Results

After exclusions (Supplementary Fig. S2), data from 1152 paediatric and 3443 adult primary admissions are summarised in Table 1. Ninety-two per cent of patients were admitted to a critical care unit, of which 92% were ventilated transiently. Eighty-seven percent of patients survived to hospital discharge, with 55% of survivors decannulated before hospital discharge. Decannulation rates differed significantly between continents ($P<0.001$), reflecting care model variations in acute and rehabilitation hospitals in different countries (Table 2).

Paediatric patients had significantly longer median hospital LOS (66 [34–130] days) *vs* adults (34 [16–60] days; $P<0.001$), and significantly longer median tracheostomy times (36 [19–69] days) *vs* adults (6 [9–30] days; $P<0.001$). The tracheostomy duration was similar to LOS in the USA, in contrast to the UK and Australia, where tracheostomy duration was significantly shorter than LOS. Decannulation rate in the USA was only 8%, likely owing to swift patient transitions to long-term facilities,

Table 1 Clinical course and discharge disposition of patients with new tracheostomy. Survival, decannulation, ventilation, ICU admission, length of stay (LOS), tracheostomy duration, and discharge location are described for paediatric and adult patients. Data are reported as *n* (%) or medians (inter-quartile range) days, in the case of durations. Survival, ventilation, and ICU admissions were generally similar in paediatric and adult patients. Notable differences were observed for rates of decannulation and LOS, with adult patients more likely to be decannulated and to have shorter LOS.

		Paediatric admissions (*n*=1152)	Adult admissions (*n*=3443)
Survival to discharge	Survived	1002 (87)	2833 (82)
	Died	86 (7)	457 (13)
	Unknown	64 (6)	153 (4)
Decannulated by discharge	Yes	49 (4)	1795 (52)
	No	1028 (89)	1460 (42)
	Unknown	75 (7)	188 (5)
Any time ventilated	Yes	1038 (90)	2894 (84)
	No	108 (9)	517 (15)
	Unknown	6 (1)	32 (1)
Admitted to ICU	Yes	1094 (95)	3152 (92)
	No	54 (5)	261 (8)
	Unknown	4 (0)	30 (1)
LOS collected		1071 (93)	3219 (93)
Hospital LOS (days)	(*n*=5326)	66 (34, 130)	34 (16, 60)
Tracheostomy time (days)	(*n*=4798)	36 (19, 69)	16 (9, 30)
Discharge disposition	Deceased	86 (7)	457 (13)
	Home	641 (56)	1331 (39)
	Acute care hospital	108 (9)	343 (10)
	Long-term care facility	35 (3)	363 (11)
	Rehabilitation hospital	139 (12)	508 (15)
	Skilled nursing facility	53 (5)	213 (6)
	Other	15 (1)	53 (2)
	Not recorded	75 (7)	175 (5)

Table 2 Comparison of adult tracheostomy-related outcomes across countries. Selected outcomes are shown for the three countries most heavily represented in the Global Tracheostomy database. Data are reported as median (inter-quartile range [IQR]) days for durations, *n* (%) for decannulation and mortality, and rate per 1000 tracheostomy days (95% confidence interval [CI]) for adverse events. Reduced durations, adverse events, and decannulation rates were observed for the USA, likely reflecting rapid transition of patients into rehabilitation facilities and potential differences in reporting practices.

	Australia	UK	USA	*P*-value
Tracheostomy duration, median days (IQR)	20 (12–34)	17 (9–32)	11 (7–19)	<0.001
Length of stay, median days (IQR)	46 (31–67.5)	43 (25–71)	12 (6–27)	<0.001
Decannulation, *n* (%)	348 (86)	1383 (69)	64 (8)	<0.001
Adverse events, rate per 1000 tracheostomy days (95% CI)	10.2 (8.6–12.1)	8.5 (7.7–9.3)	5.1 (3.8–6.9)	<0.001
Mortality, *n* (%)	51 (13)	321 (16)	85 (10)	<0.001

whereas most patients were decannulated in Australia and the UK (P<0.001) (Table 2).

Mortality predictors

Paediatric mortality was strongly associated with age, cardiovascular disease, haematological/immunological, and oncological co-morbidities (Fig. 1). Prognosis was favourable for children aged 1–3 yr; used as a comparator for identifying mortality risk in other age groups. Relative risk of mortality increased 10-fold for children ≥10 yr old, with significant mortality increases also observed in neonates. Mortality was lower in children with neurological conditions, with a tendency towards decreased mortality in patients with musculoskeletal or cutaneous co-morbidities.

Adult mortality showed strongest associations with indications for tracheostomy, number of co-morbid systems, sepsis, and advanced renal or gynaecological disease. There was a stepwise increase in mortality as a function of the co-morbid systems (Fig. 1), with a five-fold mortality increase observed with four or more co-morbidities. Emergency tracheostomy doubled mortality, and tracheostomy to facilitate ventilation was associated with a four-fold increase, likely related to the underlying pathophysiology associated with critical airway conditions or critical illness. Plausibly, trauma or psychiatric co-morbidities were associated with decreased mortality, likely related to younger age groups or fewer co-morbidities.

In-patient mortality was lowest in the USA followed by Australia and then the UK. This variation likely reflects different indications and thresholds for tracheostomy, and

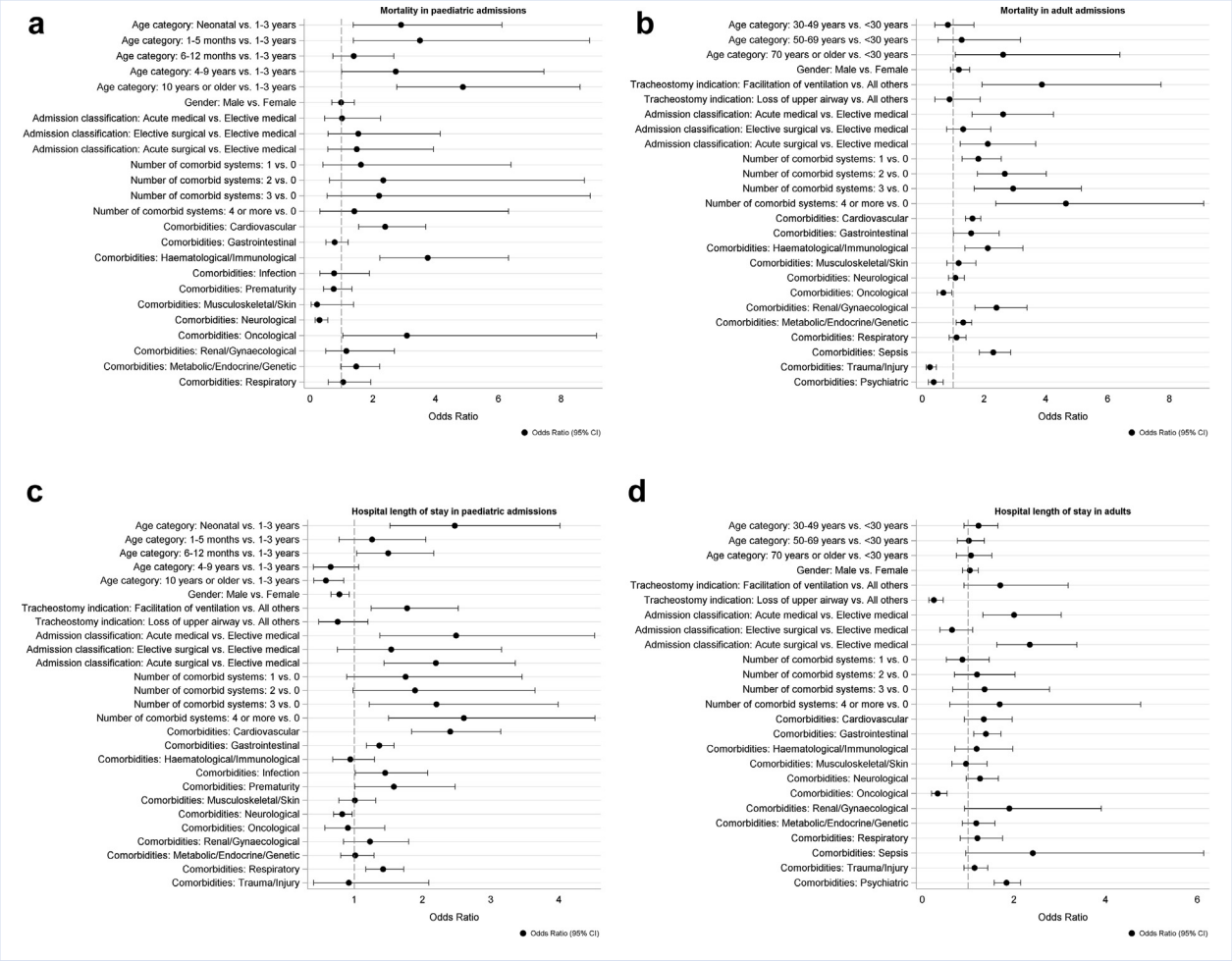

Fig 1. Mortality and length of stay in patients with new tracheostomy. (a) Mortality in children. (b) Mortality in adults. (c) Hospital length of stay in children. (d) Hospital length of stay in adults. CI, confidence interval.

failure to capture deaths that occur after transfer of patients to rehabilitation facilities. In addition, resource considerations may inform regional practices relating to performing tracheostomy for progressive neurodegenerative conditions.

Duration of care

Duration of particular periods of care (e.g. LOS and tracheostomy time) is dependent on many factors. Changes in LOS afford a window into the operational efficiency, coordination, and systems-based practice of institutions. Prior studies have noted that the prognosis and LOS of patients with tracheostomy may relate to complex co-morbidities,[113–116] requirement for emergent airway, and patient characteristics.[56,57,117]

Likelihood of prolonged LOS was increased two- to three-fold in neonates compared with children 1–3 yr old. There was a stepwise increase in LOS as a function of increasing co-morbidities, with a two- to three-fold LOS increase with four or more co-morbidities. The co-morbidities most strongly associated with prolonged LOS included cardiovascular, prematurity, respiratory, infectious, and gastrointestinal disorders (Fig. 2).

In adult patients, medical co-morbidities, sepsis, and emergent tracheostomy were associated with prolonged LOS. Patients with sepsis or psychiatric conditions had a two- to three-fold increase in LOS. In contrast, likelihood of prolonged LOS was half for patients who underwent tracheostomy for cancer or loss of upper airway. Likely explanations include the lower incidence of multi-organ dysfunction in patients with head and neck cancer, upper airway obstruction, or other anatomical anomalies.

Adverse events

Around 8% of patients experienced at least one adverse event related to tracheostomy, with an overall rate of 8.4% and 3.9% per 1000 tracheostomy days for adults and children, respectively; the total adverse events were 692 and 258 for adults and children, respectively (Table 3). The commonest adverse events in children were similar to adults, albeit with significantly lower rates of haemorrhage and roughly double the incidence of tube obstruction.

Accidental decannulation in paediatric and adult patients is an unpredictable event that may lead to catastrophic

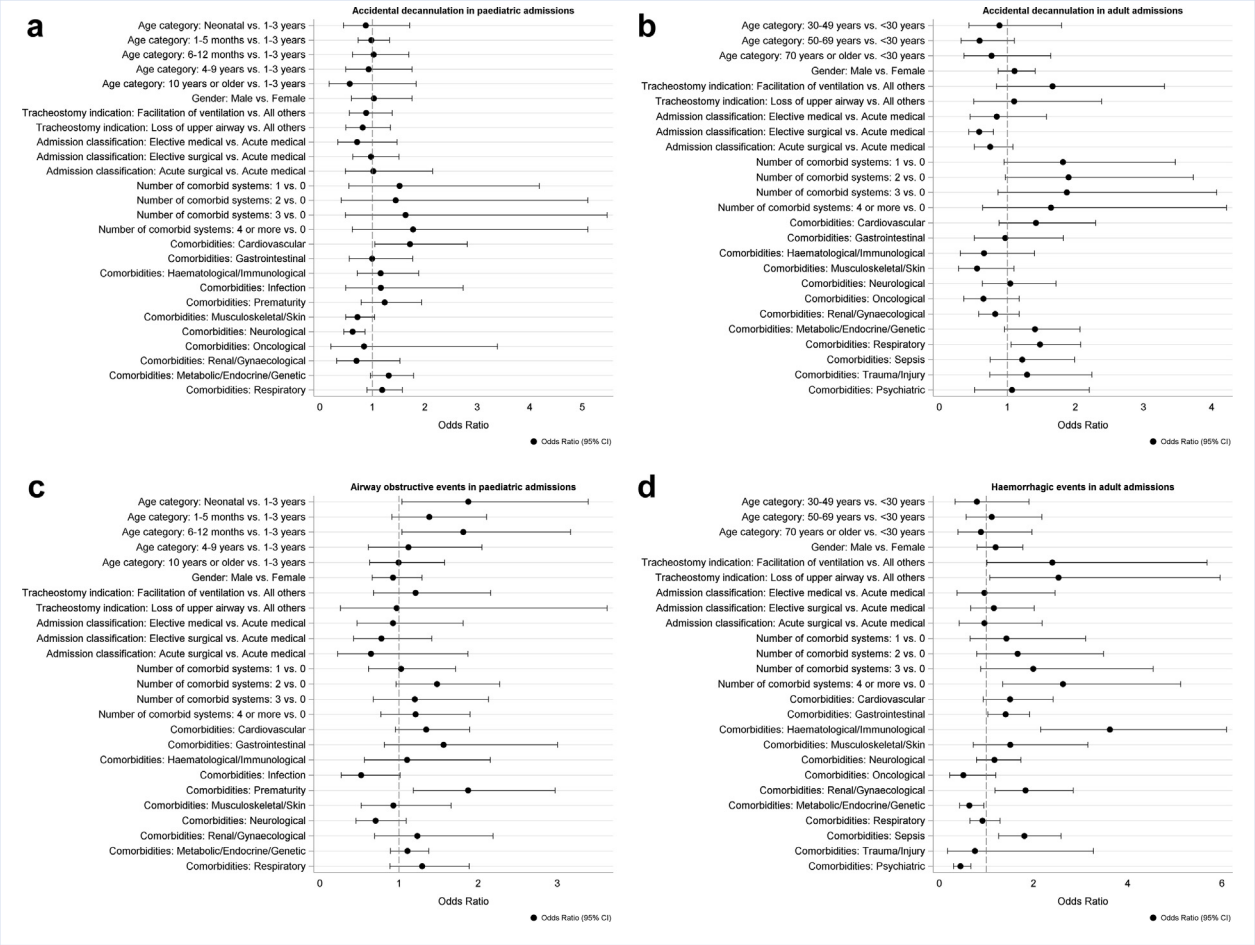

Fig 2. Adverse events in patients with new tracheostomy. (a) Accidental decannulation in children. (b) Accidental decannulation in adults. (c) Airway obstructive events in children. (d) Haemorrhagic events in adults. CI, confidence interval.

outcomes, including hypoxic brain injury and death. Whilst optimising tube position and orientation may afford a measure of protection,[118] in paediatric patients, the only significant positive association with accidental decannulation was cardiovascular disease; the sole negative association was neurological co-morbidity, possibly reflecting the decreased mobility of this group. The most notable finding in both adults and children was the stepwise trend towards increased accidental decannulation risk with increasing co-morbidity count, albeit with wide confidence intervals (Fig. 2).

Tube obstruction can lead to significant consequences in children because of small-calibre paediatric devices and limited respiratory reserve. As expected, tube obstruction was significantly higher in neonatal groups, consistent with the size of tracheostomy tubes required.

The incidence of adverse events was lowest in the USA followed by the UK and then Australia. This variation may arise from differing reporting and documentation practices, a litigious medico-legal environment in the USA, and failure to capture adverse events that may occur after transfer of patients to rehabilitation facilities. Much of the difference in adverse events may relate to under-reporting or cultural approaches to untoward outcomes.[119]

Haemorrhage

Haemorrhagic events were defined as 'excessive bleeding' (in the clinical opinion of the reporter) and featured more prominently than expected, based on previous analyses of incident series (Fig. 3). In paediatric patients, the cause of haemorrhage was often unknown. Local wound breakdown and stomal or tracheal granulation were the most commonly reported associations, whereas in adults, major vessel erosion, local wound breakdown, and granulation were most common, consistent with the literature.[120,121] Analysis of risk factors for tracheostomy-related haemorrhage in adults showed a stepwise trend towards increasing risk with increasing co-morbidity, although the risk of haemorrhage was only significantly increased with four or more co-morbidities. Haematological abnormalities, sepsis, renal, or gastrointestinal co-morbidities were all independent risk factors for haemorrhage; intuitive findings with known associations with bleeding. Considering indications for tracheostomy, tracheostomy to facilitate ventilation or for loss of airway increased the risk of haemorrhage.

Analysis of haemorrhagic events provides a compelling example of the power of data analysis at this scale to uncover potent predictors of clinical outcomes. Patients with

Table 3 Prevalence of adverse events amongst paediatric and adult patients with new tracheostomy. Adverse events in paediatric and adult patients are shown in descending frequencies for adults. Data are presented as *n* and rate per 1000 tracheostomy bed days (TBD; 95% confidence intervals [CIs]) with accidental decannulation being the most common for both paediatric and adult patients. Because median length of stay in paediatric patients was approximately double that for adults, a similar rate of a given adverse event per 1000 tracheostomy bed days corresponds to a two-fold risk during hospital stay, as in the case of tube obstruction. Tracheostomy-related haemorrhage, failed decannulation, and cuff-injury-related airway injury/hypoxaemia were higher amongst adult patients, whereas excessive granulation tissue had a predilection for paediatric patients.

	Paediatric (*n*=1152)		Adult (*n*=3443)	
	Total events	Rate per 1000 TBD (95% CI)	Total events	Rate per 1000 TBD (95% CI)
Accidental decannulation	92	1.52 (1.2–1.9)	167	2.28 (2.0–2.7)
Tracheostomy-related haemorrhage	21	0.35 (0.2–0.5)	127	1.74 (1.5–2.1)
Tube obstruction	53	0.88 (0.7–1.1)	72	0.98 (0.8–1.2)
Skin breakdown	33	0.55 (0.4–0.8)	67	0.92 (0.7–1.2)
Failed decannulation	1	0.02 (0.0–0.1)	57	0.78 (0.6–1.0)
Cuff-related airway injury/hypoxaemia	1	0.02 (0.0–0.1)	56	0.77 (0.6–1.0)
Infection	5	0.08 (0.0–0.2)	24	0.33 (0.2–0.5)
One-way valve applied whilst cuff inflated	1	0.02 (0.0–0.1)	11	0.15 (0.1–0.3)
Alteration to trachea	2	0.03 (0.0–0.1)	8	0.11 (0.1–0.2)
Tracheoesophageal fistula	1	0.02 (0.0–0.1)	7	0.10 (0.0–0.2)
Cardiopulmonary compromise	4	0.07 (0.0–0.2)	6	0.08 (0.0–0.2)
Excessive granulation tissue	17	0.28 (0.2–0.5)	6	0.08 (0.0–0.2)
Tracheocutaneous fistula	4	0.07 (0.0–0.2)	5	0.07 (0.0–0.2)

tracheostomy who suffered haemorrhage demonstrated a prominent spike in mortality rate. There were 36 (27%) deaths amongst 132 adult patients with haemorrhage, in contrast to 421 (13%) deaths amongst 3158 adult patients without haemorrhage. There were seven (33%) deaths amongst 21 paediatric patients with haemorrhage in contrast to 79 (7%) deaths amongst 1067 paediatric patients without haemorrhage. Thus, across paediatric and adult patients, haemorrhage was associated with a two- to four-fold mortality risk ($P<0.001$). The most common causes of haemorrhage included bleeding diathesis, granulation tissue, wound breakdown, and mucosal or vascular injury (Fig. 3).

Discussion

Our report characterises a large population of patients with tracheostomy, reporting predictors of adverse events, mortality, and LOS, and laying the foundation for improved care for this vulnerable population. Patients with tracheostomy vary in age, anatomic airway considerations, and medical conditions.[7,122–126] Their management occurs in diverse hospital systems, each with unique organisational structures, demands, and governance, posing unique challenges for rigorous scientific investigations.[51,127,128] The presence of a tracheostomy can itself be a marker for underlying medical complexity,[129–131] further complicating risk adjustments and analyses.

Furthermore, risk of adverse events differs amongst patient subsets. For example, children have narrow lumen tracheostomy tubes that are highly susceptible to mucus plugging and occlusion,[86,97,132] whereas adults are more susceptible to bleeding from anticoagulation.[133–135] Similarly, patients who undergo tracheostomy attributable to anatomic obstruction for head and neck cancer have a different risk profile than critically ill patients whose primary indication for tracheostomy is ventilatory support.[136–140]

The finding that tracheostomy-specific haemorrhage was more frequent and more serious than was apparent on small-scale analyses has prompted the GTC to take action. Exemplar sites with low rates of haemorrhage rapidly disseminated existing resources and strategies to decrease haemorrhage and haemorrhage-related complications (http://tracheostomy.org.uk/healthcare-staff/improving-tracheostomy-care/itc-resources). Such progress would not be possible without this large data set, coupled with the GTC's infrastructure to disseminate best practice initiatives. Data captured by the Collaborative expand our understanding of what is known about tracheostomy,[141] uncovering latent risks and identifying impactful QI opportunities.

Hospitals differ in geography, healthcare structure, resources, and regulatory environment, all of which may influence implementation efforts.[142] For example, in the UK, centralised organisation and substantial capital investment[128] may yield different outcomes from more fragmented healthcare systems or low-resource settings.[143] There is a need for standardised protocols and approaches for decannulation.[131,144–146] The notion of collaboratives as learning communities is not new; however, their impact remains poorly understood because of the difficulty in randomising hospital-level and larger systems to specific intervention.[106] The GTC provides a network for not only learning, but also QI, research, and carer engagement.

The bimonthly webinars offered by the GTC address gaps in knowledge between and within disciplines, and contribute to overall knowledge about care of patients with tracheostomy. Moderators engage panellists from different countries and specialties to provide a well-rounded perspective and reflect local practices. Because the care of patients with tracheostomy is inherently multifaceted, webinars engage airway specialists, patients, carers, allied health professionals, and hospital leaders. These webinars are recorded and available at www.globaltrach.org. Webinars complement the educational meetings sponsored by the GTC, including both continental kick-off events and International Tracheostomy Symposia, hosted in Melbourne (Australia), London (UK), Baltimore (MD, USA), and Dallas (TX, USA) to date, anchoring education as a cornerstone of the GTC's mission.

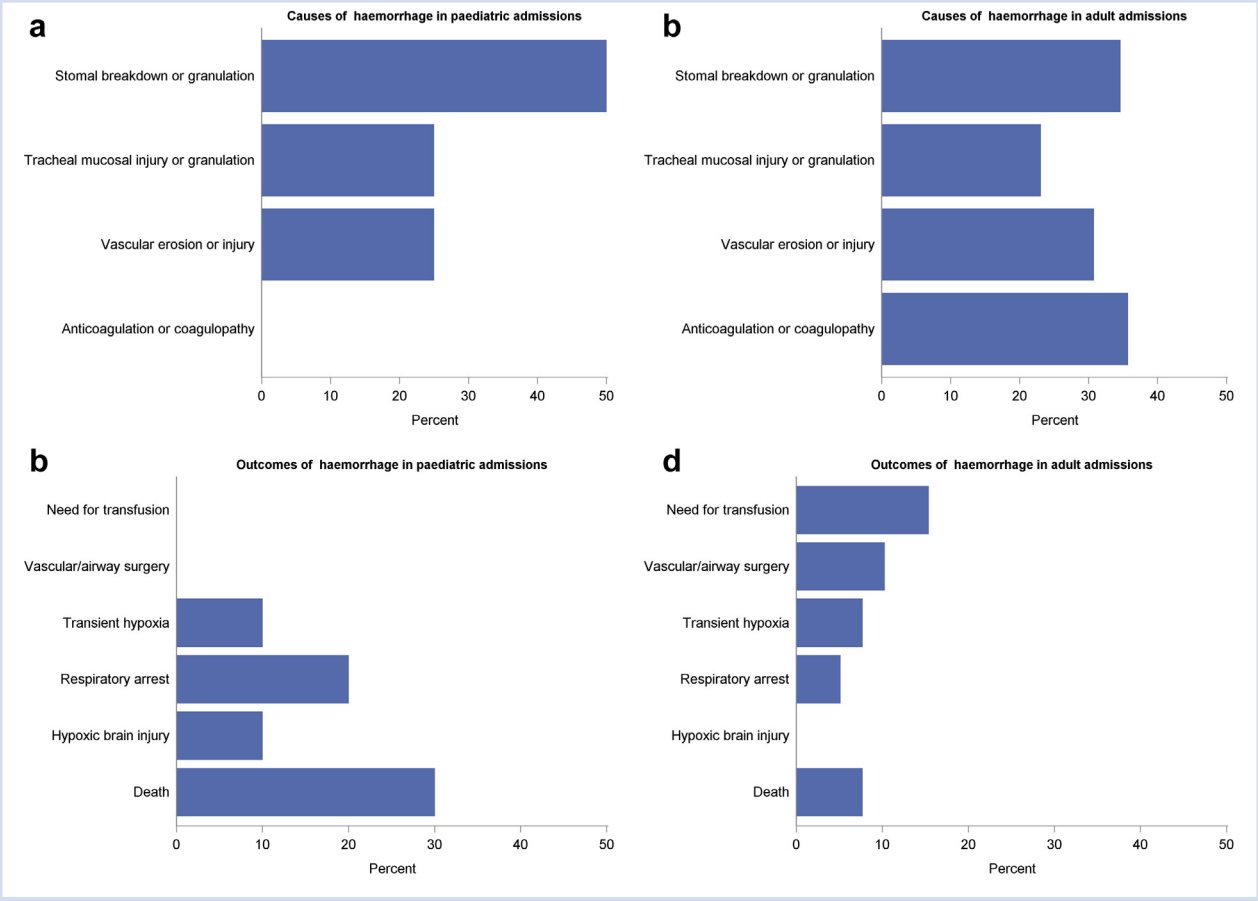

Fig 3. Primary causes and outcomes of haemorrhage in children (n=21) and adults (n=132) with tracheostomy. (a) Primary cause of haemorrhage (paediatric). (b) Primary cause of haemorrhage (adults). (c) Outcomes after haemorrhage (paediatric). (d) Outcomes after haemorrhage (adults).

Effective patient and carer education ensures optimal tracheostomy care after hospital discharge. One Midwest United States academic medical centre found that 34% of 928 patients discharged with a tracheostomy were readmitted because of pneumonia/secretions (n=204), hypoxia (n=46), or other tracheostomy-related complications (n=65).[147] This alarming readmission rate highlights the importance of empowering patients and carers with education to prevent complications and identify early warning signs before they warrant escalated care.[148]

The GTC engages patients and carers within all aspects of the Collaborative. One under-recognised aspect of patient-centred care is receptiveness of the healthcare team to embracing learning from patients and carers. Examples include reflective listening, supporting self-efficacy, building trust, and formulating strategies to promote independence of patients living with tracheostomy. The Collaborative shares and disseminates experiences and resources from exemplars in these practices.

Implementing the GTC's key drivers has resulted in safer care, reduced hospital and ICU LOS, and improved patient-focused quality of care.[127] Patients benefit from reductions in anxiety, shorter times to vocalisation, and earlier oral intake after tracheostomy.[127,149,150] The ability to track these metrics over time and benchmark between sites will add rigor to comparisons as the database expands. The UK Improving Tracheostomy Care project, reported in this issue, details not just the potential quality, safety, and economic impact, but also affords powerful insights into strategies for changes that are likely reproducible in sites around the world.[127]

One limitation of this study is the lack of detailed information pertaining to certain variables, such as accidental decannulation. Data on whether it was partial or complete decannulation were not elicited; however, the data set team plans to collect additional variables to elucidate clinically meaningful findings. Another limitation revolves around the fact that data collection for a particular episode was closed when a patient was discharged from the member hospital. This might explain the lower rates of decannulation in the USA compared with Australia and the UK, because patients typically tend to get discharged to long-term ventilator facilities in the USA and the member hospitals in the USA tend to be acute care facilities.

Conclusions

The past 15 yr have witnessed a major shift in the characteristics of patients with tracheostomy in tandem with the

modern paradigm emphasising system-wide improvements. We describe the development and implementation of a global QI collaborative that has promoted building a learning community by leveraging patient and family involvement, social media, international meetings, and webinars, and by capturing patient-level data. It is now possible to conduct an in-depth enquiry into problematic areas for improvement. Through the GTC, hospitals forge new partnerships and rapidly disseminate knowledge through participation in webinars and international forums, with a common goal of functioning as high-reliability organisations. The GTC, created in response to a pressing need for improving the prevailing standard of care, is now increasingly realising its potential to deliver transformational improvements in patient-centred tracheostomy care.

Authors' contributions

Study conception: MJB, LLM, TSC, BAM, DWR, PD, HZ, EW, SJW, AA, AN
Study design: MJB, LLM, TSC, BAM, DWR, VP, AP, DAG, CEM, KC, JMS, PD, HZ, EW, SJW, AA, AN
Data acquisition: MJB, LLM, TSC, BAM, DMR, VP, AP, JRB, CZ, JLA, BAS, DWR, DF
Data analysis/interpretation: all authors
Drafting: MJB, LLM, TSC, BAM, DMR, VP, AP, DAG, CEM, KC, JMS, JRB, CZ, JLA, BAS, DWR, DF
Critical revision of work for intellectual content: all authors
All authors provided final approval of article and agree to be accountable for all aspects of the work.

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Declaration of interest

The authors declare that they have no conflicts of interest. For transparency, the following authors serve in varying capacities within the Global Tracheostomy Collaborative (GTC): DR is the Founder and President; EW, MJB, AN, and TSC serve as the Board of Directors; and AA, BAM, CEM, CS, CZ, DR, DAG, JMS, JRB, LLM, SJW, and VP serve as committee members. EW received travel funding for International Tracheostomy Symposia. BAM is also the Chair of the UK National Tracheostomy Safety Project; European lead of the GTC; and national clinical advisor for tracheostomy, NHS England.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2020.04.054.

References

1. Stock CR. What is past is prologue: a short history of the development of tracheostomy. *Ear Nose Throat J* 1987; **66**: 166–9
2. Szmuk P, Ezri T, Evron S, Roth Y, Katz J. A brief history of tracheostomy and tracheal intubation, from the Bronze Age to the Space Age. *Intensive Care Med* 2008; **34**: 222–8
3. Carroll CM, Pahor A. The history of tracheotomy. *J Ir Coll Physicians Surg* 2001; **30**: 237–8
4. Ezri T, Evron S, Hadad H, Roth Y. Tracheostomy and endotracheal intubation: a short history. *Harefuah* 2005; **144**: 891–3. 908
5. Olszewski J, Milonski J. History of tracheotomy. *Otolaryngol Pol* 2007; **61**: 349–52
6. Trubuhovich RV. Primary sources and the tracheostomy legend about Alexander the Great. *J Anesth Hist* 2018; **4**: 38
7. Chia AZH, Ng ZM, Pang YX, et al. Epidemiology of pediatric tracheostomy and risk factors for poor outcomes: an 11-year single-center experience. *Otolaryngol Head Neck Surg* 2020; **162**: 121–8
8. Lavin J, Shah R, Greenlick H, Gaudreau P, Bedwell J. The Global Tracheostomy Collaborative: one institution's experience with a new quality improvement initiative. *Int J Pediatr Otorhinolaryngol* 2016; **80**: 106–8
9. O'Connor HH, White AC. Tracheostomy decannulation. *Respir Care* 2010; **55**: 1076–81
10. Sagiv D, Nachalon Y, Mansour J, et al. Awake tracheostomy: indications, complications and outcome. *World J Surg* 2018; **42**: 2792–9
11. Zenk J, Fyrmpas G, Zimmermann T, Koch M, Constantinidis J, Iro H. Tracheostomy in young patients: indications and long-term outcome. *Eur Arch Otorhinolaryngol* 2009; **266**: 705–11
12. Cheung NH, Napolitano LM. Tracheostomy: epidemiology, indications, timing, technique, and outcomes. *Respir Care* 2014; **59**: 895–915. discussion 6–9
13. Das P, Zhu H, Shah RK, Roberson DW, Berry J, Skinner ML. Tracheotomy-related catastrophic events: results of a national survey. *Laryngoscope* 2012; **122**: 30–7
14. Halum SL, Ting JY, Plowman EK, et al. A multi-institutional analysis of tracheotomy complications. *Laryngoscope* 2012; **122**: 38–45
15. McGrath BA, Thomas AN. Patient safety incidents associated with tracheostomies occurring in hospital wards: a review of reports to the UK National Patient Safety Agency. *Postgrad Med J* 2010; **86**: 522–5
16. Wilkinson K, Martin I, Freeth H, Kelly K, Mason H. *On the right trach? A review of the care received by patients who underwent a tracheostomy. A report by the National Confidential Enquiry into Patient Outcome and Death* 2014. Available from: https://www.ncepod.org.uk/2014report1/downloads/OnTheRightTrach_FullReport.pdf. [Accessed 29 November 2019]

17. Shah RK, Lander L, Berry JG, Nussenbaum B, Merati A, Roberson DW. Tracheotomy outcomes and complications: a national perspective. *Laryngoscope* 2012; **122**: 25–9
18. Sandler ML, Ayele N, Ncogoza I, et al. Improving tracheostomy care in resource-limited settings. *Ann Otol Rhinol Laryngol* 2020; **129**: 181–90
19. Adedeji TO, Tobih JE, Olaosun AO, Idowu J. Indications and outcomes of tracheostomy: an experience in a resource-limited environment. *J Health Res Rev* 2014; **1**: 40–3
20. Vanker A, Kling S, Booysen JR, et al. Tracheostomy home care: in a resource-limited setting. *Arch Dis Child* 2012; **97**: 121–3
21. Fernandez R, Bacelar N, Hernandez G, et al. Ward mortality in patients discharged from the ICU with tracheostomy may depend on patient's vulnerability. *Intensive Care Med* 2008; **34**: 1878–82
22. McGrath BA, Calder N, Laha S, et al. Reduction in harm from tracheostomy-related patient safety incidents following introduction of the National Tracheostomy Safety Project: our experience from two hundred and eighty-seven incidents. *Clin Otolaryngol* 2013; **38**: 541–5
23. Needham DM, Thompson DA, Holzmueller CG, et al. A system factors analysis of airway events from the intensive care unit safety reporting system (ICUSRS). *Crit Care Med* 2004; **32**: 2227–33
24. Ward E, Pandian V, Brenner MJ. The primacy of patient-centered outcomes in tracheostomy care. *Patient* 2018; **11**: 143–5
25. Cameron TS, McKinstry A, Burt SK, et al. Outcomes of patients with spinal cord injury before and after introduction of an interdisciplinary tracheostomy team. *Crit Care Resusc* 2009; **11**: 14–9
26. Pandian V, Boisen S, Mathews S, Brenner MJ. Speech and safety in tracheostomy patients receiving mechanical ventilation: a systematic review. *Am J Crit Care* 2019; **28**: 441–50
27. McGrath B, Coe JLB, Wallace S, Bonvento B, Eusuf D, Firn M. Improving tracheostomy care: collaborative national consensus and prioritisation of quality improvements in the United Kingdom. *Med Res Arch* 2018; **6**: 1–10
28. McGrath BA, Wallace S, Lynch J, et al. Improving tracheostomy care in the United Kingdom: results of a guided quality improvement program in 20 diverse hospitals. *Br J Anaesth* 2017
29. McGrath BA, Wilkinson K. The NCEPOD study: on the right trach? Lessons for the anaesthetist. *Br J Anaesth* 2015; **115**: 155–8
30. Wilkinson K, Freeth H, Kelly K. 'On the right trach?' A review of the care received by patients who undergo tracheostomy. *Br J Hosp Med (Lond)* 2015; **76**: 163–5
31. Roberson DW, Healy GB. The Global Tracheostomy Collaborative: multidisciplinary quality improvement in tracheostomy. *Bull Am Coll Surg* 2017; **102**(9): 44–5
32. Twose P, Jones G, Lowes J, Morgan P. Enhancing care of patients requiring a tracheostomy: a sustained quality improvement project. *J Crit Care* 2019; **54**: 191–6
33. Cook TM, Woodall N, Harper J, Benger J. Fourth national audit project. Major complications of airway management in the UK: results of the fourth national audit project of the royal college of anaesthetists and the difficult airway society. Part 2: intensive care and emergency departments. *Br J Anaesth* 2011; **106**: 632–42
34. McKeon M, Kohn J, Munhall D, et al. Association of a multidisciplinary care approach with the quality of care after pediatric tracheostomy. *JAMA Otolaryngol Head Neck Surg* 2019; **145**: 1035–42
35. McKeon M, Munhall D, Walsh BK, et al. A standardized, closed-loop system for monitoring pediatric tracheostomy-related adverse events. *Laryngoscope* 2018; **128**: 2419–24
36. Southcott AM, Holdsworth C, Malcolm L, Muruganandan S, Skinner E. Evaluation of the implementation of a Tracheostomy Review Services (TRS): an observational cohort study. *J Interprof Care* 2019; **33**: 697–705
37. Pronovost P. Interventions to decrease catheter-related bloodstream infections in the ICU: the keystone intensive care unit project. *Am J Infect Control* 2008; **36**: S171. e1–5
38. Pronovost PJ, Berenholtz SM, Goeschel C, et al. Improving patient safety in intensive care units in Michigan. *J Crit Care* 2008; **23**: 207–21
39. Costello JM, Morrow DF, Graham DA, Potter-Bynoe G, Sandora TJ, Laussen PC. Systematic intervention to reduce central line-associated bloodstream infection rates in a pediatric cardiac intensive care unit. *Pediatrics* 2008; **121**: 915–23
40. Balakrishnan K, Brenner MJ, Gosbee JW, Schmalbach CE. Patient safety/quality improvement primer, part II: prevention of harm through root cause analysis and action (RCA^2). *Otolaryngol Head Neck Surg* 2019; **161**: 911–21
41. Eskander A, de Almeida JR, Irish JC. Acute upper airway obstruction. *N Engl J Med* 2019; **381**: 1940–9
42. Meade JW. Tracheotomy—its complications and their management. A study of 212 cases. *N Engl J Med* 1961; **265**: 519–23
43. Casserly P, Lang E, Fenton JE, Walsh M. Assessment of healthcare professionals' knowledge of managing emergency complications in patients with a tracheostomy. *Br J Anaesth* 2007; **99**: 380–3
44. McGrath BA. Tracheostomy care: it is not just about the training. *Br J Anaesth* 2014; **112**: 940–1
45. McGrath BA, Doherty C. Quality of tracheostomy care is probably as important as timing. *Br J Anaesth* 2016; **116**: 300
46. Szakmany T. Quality of tracheostomy care is probably as important as timing. *Br J Anaesth* 2016; **116**: 301
47. Mark LJ, Herzer KR, Cover R, et al. Difficult airway response team: a novel quality improvement program for managing hospital-wide airway emergencies. *Anesth Analg* 2015; **121**: 127–39
48. McGrath BA, Bates L, Atkinson D, Moore JA, National Tracheostomy Safety Project. Multidisciplinary guidelines for the management of tracheostomy and laryngectomy airway emergencies. *Anaesthesia* 2012; **67**: 1025–41
49. Brenner MJ, Cramer JD, Cohen S, Balakrishnan K. Leveraging quality improvement and patient safety initiatives to enhance value and patient-centered care in otolaryngology. *Curr Otorhinolaryngol Rep* 2018; **6**: 231–8
50. Doherty C, Bowler M, Monks S, et al. Reduction in harm from tracheostomy-related incidents after implementation of the paediatric National Tracheostomy Safety Project resources: a retrospective analysis from a tertiary paediatric centre. *Clin Otolaryngol* 2018; **43**: 674–8
51. McGrath B, Wilkinson K, Shah RK. Notes from a small island: lessons from the UK NCEPOD Tracheotomy Report. *Otolaryngol Head Neck Surg* 2015; **153**: 167–9

52. Flanagan F, Healy F. Tracheostomy decision making: from placement to decannulation. *Semin Fetal Neonatal Med* 2019; **24**: 101037
53. Paulich S, Kelly FE, Cook TM. 'Neck breather' or 'neck-only breather': terminology in tracheostomy emergencies algorithms. *Anaesthesia* 2019; **74**: 947
54. Ng FK, McGrath BA. 'Neck-only breather' is a better term than 'neck breather' in algorithms and bedhead signs for the management of tracheostomy emergencies. A reply. *Anaesthesia* 2019; **74**: 1475
55. Arora A, Hettige R, Ifeacho S, Narula A. Driving standards in tracheostomy care: a preliminary communication of the St Mary's ENT-led multi disciplinary team approach. *Clin Otolaryngol* 2008; **33**: 596–9
56. Mirski MA, Pandian V, Bhatti N, et al. Safety, efficiency, and cost-effectiveness of a multidisciplinary percutaneous tracheostomy program. *Crit Care Med* 2012; **40**: 1827–34
57. Pandian V, Miller CR, Mirski MA, et al. Multidisciplinary team approach in the management of tracheostomy patients. *Otolaryngol Head Neck Surg* 2012; **147**: 684–91
58. Bodenheimer TS. Find the "bright spots". *Jt Comm J Qual Patient Saf* 2014; **40**: 147
59. Carlhed R, Bellman C, Bojestig M, et al. Quality improvement in coronary care: analysis of sustainability and impact on adjacent clinical measures after a Swedish controlled, multicenter quality improvement collaborative. *J Am Heart Assoc* 2012; **1**, e000737
60. Siegel B, Sears V, Bretsch JK, et al. A quality improvement framework for equity in cardiovascular care: results of a national collaborative. *J Healthc Qual* 2012; **34**: 32–42. quiz 42–3
61. Siriwardena AN, Shaw D, Essam N, et al. The effect of a national quality improvement collaborative on pre-hospital care for acute myocardial infarction and stroke in England. *Implement Sci* 2014; **9**: 17
62. Bonello RS, Fletcher CE, Becker WK, et al. An intensive care unit quality improvement collaborative in nine Department of Veterans Affairs hospitals: reducing ventilator-associated pneumonia and catheter-related bloodstream infection rates. *Jt Comm J Qual Patient Saf* 2008; **34**: 639–45
63. Ting JY, Goh VS, Osiovich H. Reduction of central line-associated bloodstream infection rates in a neonatal intensive care unit after implementation of a multidisciplinary evidence-based quality improvement collaborative: a four-year surveillance. *Can J Infect Dis Med Microbiol* 2013; **24**: 185–90
64. Wheeler DS, Giaccone MJ, Hutchinson N, et al. A hospital-wide quality-improvement collaborative to reduce catheter-associated bloodstream infections. *Pediatrics* 2011; **128**: e995–1004. quiz e1004–7
65. Wirtschafter DD, Pettit J, Kurtin P, et al. A statewide quality improvement collaborative to reduce neonatal central line-associated blood stream infections. *J Perinatol* 2010; **30**: 170–81
66. Arling PA, Abrahamson K, Miech EJ, Inui TS, Arling G. Communication and effectiveness in a US nursing home quality-improvement collaborative. *Nurs Health Sci* 2014; **16**: 291–7
67. Clauss SB, Anderson JB, Lannon C, et al. Quality improvement through collaboration: the national pediatric quality improvement collaborative initiative. *Curr Opin Pediatr* 2015; **27**: 555–62
68. Mathur M, Campbell S. Statewide pediatric quality improvement collaborative for HPV vaccine initiation. *WMJ* 2019; **118**: 42–3
69. Scott E, Downs S, Pottenger A, Saysana M. Quality improvement learning collaborative improves timely newborn follow-up appointments. *Jt Comm J Qual Patient Saf* 2019; **45**: 808–13
70. Tripathi S, Nunez DJ, Katyal C, Ushay HM. Plan to have no unplanned: a collaborative, hospital-based quality-improvement project to reduce the rate of unplanned extubations in the pediatric ICU. *Respir Care* 2015; **60**: 1105–12
71. Wells S, Tamir O, Gray J, Naidoo D, Bekhit M, Goldmann D. Are quality improvement collaboratives effective? A systematic review. *BMJ Quality and Safety* 2018; **27**(3): 226–40
72. Barron CL, Elmaraghy CA, Lemle S, Crandall W, Brilli RJ, Jatana KR. Clinical indices to drive quality improvement in otolaryngology. *Otolaryngol Clin North Am* 2019; **52**: 123–33
73. Bonvento B, Wallace S, Lynch J, Coe B, McGrath BA. Role of the multidisciplinary team in the care of the tracheostomy patient. *J Multidiscip Healthc* 2017; **10**: 391–8
74. McGrath BA, Wallace S. The UK National Tracheostomy Safety Project and the role of speech and language therapists. *Curr Opin Otolaryngol Head Neck Surg* 2014; **22**: 181–7
75. Enamandram SS, Peltz A, Arora A, Narula AA, Roberson DW, Hettite R. The Global Tracheostomy Collaborative: the future of quality improvement strategies. *Curr Otorhinolaryngol Rep* 2014; **2**: 13–9
76. Abode KA, Drake AF, Zdanski CJ, Retsch-Bogart GZ, Gee AB, Noah TL. A multidisciplinary children's airway center: impact on the care of patients with tracheostomy. *Pediatrics* 2016; **137**, e20150455
77. Yaneza MM, James HL, Davies P, et al. Changing indications for paediatric tracheostomy and the role of a multidisciplinary tracheostomy clinic—ERRATUM. *J Laryngol Otol* 2015; **129**: 1256
78. Brenner MJ. Implementing multidisciplinary team care for tracheostomy patients: a way to go before we rest. In: *Proceedings of the 4th international tracheostomy symposium GTC. Dallas, TX*; 2018
79. Zhao C, MacEachern M, MacEachern M, Brenner MJ, Sun G. A systematic review and meta-analysis of multidisciplinary team-based tracheostomy management outcomes. In: *Proceedings of the 4th international tracheostomy symposium GTC. Dallas, TX*; 2018
80. Cetto R, Arora A, Hettige R, et al. Improving tracheostomy care: a prospective study of the multidisciplinary approach. *Clin Otolaryngol* 2011; **36**: 482–8
81. Garrubba M, Turner T, Grieveson C. Multidisciplinary care for tracheostomy patients: a systematic review. *Crit Care* 2009; **13**: R177
82. Speed L, Harding KE. Tracheostomy teams reduce total tracheostomy time and increase speaking valve use: a systematic review and meta-analysis. *J Crit Care* 2013; **28**: 216. e1–10
83. Prager JD, Baker CD. The multidisciplinary tracheostomy team: a parachute for tracheostomy-dependent children. *JAMA Otolaryngol Head Neck Surg* 2019; **145**: 1042–3
84. Holmes TR, Cumming BD, Sideris AW, Lee JW, Briggs NE, Havas TE. Multidisciplinary tracheotomy teams: an

analysis of patient outcomes and resource allocation. *Ear Nose Throat J* 2019; **98**: 232–7
85. Gaudreau PA, Greenlick H, Dong T, et al. Preventing complications of pediatric tracheostomy through standardized wound care and parent education. *JAMA Otolaryngol Head Neck Surg* 2016; **142**: 966–71
86. Masood MM, Farquhar DR, Biancaniello C, Hackman TG. Association of standardized tracheostomy care protocol implementation and reinforcement with the prevention of life-threatening respiratory events. *JAMA Otolaryngol Head Neck Surg* 2018; **144**: 527–32
87. Pandian V, Miller CR, Schiavi AJ, et al. Utilization of a standardized tracheostomy capping and decannulation protocol to improve patient safety. *Laryngoscope* 2014; **124**: 1794–800
88. Mehta K, Schwartz M, Falcone TE, Kavanagh KR. Tracheostomy care education for the nonsurgical first responder: a needs-based assessment and quality improvement initiative. *OTO Open* 2019; **3**. 2473974X19844993
89. Wells S, Shermont H, Hockman G, et al. Standardized tracheostomy education across the enterprise. *J Pediatr Nurs* 2018; **43**: 120–6
90. Bedwell JR, Pandian V, Roberson DW, McGrath BA, Cameron TS, Brenner MJ. Multidisciplinary tracheostomy care: how collaboratives drive quality improvement. *Otolaryngol Clin North Am* 2019; **52**: 135–47
91. Leeper WR, Haut ER, Pandian V, et al. Multidisciplinary difficult airway course: an essential educational component of a hospital-wide difficult airway response program. *J Surg Educ* 2018; **75**: 1264–75
92. Prickett K, Deshpande A, Paschal H, Simon D, Hebbar KB. Simulation-based education to improve emergency management skills in caregivers of tracheostomy patients. *Int J Pediatr Otorhinolaryngol* 2019; **120**: 157–61
93. Thrasher JM, Dawnson J, Smith W, et al. Emergency tracheostomy training for family caregivers utilizing high-fidelity simulation: a new standard of care. In: *Proceedings of the 4th international tracheostomy symposium GTC. Dallas, TX*; 2018
94. Nguyen LHP, Bank I, Fisher R, Mascarella M, Young M. Managing the airway catastrophe: longitudinal simulation-based curriculum to teach airway management. *J Otolaryngol Head Neck Surg* 2019; **48**: 10
95. Agarwal A, Marks N, Wessel V, et al. Improving knowledge, technical skills, and confidence among pediatric health care providers in the management of chronic tracheostomy using a simulation model. *Pediatr Pulmonol* 2016; **51**: 696–704
96. Dorton LH, Lintzenich CR, Evans AK. Simulation model for tracheotomy education for primary health-care providers. *Ann Otol Rhinol Laryngol* 2014; **123**: 11–8
97. Pritchett CV, Foster Rietz M, Ray A, Brenner MJ, Brown D. Inpatient nursing and parental comfort in managing pediatric tracheostomy care and emergencies. *JAMA Otolaryngol Head Neck Surg* 2016; **142**: 132–7
98. Yelverton JC, Nguyen JH, Wan W, Kenerson MC, Schuman TA. Effectiveness of a standardized education process for tracheostomy care. *Laryngoscope* 2015; **125**: 342–7
99. Miles A, Greig L, Jackson B, Keesing M. Evaluation of a tracheostomy education programme for speech-language therapists. *Int J Lang Commun Disord* 2020; **55**: 70–84
100. Baiu I, Backhus L. What is a tracheostomy? *JAMA* 2019; **322**: 1932
101. Cameron M, Corner A, Diba A, Hankins M. Development of a tracheostomy scoring system to guide airway management after major head and neck surgery. *Int J Oral Maxillofac Surg* 2009; **38**: 846–9
102. McCormick ME, Ward E, Roberson DW, Shah RK, Stachler RJ, Brenner MJ. Life after tracheostomy: patient and family perspectives on teaching, transitions, and multidisciplinary teams. *Otolaryngol Head Neck Surg* 2015; **153**: 914–20
103. Morrison RJ, Bowe SN, Brenner MJ. Teaching quality improvement and patient safety in residency education: strategies for meaningful resident quality and safety initiatives. *JAMA Otolaryngol Head Neck Surg* 2017; **143**: 1069–70
104. Quality AfHRa. *Guide to patient and family engagement in hospital quality and safety* 2013. Available from: https://www.ahrq.gov/professionals/systems/hospital/engagingfamilies/guide.html. [Accessed 11 December 2018]
105. Cherney RL, Pandian V, James A, et al. The trach trail: a systems-based pathway to improve quality of tracheostomy care and interdisciplinary collaboration. *Otolaryngol Head Neck Surg* 2020. https://doi.org/10.1177/0194599820917427. in press
106. Nadeem E, Olin SS, Hill LC, Hoagwood KE, Horwitz SM. A literature review of learning collaboratives in mental health care: used but untested. *Psychiatr Serv* 2014; **65**: 1088–99
107. Westwood EL, Hutchins JV, Thevasagayam R. Quality of life in paediatric tracheostomy patients and their caregivers—a cross-sectional study. *Int J Pediatr Otorhinolaryngol* 2019; **127**: 109606
108. Swords C, Manji A, Ward E, Arora A. A pilot study on the provision of tracheostomy healthcare and patient engagement in quality improvement measures: a global perspective. *J Laryngol Otol* 2018; **132**: 1093–6
109. Ng FK, Wallace S, Coe B, et al. From smartphone to bedside: exploring the use of social media to disseminate recommendations from the National Tracheostomy Safety Project to front-line clinical staff. *Anaesthesia* 2020; **75**: 227–33
110. Swords C, Wilson RJ, Morris LL, Randall D, Arora A. Improving the management of tracheostomy care among paediatric healthcare providers using interactive online lectures. In: *Proceedings of the 4th international tracheostomy symposium GTC. Dallas, TX*; 2018
111. Harris PA, Taylor R, Minor BL, et al. The REDCap consortium: building an international community of software platform partners. *J Biomed Inform* 2019; **95**: 103208
112. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform* 2009; **42**: 377–81
113. Busl KM, Ouyang B, Boland TA, Pollandt S, Temes RE. Prolonged mechanical ventilation is associated with pulmonary complications, increased length of stay, and unfavorable discharge destination among patients with subdural hematoma. *J Neurosurg Anesthesiol* 2015; **27**: 31–6
114. Morrow CB, McGrath-Morrow SA, Collaco JM. Predictors of length of stay for initial hospitalization in infants with

bronchopulmonary dysplasia. *J Perinatol* 2018; **38**: 1258–65
115. Turcotte LA, Perlman CM, Fries BE, Hirdes JP. Clinical predictors of protracted length of stay in Ontario complex continuing care hospitals. *BMC Health Serv Res* 2019; **19**: 218
116. Winslow C, Bode RK, Felton D, Chen D, Meyer Jr PR. Impact of respiratory complications on length of stay and hospital costs in acute cervical spine injury. *Chest* 2002; **121**: 1548–54
117. Nobleza COS, Pandian V, Jasti R, Wu DH, Mirski MA, Geocadin RG. Outcomes of tracheostomy with concomitant and delayed percutaneous endoscopic gastrostomy in the neuroscience critical care unit. *J Intensive Care Med* 2019; **34**: 835–43
118. Chandrasena AN, Goswamy J, Calder N, Khalil U, McGrath BA. Our experience: quantifying changes in tracheostomy tube position and orientation with repositioning of 14 patients (the Lunar positioning study). *Clin Otolaryngol* 2020; **45**: 143–7
119. Klemm E, Nowak A. Regarding "Mortality associated with tracheostomy complications in the United States: 2007–2016". *Laryngoscope* 2019; **129**: E198
120. Pothier L, LeBlanc J, McGauley A, Truax AE, Singh J. Skin and Wound Complication Risk Assessment in Tracheostomy: A Review of Current Literature. *The Otorhinolaryngologist* 2020; **13**: 30–1
121. Ruth BM, Justice L, Seim NB, Lemle SR, Elmaraghy CA, Jatana KR. Multidisciplinary team approach for prevention of post-operative pediatric tracheostomy-related pressure wounds. *The Otorhinolaryngologist* 2020; **13**: 4
122. Abdelaal Ahmed Mahmoud MAA, Younis M, Jamshidi N, et al. Timing of tracheostomy in pediatric patients: a systematic review and meta-analysis. *Crit Care Med* 2020; **48**: 233–40
123. Cinotti R, Voicu S, Jaber S, et al. Tracheostomy and long-term mortality in ICU patients undergoing prolonged mechanical ventilation. *PLoS One* 2019; **14**, e0220399
124. Higashi T, Eguchi H, Wakayama Y, Sumi M, Saito T, Inaba Y. Analysis of the risk factors for tracheostomy and decannulation after traumatic cervical spinal cord injury in an aging population. *Spinal Cord* 2019; **57**: 843–9
125. Kashlan KN, Williams AM, Chang SS, Yaremchuk KL, Mayerhoff R. Analysis of patient factors associated with 30-day mortality after tracheostomy. *Laryngoscope* 2019; **129**: 847–51
126. Sakai M, Kou YF, Shah GB, Johnson RF. Tracheostomy demographics and outcomes among pediatric patients ages 18 years or younger—United States 2012. *Laryngoscope* 2019; **129**: 1706–11
127. BA M, S W, J L, et al. Improving tracheostomy care in the United Kingdom: results of a guided quality improvement program in 20 diverse sites. *Br J Anesth* 2020
128. McGrath BA, Lynch J, Bonvento B, et al. Evaluating the quality improvement impact of the Global Tracheostomy Collaborative in four diverse NHS hospitals. *BMJ Qual Improv Rep* 2017; **6**. bmjqir.u220636.w7996
129. Zhu H, Das P, Roberson DW, et al. Hospitalizations in children with preexisting tracheostomy: a national perspective. *Laryngoscope* 2015; **125**: 462–8
130. Liu C, Heffernan C, Saluja S, et al. Indications, hospital course, and complexity of patients undergoing tracheostomy at a tertiary care pediatric hospital. *Otolaryngol Head Neck Surg* 2014; **151**: 232–9
131. Watters KF. Tracheostomy in infants and children. *Respir Care* 2017; **62**: 799–825
132. Rassekh CH, Zhao J, Martin ND, Chalian AA, Atkins JH. Tracheostomy complications as a trigger for an airway rapid response: analysis and quality improvement considerations. *Otolaryngol Head Neck Surg* 2015; **153**: 921–6
133. Beiderlinden M, Eikermann M, Lehmann N, Adamzik M, Peters J. Risk factors associated with bleeding during and after percutaneous dilational tracheostomy. *Anaesthesia* 2007; **62**: 342–6
134. Bradley PJ. Bleeding around a tracheostomy wound: what to consider and what to do? *J Laryngol Otol* 2009; **123**: 952–6
135. Pilarczyk K, Haake N, Dudasova M, et al. Risk factors for bleeding complications after percutaneous dilatational tracheostomy: a ten-year institutional analysis. *Anaesth Intensive Care* 2016; **44**: 227–36
136. Xin G, Ruohoalho J, Back L, Aro K, Tapiovaara L. Analysis of 255 tracheostomies in an otorhinolaryngology-head and neck surgery tertiary care center: a safe procedure with a wide spectrum of indications. *Eur Arch Otorhinolaryngol* 2019; **276**: 2069–73
137. Cohen O, Shnipper R, Stavi D, et al. Outcomes of prolonged mechanical ventilation in patients who underwent bedside percutaneous dilatation tracheostomy in intermediate care units—a single center study. *Respir Investig* 2019; **57**: 590–7
138. Pandian V, Datta M, Nakka S, Tammineedi DS, Davidson PM, Nyquist PA. Intensive care unit readmission in patients with primary brain injury and tracheostomy. *Am J Crit Care* 2019; **28**: 56–63
139. Mehta AB, Walkey AJ, Curran-Everett D, Douglas IS. One-year outcomes following tracheostomy for acute respiratory failure. *Crit Care Med* 2019; **47**: 1572–81
140. Arcieri L, Pak V, Poli V, et al. Tracheal surgery in children: outcome of a 12-year survey. *Interact Cardiovasc Thorac Surg* 2018; **26**: 660–6
141. Aquino Esperanza J, Pelosi P, Blanch L. What's new in intensive care: tracheostomy—what is known and what remains to be determined. *Intensive Care Med* 2019; **45**: 1619–21
142. MacKinnon RJ, Volk MS. An innovative collaborative interdisciplinary approach to new paediatric tracheostomy safety guidelines. *Anaesthesia* 2018; **73**: 1309–12
143. Sutton L, Mozaffari M, Mintarti A, Indrasari SR, Narula A, Lechner M. Barriers to improving tracheostomy care in low- and middle-income countries: our experience of a 23 patient closed loop audit cycle. *Clin Otolaryngol* 2018; **43**: 1392–5
144. Seligman KL, Liming BJ, Smith RJH. Pediatric tracheostomy decannulation: 11-year experience. *Otolaryngol Head Neck Surg* 2019; **161**: 499–506
145. Jung YJ, Kim Y, Kyoung K, et al. The effect of systematic approach to tracheostomy care in patients transferred from the surgical intensive care unit to general ward. *Acute Crit Care* 2018; **33**: 252–9
146. Mah JW, Staff II , Fisher SR, Butler KL. Improving decannulation and swallowing function: a comprehensive, multidisciplinary approach to post-tracheostomy care. *Respir Care* 2017; **62**: 137–43
147. Morris LL. Creating a tracheostomy quality and safety program 2018. Available from: https://www.gotostage.com/channel/c4d2288975ce453daf8d9e09860c8da4 (accessed 22 December 2019).

148. Morris LL, Afifi M. *Tracheostomies: the complete guide*. New York, NY: Springer; 2010
149. Pandian V, Cole T, Kilonsky D, et al. Voice-related quality of life increases with a talking tracheostomy tube: a randomized controlled trial. *Laryngoscope* 2020; **130**: 1249–55
150. McGrath B, Lynch J, Wilson M, Nicholson L, Wallace S. Above cuff vocalisation: a novel technique for communication in the ventilator-dependent tracheostomy patient. *J Intensive Care Soc* 2016; **17**: 19–26

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