Original Article

Tracheostomy insertion in COVID-19: insertion practice and factors leading to unplanned tube exchange

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Background: Tracheostomy insertion in patients with coronavirus disease 2019 (COVID-19) presents unique challenges. Patients frequently have high ventilatory requirements, and as an aerosol generating procedure, tracheostomy insertion creates the potential for staff transmission. Problems with tracheostomies contribute to morbidity and mortality, and tracheostomy changes may increase risks of staff transmission. We sought to quantify the incidence of clinically necessitated tracheostomy changes, establish the indications for change and investigate the incidence of staff transmission.

Methods: We conducted a single institution, retrospective, observational cohort study of all intensive care unit (ICU) patients with COVID-19 who had a tracheostomy between March 2020 and April 2021. The institution is a large tertiary referral centre in Ireland.

Results: Forty-three patients had a tracheostomy during the study period. All were a Shiley™ Flexible Adult Taperguard or Shiley™ XLT Tracheostomy. 14 patients (33%) required a tracheostomy change, with the majority (57%) involving a change from a standard size to an extended length tracheostomy. Persistent leak was the most common indication for change (71.6%). Other indications included patient-ventilator dyssynchrony, persistent cough and accidental decannulation. No staff transmission of COVID-19 occurred during this study.

Conclusions: The incidence of tracheostomy change was 33%, highlighting the importance of selecting the right tracheostomy for each patient. We discuss how key characteristics of tracheostomies such as type, size, length and inner diameter may impact flow, resistance and work of breathing, leading to unplanned tracheostomy change. No staff transmission occurred arising from tracheostomy insertion, adding to increasing evidence that tracheostomy insertion in COVID-19 appears safe with adherence to guidelines describing the correct use of personal protective equipment.

Keywords: Tracheostomy; coronavirus disease 2019 (COVID-19); severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) aerosol-generating procedures; invasive mechanical ventilation

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Introduction

The coronavirus disease 2019 (COVID-19) pandemic has increased the number of patients requiring critical care treatment. At the peak of the second wave, patients with COVID-19 accounted for two-thirds of intensive care unit (ICU) patients in Ireland. During the entire pandemic to date, these patients accounted for 32% of invasive ventilation days (1). Intensive Care National Audit and Research Centre (ICNARC) data from September 2020 to April 2021 reported that patients with COVID-19 were invasively ventilated for a median of 12 days [interquartile range (IQR), 6–24 days] (2). An Italian cohort study of 1,057 patients with mild to severe acute respiratory distress syndrome (ARDS) secondary to COVID-19 reported that 61% underwent proning, with a median of 3 sessions (3). Typically, proning requires deep sedation and muscle relaxation, reducing the possibility of attempts at weaning from mechanical ventilation. The heightened demand COVID-19 has placed on critical care resources has led to increasing consideration of tracheostomy insertion in this cohort.

The indications for tracheostomy in ICU are well established, ranging from emergency relief of airway obstruction, to planned insertion for respiratory weaning (4,5). The incidence of tracheostomy in ICU patients varies from 7.2–13% (6-8), increasing to 13–15% in those with ARDS (9). The prevalence of tracheostomy in ICU is higher (10–24%), reflecting the longer invasive ventilation days and ICU length of stay (LOS) associated with patients requiring a tracheostomy (10-12). The benefits of tracheostomy include decreased intrinsic positive end expiratory pressure (PEEP) and decreased work of breathing (13-15). Advantages also include improved patient comfort, decreased sedation requirements and earlier mobilization (16-19). The timing of tracheostomy insertion remains debated. Multiple studies examining 'early' versus 'late' tracheostomy prior to COVID-19 fail to show mortality benefits, and although some studies suggest a decrease in ventilator associated pneumonia, several large studies and meta-analyses dispute this (18,20-27). The definition of 'early' is not categorical, with trial definitions varying from 48 hours to 10 days (17,18,22,23,28,29).

Many factors complicate the timing of tracheostomy insertion in COVID-19, particularly the risk to staff from aerosol generation arising from the procedure (30-32). Intubation, mechanical ventilation and tracheostomy insertion increased the infection risk of SARS-CoV-1 virus in healthcare workers (odds ratio 4.2) (31,32). The median COVID-19 incubation period is 4 days (IQR, 2–7 days), with viral loads starting to decrease 3–5 days following symptom onset in mild illness (33-35). Viral loads and replication-competent virus (infectiousness) decrease rapidly by day 8–10 in mild illness, and day 15–20 in severe illness (36-40). However, in severe disease and immunocompromised patients, viral loads may remain high, and patients may shed replication-competent virus beyond 20 days, further complicating the timing of tracheostomy insertion (41-43).

Timing has been specifically considered in the context of COVID-19. Although most early guidelines proposed waiting for a minimum of 14 days of mechanical ventilation, with percutaneous tracheostomy the preferred technique within ICU, there is now a broad consensus for 10–14 days (30,44-50). A percutaneous approach has been found to be safe and effective. However, consideration must be given to potential difficulties arising during percutaneous insertion, and the implications for patient and staff safety. Accordingly, a surgical approach should be considered based on patient clinical characteristics (e.g., unfavourable anatomy) and where there is any anticipation of difficulty. For example, obesity is a known risk factor for severe respiratory failure in COVID-19 (51). This may increase the technical complexity of percutaneous tracheostomy, occasionally necessitating a surgical approach. Thromboembolic events caused by COVID-19 often require therapeutic anticoagulation, further complicating the timing and decision-making process (52,53).

Many different tracheostomies are produced by multiple manufacturers. They differ in relation to size:

Highlight box

Key points

- Problems with tracheostomies contribute to morbidity and mortality, and tracheostomy changes in patients with COVID-19 may present transmission risks to staff.

What is known and what is new?

- Strict adherence to PPE protocols mitigates the risk of staff transmission, with none reported in this study.
- The incidence of clinically necessary tracheostomy changes may be underappreciated, and in this study was 33%.

What is the implication, and what should change now?

- The high incidence of tracheostomy changes highlights the importance of individualising tracheostomy selection to each patient.

inner diameter (ID), outer diameter (OD) and length, and cuff design: barrel or conical type. Our institution uses the Shiley™ Flexible Adult Taperguard Tracheostomy (Medtronic, Minneapolis, USA) and Shiley XLT. They were chosen by a multidisciplinary group based on favourable features relating to patient comfort, tracheal lateral wall force exerted by its thin conical cuff, and phonation characteristics with cuff deflation.

The Fourth National Audit Project (NAP 4) revealed significant morbidity and mortality associated with tracheostomies in ICU (54). In NAP 4, tracheostomy displacement accounted for 14 of 36 events, leading to seven deaths. Contributory factors included obesity, patient movement and a known difficult airway (55). Accordingly, many factors must be considered when choosing a tracheostomy for a patient including inner diameter, length and degree of angulation. Previous authors have suggested standard tracheostomies may be up to 2 cm too short and that the degree of angulation may affect final tracheal positioning (56). It is worth noting that although the degree of angulation may differ between manufacturers, angulation in each tracheostomy is relatively fixed. Studies have highlighted the importance of correct positioning and the potential underappreciation of malposition, which may lead to dislodgment and accidental decannulation (57-59). Incorrect length can also lead to unintended endobronchial placement, irritation, or patient discomfort. A poor seal can result in loss of PEEP, derecruitment, and potential aerosolization of virus particles such as COVID-19 into the surrounding environment, with implications for healthcare workers. Furthermore, changing and reinserting a tracheostomy potentially constitutes a further aerosol generating procedure.

Given the morbidity and mortality risks associated with tracheostomies, the potential aerosolization risk to staff, and the importance of considering multiple design characteristics when selecting a tracheostomy for a patient, we conducted a retrospective analysis of patients with COVID-19 who underwent tracheostomy insertion in our institution. In particular, we sought to examine the incidence of unplanned tracheostomy change and identify the reasons for this. We present the following article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-896/rc).

Methods

We conducted a retrospective, single institution, observational cohort study of all mechanically ventilated patients with COVID-19 who underwent tracheostomy insertion from March 2020 to April 2021. The institution is a large tertiary referral centre in Ireland. This study conformed to the provisions of the Declaration of Helsinki (as revised in 2013). It was registered with the Office of Clinical Audit (Ref: CA1042), and as it was deemed a service evaluation, ethics committee approval for publication was waived. Furthermore, as a de-identified, retrospective, non-interventional study, informed consent was not required. Data was collected from electronic ICU patient records and manual chart review and included: patient demographics, background medical history, body mass index (BMI), ICU LOS and outcomes. Tracheostomy data included: time from admission to tracheostomy insertion, time from intubation to tracheostomy insertion, size and type of tracheostomy inserted, unplanned tracheostomy change, reason for change, size and type of tracheostomy inserted at the time of change, and time to decannulation. Ventilatory data included the fraction of inspired oxygen (FiO_2), PEEP and peak airway pressure (PP) on the day of tracheostomy insertion and at days 1, 3 and 5 post insertion. This was done to determine if changing a tracheostomy led to any clinically relevant derecruitment, characterized by increasing PEEP requirements and peak airway pressures.

Patient selection and insertion method

All patients included in this study were aged >18 years and had a polymerase chain reaction (PCR) confirmed diagnosis of COVID-19.

As is standard practice in our institution, the size and type of tracheostomy selected for insertion remained at the discretion of the senior ICU physician and/or Ear, Nose and Throat (ENT) surgeon. Percutaneous tracheostomy consisted of a small 1–2 cm horizontal incision in the anterior neck, just below the level of the cricoid cartilage. Blunt dissection was performed to the level of the pre-tracheal fascia, followed by cannulation of the trachea under bronchoscope guidance. The "Blue Rhino G2-Multi Percutaneous Tracheostomy Introducer Set" was used for all patients (COOK MEDICAL EUROPE LTD. Europe Shared Service Centre, O'Halloran Road National Technology Park Limerick, IRELAND).

The two patients who required surgical tracheostomies had these performed in the operating theatres. A horizontal incision was followed by dissection of the strap muscles and division of the thyroid isthmus to expose tracheal rings 2–4. Tracheal stay-sutures were applied to the tracheal rings

above and below the tracheal incision. The endotracheal tube was then withdrawn with the ventilator placed in apnoea mode, the tracheostomy was inserted and the cuff immediately inflated to minimise aerosolisation. PEEP was maintained as far as possible throughout and apnoeic times, although not recorded, were kept to a minimum.

Staffing for percutaneous tracheostomy insertion comprised the minimum number of staff (three) required to safely perform the procedure (40,60). This included an experienced ICU nurse, and either two Consultants, or a Consultant and a Fellow. All staff wore full personal protective equipment (PPE) including; FFP3 (N95) mask, full gown, gloves, goggles and hooded face shields (61-63). This complied with local infection control policies and conformed to World Health Organisation and Centre for Disease Control recommendations (44,64,65). All patients were preoxygenated, sedated and muscle relaxed (62,63). Ventilation was ceased prior to tracheal dilatation to minimise aerosolization, and correct positioning was confirmed with bronchoscopy, end-tidal capnography and chest X-ray (30,31,44,48,49,60-63). The apnoea time was not recorded but kept at a minimum to reduce the risk of clinical harm and patient desaturation. Following insertion, cuff pressures were monitored and recorded four hourly and kept in the green zone of the manometer 20–30 cmH_2O. Where leaks were apparent, cuffs were inflated to higher pressures to maintain tidal volumes.

We wished to determine the incidence of unplanned tracheostomy change, the reason for the change, and the tracheostomy inserted during the change. Unplanned tracheostomy change was defined as a change in the size or type of tracheostomy necessitated by clinical need, such as persistent leak or patient-ventilator dyssynchrony. Persistent leak and ventilator dyssnychrony was assessed clinically by the Consultant ICU physician. The requirement for tracheostomy change was determined clinically on a case-by-case basis. It did not include tracheostomy changes to facilitate respiratory weaning such as downsizing, or changing a cuffed to an uncuffed tracheostomy.

Each time an unplanned tracheostomy change was undertaken (outside of downsizing for weaning) the patient was deeply sedated and muscle relaxed. The tracheostomy was changed by mounting the introducer over a guidewire from the new sterile insertion set. This is standard practice in our institution. Where upsizing was required, the Blue Rhino dilator was used as described previously.

We also sought to assess time from intubation to tracheostomy insertion, time from ICU admission to tracheostomy, ICU LOS and time to decannulation, and to examine the changes, if any, in FiO_2, PEEP and PP at the time of tracheostomy insertion and at days 1, 3 and 5 post insertion. The follow-up time to determine time to decannulation, overall outcome of mortality rate was 6 months post tracheostomy insertion.

Statistical analysis

Data was analysed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). Categorical data was represented as numbers and percentages. Continuous data was tested for normality utilising the Shapiro-Wilk test. Distributed data was expressed as range (minimum and maximum), mean, standard deviation, median and IQR. ANOVA with repeated measures was used to compare between more than two periods for normally distributed quantitative variables, followed by Post Hoc Test (Bonferroni adjusted) for pairwise comparisons. Friedman test was used to compare between more than two periods for non-normally distributed quantitative variables and followed by Post Hoc Test (Dunn's) for pairwise comparisons. Significance of the obtained results was judged at the 5% level. Qualitative data was described using number and percentage. The Shapiro-Wilk test was used to verify the normality of distribution.

Results

Between March 2020 and April 2021, 107 patients were admitted to ICU for mechanical ventilation. Of these, 43 patients had a tracheostomy Baseline patient characteristics are detailed in *Tables 1,2*. Baseline FiO_2, PEEP and PP values on the day of tracheostomy insertion (and days 1, 3 and 5 post insertion) are listed in *Table 3*.

Three of the 43 patients included in the study analysis had a tracheostomy *in situ* on admission to ICU. In the remaining 40 patients, 38 tracheostomies were inserted percutaneously under bronchoscopy guidance in the ICU airborne infection isolation rooms with ENT backup immediately available. Two tracheostomies were inserted surgically by ENT due to unfavourable anatomy and anticipated difficulty with the percutaneous approach.

The three patients who were admitted with a tracheostomy in-situ were excluded from data analysing time from admission to tracheostomy and ventilatory data at tracheostomy insertion, but were included in analysis of ICU LOS and time to decannulation. Four patients

Table 1 Patient characteristics and ICU outcomes

Patient characteristics and outcomes (n=43)	Data
6-month mortality rate, n (%)	
Alive	33 (76.7)
Dead	10 (23.3)
Gender, n (%)	
Male	30 (69.8)
Female	13 (30.2)
Age (years)	
Min.–Max.	38.0–75.0
Mean ± SD	59.7±10.4
Median (IQR)	61.0 (53.0–69.5)
BMI (kg/m^2)	
Min.–Max.	16.2–55.1
Mean ± SD	32±8.4
Median (IQR)	31.5 (27.6–34.7)
HTN, n (%)	33 (76.7)
Cardiac disease, n (%)	10 (23.3)
Chronic lung disease, n (%)	15 (34.9)
Current smoker, n (%)	15 (34.9)
Ex-smoker, n (%)	19 (44.2)
Diabetes mellitus, n (%)	9 (20.9)
Time from admission to intubation (days) (n=30)*	
Min.–Max.	0.0–5.0
Mean ± SD	1.0±1.6
Median (IQR)	0.0 (0.0–1.0)
Time from admission to tracheostomy (days) (n=40)**	
Min.–Max.	0.0–31.0
Mean ± SD	10.3±6.2
Median (IQR)	10.0 (7.5–13.5)
Length of ICU stay (days) (n=36)†	
Min.–Max.	7.0–108.0
Mean ± SD	31.8±21.2
Median (IQR)	25.5 (16.0–43.5)
Time from intubation to tracheostomy (days) (n=42)‡	
Min.–Max.	3.0–30.0
Mean ± SD	12.7±6.7
Median (IQR)	10.5 (8.0–16.0)
Time to decannulation (days) (n=24)	
Min.–Max.	4.0–71.0
Mean ± SD	27.9±17.8
Median (IQR)	25.5 (11.5–39.0)
Clinically mandated change of tracheostomy, n (%)	14 (32.6)
Reasons for the change (n=14), n (%)	
Leak	10 (71.4)
Patient discomfort, coughing	1 (7.14)
Accidental decannulation	1 (7.14)
Patient-ventilator dyssynchrony	1 (7.14)
Thick secretions	1 (7.14)

*, 13 patients who either had a tracheostomy *in situ*, or were already intubated on admission were excluded from this analysis; **, 3 patients with a tracheostomy *in situ* were excluded from this analysis. Note: patients were typically admitted to ICU following failed ward level care, up to and including non-invasive ventilation; †, 7 patients were repatriated or transferred to another institution whilst still mechanically ventilated were excluded from this analysis; ‡, 1 patient had a tracheostomy in-situ prior to contracting COVID-19 and was excluded from this analysis. ICU, intensive care unit; SD, standard deviation; IQR, interquartile range; BMI, body mass index; HTN, hypertension.

were transferred to our institution for tracheostomy insertion. These patients were included in analysing time to tracheostomy, and ventilatory parameters around the time of tracheostomy insertion, but excluded from analysis of ICU LOS and time to decannulation. This was because, following successful tracheostomy insertion, these patients were repatriated back to their referring hospital for ongoing care. Patients transferred to another hospital whilst still requiring mechanical ventilation were excluded from analysis of ICU LOS and time to decannulation.

The principal indication for tracheostomy insertion was prolonged mechanical ventilation and/or slow respiratory wean. Patient demographics are detailed in (*Table 1*). Thirty-three (76.7%) tracheostomies were Shiley Flexible Adult Taperguard tracheostomies and 10 (23.3%) were Shiley XLT. Almost one-third of patients (14/44) underwent a tracheostomy change (*Table 2*). One patient's tracheostomy was changed twice (from a Shiley 7 to a Shiley 7 XLT, and ultimately to a Shiley 10 tracheostomy). Of the remaining 13 patients, eight had their tracheostomy changed from a standard Shiley to a Shiley XLT, four of whom had a BMI >30 kg/m^2. The remaining five patients had their standard tracheostomy upsized. None of the patients who had an extended length tracheostomy inserted as their initial tracheostomy required an unplanned change. The time from initial insertion to unplanned change ranged from <1 day (within 24 hours) to 35 days with a median of 5.5 days. The ICU airway trolley was always in close proximity and no adverse incidents were recorded.

Table 2 Distribution of the studied cases according to size and type of tracheostomy at first insertion, and change of tracheostomy

Tracheostomy type and size	Initial tracheostomy (n=43)	Tracheostomy inserted during change (n=14)
Type first insertion, n (%)		
Shiley	33 (76.7)	6 (42.88)
Shiley XLT	10 (23.3)	8 (57.12)
Size, n (%)		
5	1 (2.3)	0 (0)
6	2 (4.7)	1 (7.14)
7	5 (11.6)	0 (0)
8	9 (20.95)	1 (7.14)
9	16 (37.2)	2 (14.28)
10	0 (0)	2 (14.28)
7 XLT	1 (2.3)	2 (14.28)
8 XLT	9 (20.95)	6 (42.88)

XLT, extended length tracheostomy tube.

Persistent leak was the indication for change in 10 of 14 patients (71.4%). Of the remaining four patients, one change was due to patient-ventilator dyssynchrony, one due to persistent coughing and discomfort, one upsized to facilitate secretion clearance and finally, one changed to a longer tube to prevent a recurrence of accidental decannulation.

The median time from intubation to tracheostomy insertion was 10.5 days (IQR, 8.0–16.0 days). Median time from admission to tracheostomy insertion was 10.0 days (IQR, 7.5–13.5 days). This slightly shorter time is explained

Table 3 Comparison between the different studied periods according to FiO_2, PEEP and peak airway pressure

Oxygen requirements and airway pressures	Before	Day 1	Day 3	Day 5	Test of Sig.	P
FiO_2	(n=37)	(n=34)	(n=31)	(n=29)		
Min.–Max.	0.25–0.90	0.25–1.0	0.30–1.0	0.25–1.0	Fr=0.916	0.821
Mean ± SD	0.50±0.14	0.54±0.19	0.54±0.17	0.54±0.20		
Median (IQR)	0.50 (0.40–0.60)	0.55 (0.40–0.65)	0.50 (0.43–0.68)	0.50 (0.40–0.65)		
PEEP	(n=40)	(n=32)	(n=27)	(n=23)		
Min.–Max.	5.0–16.0	5.0–17.0	7.0–16.0	8.0–16.0	Fr=2.574	0.462
Mean ± SD	10.53±2.80	10.38±2.55	11.22±2.41	11.39±2.74		
Median (IQR)	10.0 (8.0–12.0)	10.0 (8.50–12.0)	12.0 (10.0–12.0)	11.0 (9.0–13.0)		
PP	(n=40)	(n=32)	(n=27)	(n=23)		
Min.–Max.	10.0–44.0	14.0–46.0	14.0–41.0	8.0–48.0	F=0.052	0.953
Mean ± SD	24.67±7.74	26.22±7.69	26.67±7.23	26.96±10.95		
Median (IQR)	24.0 (19.5–30.0)	24.0 (21.5–27.5)	26.0 (21.5–32.5)	28.0 (20.0–33.5)		

PEEP, positive end expiratory pressure; Sig., significance; SD, standard deviation; Fr, Friedman test; PP, peak airway pressure; IQR, interquartile range; F, F test (ANOVA) with repeated measures; P, P value for comparing between the studied periods.

by the fact that a small cohort of patients were admitted to our unit from other hospitals already intubated. The intubation time in their original hospital was recorded for data analysis.

FiO_2, PEEP and peak airway pressure (PP) values on the day of tracheostomy insertion, and on days 1, 3 and 5 post insertion were analysed (*Table 3*). No statistically significant differences were observed. The reduction in patient numbers in the analysis of ventilatory parameters from the day of tracheostomy insertion through to day 5 post tracheostomy insertion was due to a combination of: weaning to spontaneous ventilation (n=6), discharge from ICU (n=3), repatriation (n=4), decannulation (n=1) and death (n=3).

The median ICU LOS for all patients was 25.5 days (IQR, 16.0–43.5 days). Amongst survivors, this increased to 28.5 days (IQR, 16.0–48.0 days). Median time from tracheostomy insertion to decannulation was 25.5 days (IQR, 11.5–39.0 days). Overall mortality was 23.3% at 6 months.

Regarding staff transmission, in our institution, each member of staff infected with COVID-19 underwent rigorous contact tracing. No cases of transmission were attributed to tracheostomy placement.

Discussion

Our study demonstrated a 32.6% incidence of unplanned tracheostomy change. This was due to persistent and clinically significant leak (n=10), patient-ventilator dyssynchrony (n=1), patient discomfort (n=1), inability to clear secretions (n=1) and accidental decannulation (n=1). Leak was characterized by audible air escape through the mouth synchronous with the highest inspiratory pressures seen during each respiratory cycle. Clinically significant leak was associated with a significant loss of expired tidal volume and failure to maintain airway pressures which was likely to lead to de-recruitment for the patient and environmental contamination for the staff. This has important clinical consequences. First, a significant leak may increase aerosolization with potential exposure hazards to healthcare workers. Second, patients dependent on moderate to high levels of PEEP may develop atelectasis or collapse in the absence of an appropriate seal. A large leak may cause acute hypoxaemia, hypercarbia and precipitate acute life-threatening ventilatory failure (66,67). Third, tracheostomy reinsertion has risks including tracheal trauma, bleeding and false passage creation (5). Fourth, tracheostomy reinsertion is an aerosol generating procedure, potentially increasing staff exposure to COVID-19 (30-32). Avoiding significant tracheostomy leaks highlights the importance of choosing the right tracheostomy for the right patient. The most frequent change was from a standard sized tracheostomy to an extended length tracheostomy. Four patients requiring a change to an extended length tracheostomy had a BMI >30 kg/m². The manufacturer recommends the Shiley XLT for patients with a BMI >30 kg/m^2, and in these patients, perhaps a Shiley XLT should have been used at initial insertion. However, the remaining patients requiring a Shiley XLT had a BMI <30 kg/m^2, demonstrating the individualised, patient-specific approach required in tracheostomy selection. Regarding taperguard type cuffs, data provided from Covidien on their endotracheal tubes demonstrates that the high pressure contact area of the taperguard cuff was 2.7 times lower than the barrel cuff. This may be similar with tracheostomies and contribute to potential leaks at high pressures (68).

Whilst our study dealt with Shiley tracheostomies, the issues experienced with correct tracheostomy selection are applicable to all makes and models. Current convention is to refer to tracheostomies by their 'size.' However, despite attempts at standardisation, tracheostomy sizing and nomenclature remain confusing. The International Organization for Standardization (ISO) mandate that all tracheostomies carry an ISO number and display their inner diameter (ID) measurement in millimetres (69) (*Table 4*). Specifically, this measures the ID of a tracheostomy that enables connection to a standard 15 mm ventilator circuit, regardless of whether an inner cannula is required or not. Using the ISO classification system, a size 8 tracheostomy describes a tracheostomy with an ID of 8.0 mm when connected to a ventilator circuit. The ID of an ISO size 8 Tracoe® Twist tracheostomy (TRACOE medical GmbH, Germany) is 8.0 mm. As the inner cannula is required for connection, it is 8.0 mm with the inner cannula in-situ (70). The ISO size 8 Portex® Blue Line Ultra® tracheostomy (Smiths Medical, Minneapolis, USA) also has an ID of 8.0 mm (71). However, the inner cannula is not required for ventilator circuit connection. Consequently, its ID with the inner cannula in-situ is 7.0 mm. Similarly, the ISO size 8 Shiley Flexible Adult Taperguard has an ID of 7.0 mm with its inner cannula *in-situ* (72). Thus, despite the ISO size standardisation, the ID in clinical practice may differ depending on whether it includes the inner cannula. Furthermore, Shiley tracheostomies are commonly sized according to the Jackson classification (72). A 'size 8'

Table 4 Characteristics of ISO 8.0 mm tracheostomies

Tracheostomy	Size (ISO)	Inner diameter with inner cannula *in situ*	Outer diameter	Length
*Shiley™ Flexible Adult Taperguard	8	7.5 mm	12.2 mm	79 mm
Portex® Blue Line Ultra®	8	7.0 mm	11.9 mm	75.5 mm
Tracoe® Twist	8	8.0 mm	12.7 mm	74 mm

*, Shiley also classify this tracheostomy by Jackson size, which in this case is a Jackson size 7. ISO, the International Organization for Standardization.

Shiley tracheostomy typically refers to Jackson size. This corresponds to a size 8.5 on the ISO classification system. Its ID is 7.5 mm with the inner cannula in-situ (72). Thus, a 'size 8' tracheostomy may refer to either the Jackson or the ISO size, and the ISO size itself may not represent the ID in clinical practice.

These differences are important, as the ID of a tracheostomy has significant implications on airflow, resistance, and work of breathing (73-75). The Hagen-Poiseuille equation dictates that laminar flow is proportional to the radius of the vessel to the power of 4. In laminar flow states, a 1.0mm difference in the ID of an ISO size 8 tracheostomy may decrease flow by up to 41% and increase resistance, with potentially significant consequences for work of breathing. Carter & Fletcher revealed that flow is turbulent much of the time, increasing resistance further (73). The same authors also found that inner cannulae increased the resistive work of breathing by an average factor of 2.2, whilst a study by Pryor *et al.* found that inner cannulae increased bidirectional resistance by a factor of 3 (73,74). These were bench tests, and in clinical practice resistance to airflow may be more dynamic. Secretions in particular have been shown to increase resistance in endotracheal tubes (76), with similar effects likely in tracheostomy tubes. Accordingly, the ID is particularly important in patients with COVID-19, as these patients often have rapid respiratory rates and high minute ventilation rates.

Tracheostomy length affects airflow and resistance, flow being inversely proportional to length. However, tracheostomies must be appropriately long to reduce risk of dislodgement and accidental decannulation. In a comparative analysis by Pandian et al, males, those with a higher BMI, higher SOFA score, and larger endotracheal tubes (>8.0 mm) were more likely to receive a nonstandard tracheostomy (77). Some authors have suggested that even standard size tracheostomies are up to 2 cm too short, and that degree of angulation may affect final tracheal positioning (56). Poor tracheostomy placement can cause irritation and coughing, which may be misattributed to the underlying respiratory condition. Increasing sedation and returning the patient to mandatory ventilation may prolong dependence on mechanical ventilation and delay corrective action.

Partial obstruction of the tracheostomy lumen has been examined in clinical and laboratory studies (57-59). Amongst the causes, secretion load and poorly positioned or ill-fitting tracheostomies are particularly important. Tracheostomies with inner cannulae may facilitate quick relief of obstruction when the cannula is removed, and are preferred in clinical practice. However, the benefits of inner cannulae must be balanced against the reduction in ID. Patient's with high ventilatory requirements may not tolerate the temporary circuit disconnections required to remove and clean the inner cannula, and disconnections may increase aerosolization. Despite these concerns, most institutions favour using inner cannulae.

Partial obstruction caused by malposition is an underappreciated phenomenon (57,58). In an examination of 403 tracheostomies by Schmidt et al, 10% were malpositioned. They defined this as a >50% occlusion of the tracheostomy's distal opening (57). A tracheostomy change was performed in 80% of these patients, and malposition was associated with prolonged mechanical ventilation (57). Poorly positioned tracheostomies increase airflow resistance (59), and these laboratory studies may underappreciate the dynamic processes occurring in ICU.

The external position of the tracheostomy directly affects its internal position, particularly its parallel orientation relative to the tracheal wall (59). Consequently, continuous patient movement, forceful coughing, and the weight of ventilator tubing may affect tracheostomy position. This may lead to dynamic obstruction affecting airflow, respiratory mechanics and work of breathing, and increase the risk of accidental decannulation. Tracheostomies in our institution are typically sutured upon insertion to maintain

a fixed external position.

This study adds to emerging data supporting the safety of tracheostomy insertion in patients with COVID-19 (48,49, 78-83). Similar to other studies, no staff transmission was reported (79-83), highlighting the importance of adhering to guidance, and the effectiveness of full PPE (44,61-65,78-85). Despite these reassuring findings, the possibility of staff transmission of COVID-19 during aerosol generating procedures should not be discounted. This study sample size is too small to draw definitive conclusions regarding the safety of tracheostomy insertion in COVID-19, but contributes to increasing evidence that appropriate precautions mitigate the risk of infection to healthcare workers (78-84).

The mean time from intubation to tracheostomy insertion in our study was 12.74±6.67 days. This is broadly in line with, although slightly earlier than Irish, British and North American guidelines which suggest waiting for 10 to 14 days (44-47). It is noteworthy that the range was 3–30 days, with 17 patients having a tracheostomy inserted ≤10 days of mechanical ventilation. The median duration of virus detection by RT PCR is 13 days (86). Considering the median time from onset of symptoms to ICU admission is 9.5 to 12 days (43,40,87-89), most patients in this study are likely to have been at least 22 days into their illness, and the earliest patients at least 14 days into their illness, at the time of tracheostomy insertion. In addition to appropriate PPE, this may partly explain why no staff transmission occurred, even in 'early' tracheostomy insertion. The median time from admission to intubation was slightly shorter at 10.9 days (IQR, 7.5–13.5 days). Perhaps confusing at first, it is explained by a small cohort who were referred to our ICU intubated, and who subsequently underwent tracheostomy.

This study did not demonstrate any statistically significant differences in FiO_2, PEEP or PP from baseline values on the day of tracheostomy insertion to days 1, 3 and 5 post tracheostomy insertion. Potential concerns regarding possible de-recruitment and increased ventilatory requirements, at least temporarily post tracheostomy insertion, are not borne out in this study.

The median ICU LOS for all patients was 25.5 days (IQR, 16.0–43.5 days). Amongst survivors, it was 28.5 days (IQR, 16.0–48.0 days). ICNARC data from September 2020–April 2021, reported a median critical care LOS amongst survivors of 17 days (IQR, 8–36 days) (2). Our data includes patients admitted at the beginning of the COVID-19 pandemic, when a more conservative approach to the timing of tracheostomy insertion prevailed. Moreover, six patients had an ICU LOS of >50 days, which may have contributed to the higher median LOS found in our study.

Whilst this study highlights the importance of choosing the correct tracheostomy for each patient, it has some limitations. First, it is a single institution retrospective observational study. Second, our experience examined Shiley tracheostomies only. Third, broad generalisations relating to staff safety during tracheostomy insertion cannot be assumed from these numbers. Although this is a retrospective, observational study, and not designed or powered to investigate staff safety in performing 'early' tracheostomy (<10 days) in patients with COVID-19, no staff transmission occurred. This adds to evidence demonstrating the effectiveness of full PPE, and the potentially reduced tracheal viral load by the time of tracheostomy insertion (33-35,64,65).

Conclusions

Our study demonstrated a 33% incidence of unplanned tracheostomy change, with 71.4% due to persistent and clinically relevant leaks. It emphasizes the importance of choosing the right tracheostomy for the right patient. Although individual to each patient, extended length tracheostomies should be considered in those with a BMI >30 kg/m². Our study also highlights the confusing nature of tracheostomy nomenclature. It illustrates the importance of considering the characteristics of a tracheostomy such as size, ID and length when choosing a tracheostomy for a patient (56-59). Understanding their effects on flow, resistance and work of breathing is important for ensuring each patient receives the right tracheostomy. Additionally, the study adds to increasing evidence that planned percutaneous tracheostomy insertion in patients with COVID-19 is safe with strict adherence to PPE guidelines (78-84).

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Footnote

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-896/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study conformed to the provisions of the Declaration of Helsinki (as revised in 2013). It was registered with the Office of Clinical Audit (Ref: CA1042), and as it was deemed a service evaluation, ethics committee approval for publication was waived. Furthermore, as a deidentified, retrospective, non-interventional study, informed consent was not required.

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