

# Tracheostomy outcomes in coronavirus disease 2019: a systematic review and meta-analysis

Ankur Sharma, Akhil D. Goel, Pankaj Bhardwaj, Nikhil Kothari, Shilpa Goyal, Deepak Kumar, Manoj Gupta, Mahendra K. Garg, Nishant K. Chauhan, Pradeep Bhatia, Amit Goyal, Sanjeev Misra

All India Institute of Medical Sciences, Jodhpur, India

## Abstract

Tracheostomy is a standard surgical procedure that is used in critically ill patients who require sustained mechanical ventilation. In this article, we review the outcomes of coronavirus disease 2019 (COVID-19) patients who underwent tracheostomy. We searched for relevant articles on PubMed, Scopus, and Google Scholar, up to April 20, 2021. This meta-analysis examines ventilation liberation, decannulation, and hospital mortality rates in COVID-19 patients who have undergone tracheostomy. Two investigators evaluated the articles, and the differences of opinion were settled by consensus with a third author. A total of 4366 patients were included in 47 related articles for this meta-analysis. After data pooling, the proportions of ventilation liberation, decannulation and mortality were found to be 48% (95% CI: 31–64), 42% (95% CI: 17–69) and 18% (95% CI: 9–28) respectively. The Luis Furuya-Kanamori (LFK) index values for ventilation liberation, decannulation and mortality were 4.28, 1.32 and 0.69. No transmission of the disease attributable to participating in tracheostomy procedures was reported in most of the included articles.

**Key words:** tracheostomy, COVID-19, mortality, decannulation.

Anestezjologia Intensywna Terapia 2021;  
53, 5: 419–429

Otrzymano: 30.12.2020,  
zaakceptowano: 03.06.2021

## ADRES DO KORESPONDENCJI:

Dr. Ankur Sharma, All India Institute of Medical Sciences,  
Jodhpur, India, e-mail: ankuranaesthesia@gmail.com

## INTRODUCTION

Coronavirus disease 2019 (COVID-19) was first identified in Wuhan, China in December 2019 [1]. Within a few months, this new virus disseminated globally and caused a worldwide pandemic. The disease severity is variable; however, many patients require ventilator support [2]. The weaning of COVID-19 patients from mechanical ventilation is very difficult. Accidental extubation may cause substantial injury or death as well as putting the health care personnel at risk [3].

Generally, tracheostomy is performed in mechanically ventilated, severely ill individuals requiring ventilator support for a longer period. It reduces the requirement for sedation, facilitates tracheal toilet, increases convenience, and decreases the duration of ventilation and hospitalization, which, in an overloaded healthcare system lacking ventilators and skilled medical staff, has a significant impact [4]. However, while tracheostomy allows for smoother weaning, it also entails risks associated with viral transmission [5]. Current descriptive studies regarding tracheostomy in patients suffering from COVID-19 show variable outcomes [6, 7]. The amount of scientific literature discussing tracheostomy in COVID-19 patients is constantly increasing.

In this meta-analysis, we examine the outcomes such as ventilation liberation, decannulation and

mortality in patients suffering from COVID-19 who underwent a tracheostomy.

## METHODS

This review adheres to the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [8].

## Eligibility criteria

In this review, we included all studies where patients with COVID-19 had undergone a tracheostomy. We excluded studies that used extracorporeal membrane oxygenation (ECMO) in COVID-19 patients who had undergone a tracheostomy.

## Information sources

The databases PubMed, Google Scholar, and SCOPUS were searched using keywords (“Tracheostomy” [Mesh] OR Tracheostomy) AND (“COVID-19” OR “SARS-CoV-2”). All articles published in these databases up to April 20, 2021, were included.

## Study selection

Rayyan QCRI, an online citation screening tool, was used for the management of selected studies [9]. Two authors (A.S. and A.D.G.) separately screened all the titles and abstracts to remove duplicates. In the second stage, two authors independently screened

the remaining articles for their full text to consider potential inclusion in the review. Any discrepancies regarding the inclusion of an article were settled by agreement with the third author (P.B.). The process of selection of the articles is described in detail in Figure 1.

### Data extraction

The extraction of data was carried out in a standardised format in Microsoft Excel for the following parameters: author, country, sample size, study settings, population characteristics such as age, gender, tracheostomy type, and various outcomes. Two authors (A.S. and A.D.G.) executed data extraction separately (Table 1). Any discrepancy was resolved by consensus with a third author (P.B.).

### Quality assessment of studies

A critical appraisal tool to assess the quality of cross-sectional studies (AXIS tool) was utilised to evaluate the methodological quality of the studies included [10]. It consists of 20 questions with the responses “yes”, “no” or “don’t know”. Two authors independently critically evaluated each article by applying this method. The discussion and consensus settled discrepancies that arose during the critical appraisal. A risk of bias diagram was prepared to represent the quality of the included studies.

### Data synthesis and analyses

This meta-analysis focuses on pooling ventilation liberation, decannulation, and mortality rates in COVID-19 patients who have undergone a tracheostomy. The pooled estimates were evaluated us-

ing the inverse variance heterogeneity model [11]. The I squared ( $I^2$ ) statistic and Cochran’s Q test were used to test for heterogeneity. Both effect sizes and pooled estimates are expressed as proportions with 95% confidence intervals.

Small study effects such as publication bias were discerned by visual assessment of DOI plots and the Luis Furuya-Kanamori (LFK) index [12]. Heterogeneity was further investigated using sensitivity analysis. MetaXL software was used for meta-analysis [13].

## RESULTS

The records were identified through database searching (PubMed,  $n = 379$ , Scopus,  $n = 453$ , and Google Scholar,  $n = 244$ ) using the above-mentioned searched strategy. After removing duplicates, 689 records were analysed. Out of 689 articles screened, 426 articles were removed based on titles and abstracts. Subsequently, 263 full-text studies were evaluated for eligibility. Out of them, 86 were review articles, 62 were case reports, 35 were not about tracheostomy, 23 were on tracheostomy + ECMO, five were simulation studies, four were surveys, and one was not about COVID-19. These were not included. Finally, 47 studies including a total of 4,366 patients were incorporated into the qualitative and quantitative synthesis (Figure 1) [6, 7, 14–58]. Out of them, 12 studies were from the USA, 12 from the UK, seven from Italy, seven from Spain, two from China, two from Germany, and one each from Brazil, France, Belgium, Israel, and Korea. These studies included percutaneous tracheostomy (PCT), surgical tracheostomy (ST), and hybrid tracheostomy. The smallest case series among these included five patients and was reported by Tabaoda *et al.* [22], while the largest analysis, which included 1890 patients, was performed by Martin-Villares *et al.* [20]. All studies included adult patients (older than 18).

The pooled proportion of ventilation liberation rate was 48% (95% CI: 31–64,  $I^2 = 87$ ,  $n = 25$  studies] (Figure 2, Supplementary Table 1). There is a high risk of publication bias, as shown by the asymmetrical DOI plot with an LFK index value of 4.28 (major asymmetry) (Figure 3A). Sensitivity analysis did not have a significant impact on the pooled estimate (Supplementary Table 2).

The pooled proportion of decannulation rate was 42.0% (95% CI: 17–69,  $I^2 = 95$ ,  $n = 31$  studies] (Figure 4, Supplementary Table 3). There was a moderate risk of publication bias as seen in the DOI plot with the LFK index value of 1.32 (minor asymmetry) (Figure 3B). The sensitivity analysis shows no significant impact on the pooled estimate (Supplementary Table 4).

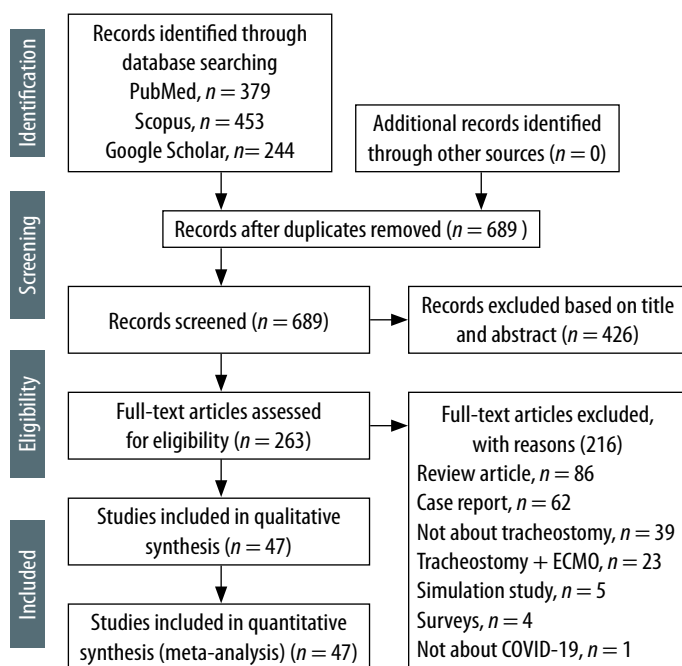


FIGURE 1. PRISMA flow chart

TABLE 1. Data extraction table

SN	Author/Country	n	Study settings	Population characteristics	Tracheostomy type	Outcomes
1.	Chao [6], USA (2020)	53	Prospective	Mean age: 62.0 ± 14.3 years M : F = 33 : 20	Both PCT = 29 ST = 24	Decannulation = 7 Ventilation liberation = 30 Death = 6
2.	Angel [7], USA (2020)	98	Retrospective	Mean age: 57 years M : F = 80 : 18	PCT	Decannulation = 8 Ventilation liberation = 32 Death = 7
3.	Zhang [14], China (2020)	11	Retrospective	Mean age: 66.2 (range 32–93) years M : F = 7 : 4	Both PCT = 6 ST = 5	Decannulation = NA Ventilation liberation = Total = 9 Death = 0
4.	Ferri [15], Italy (2020)	8	Retrospective	NA	ST	Decannulation = NA Ventilation liberation = NA Death = 2
5.	Volo [16], Italy (2020)	23	Retrospective cohort	Median age: 69 (42–84) years 21 M, 2 F	ST	Decannulation = 6 Ventilation liberation = NA Death = 9
6.	Riestra-Avora [17], Spain (2020)	27	Prospective	PCT, mean age: 67.2 ± 11.7 years ST, mean age: 67.9 ± 9.5 years	Both PCT = 17 ST = 10	Decannulation = NA Ventilation liberation = PCT = 62%; ST = 55% Death = 11
7.	Broderick [18], UK (2020)	10	Prospective	Mean age: 57.3	ST	Decannulation = 6 Ventilation liberation = 6 Death = NA
8.	Turri-Zanoni [19], Italy (2020)	32	Case series	Mean age: 62 years (range, 32–74 years)	Both PCT = 10 ST = 22	Decannulation = 1 Ventilation liberation = NA Death = 5
9.	Martin-Villares [20], Spain (2020)	1890	Multicentric, prospective observational	NA	Both PCT = 429 ST = 1,461	Decannulation = 683 Ventilation liberation = 842 Death = 383
10.	Betancourt-Ramire [21], USA (2020)	10	Case series	Mean age: 60.8 years	PCT	Decannulation = NA Ventilation liberation = 8 Death = 0
11.	Taboada [22], Spain (2020)	5	Case series	Age range: 63–70 years	PCT	Decannulation = NA Ventilation liberation = NA Death = 2
12.	Floyd [23], USA (2020)	38	Retrospective cohort	Median age: 62 (56–73) years – weaned Median age: 69 (62–79) years – ventilator dependent	ST	Decannulation = 7 Ventilation liberation = 21 Death = 2

TABLE 1. Cont.

SN	Author/Country	n	Study settings	Population characteristics	Tracheostomy type	Outcomes
13	Kwak [24], USA (2020)	148	Retrospective	NA	NA	Decannulation = 65 Ventilation liberation = NA Death = NA
14	Nibbe [25], Germany (2020)	6	Prospective	63–87 years	Hybrid tracheostomy	Decannulation = NA Ventilation liberation = NA Death = 2
15	Tomari [26], UK (2020)	69	Retrospective cohort	Median age: 55 (48–61) years F : M = 23 : 46 (33.3% : 66.7%)	NA	Decannulation = 35 Ventilation liberation = 46 Death = NA
16	Piccin [27], Italy (2020)	24	Retrospective	NA	ST	Decannulation = 14 Ventilation liberation = NA Death = NA
17	Temple [28], USA (2020)	17	Prospective	Age range: 41–80 years	ST	Decannulation = 4 Ventilation liberation = NA Death = 4
18	Takhar [29], UK (2020)	51	Prospective	> 18 years	PCT = 48 Hybrid = 3	Decannulation = 3 Ventilation liberation = 4 Death = 2
19	Smith [30], UK (2020)	28	Prospective	Median age: 55 (48–61) years	PCT	Decannulation = 24 Ventilation liberation = NA Death = 0
20	Botti [31], Italy (2020)	44	Retrospective	Median age: 64 (34–79) years	PCT = 29 ST = 15	Decannulation = 29 Ventilation liberation = 29 Death = 15
21	Picetti [32], Italy (2020)	66	Retrospective	Mean age: 58.7 ± 8.7 years 54 M, 12 F	ST	Decannulation = 51 Ventilation liberation = NA Death = 9
22	Gaspari [33], Brazil (2020)	31	Retrospective	Median age of 59 years	NA	Decannulation = 8 Ventilation liberation = NA Death = NA
23	Zuazua-Gonzalez [34], Spain (2020)	30	Retrospective	Mean age: 60.8 ± 8.42 years 22 M, 8 F	ST	Decannulation = NA Ventilation liberation = 7 Death = 17
24	Long [35], USA (2020)	67	Prospective	Median age: 66 (52–72) years 48 M, 19 F	Both ST = 32 PCT = 35	Decannulation = NA Ventilation liberation = 52 Death = 5

TABLE 1. Cont.

SN	Author/Country	n	Study settings	Population characteristics	Tracheostomy type	Outcomes
25	Briek [36], UK (2020)	100	Prospective	Median age: 55.2 (21–78) years 71 M, 29 F	Both ST = 25 PCT = 75	Decannulation = 84 Ventilation liberation = NA Death = 15
26	Yeung [37], UK (2020)	72	Retrospective	Median age: 58 (51.8–63.0) years 51 M, 21 F	Both ST = 44 PCT = 28	Decannulation = 25 Ventilation liberation = 44 Death = 7
27	Hamilton [38], UK (2020)	530	Multicentre, retrospective	405 M, 125 F	Both ST = 323 PCT = 217	Decannulation = NA Ventilation liberation = 244 Death = 62
28	Jonckheere [39], Belgium (2020)	16	Retrospective	Median age: 62 (58–69) years M 11, F 5	PCT	Decannulation = NA Ventilation liberation = NA Death = 4
29	Ovadya [40], Israel (2020)	18	Retrospective cohort study	Mean age: 58 ± 17 years M 15, F 3	NA	Decannulation = 16 Ventilation liberation = 16 Death = NA
30	Angamuthu [41], UK (2021)	55	Prospective	Mean age 58 (range 29–78) years 37 M, 18 F	ST	Decannulation = NA Ventilation liberation = NA Death = 6
31	Bartier [42], France (2021)	59	Multicentre, retrospective, observational	Mean age: 56 ± 12 years 39 M, 20 F	ST = 54 PCT = 3 Hybrid = 2	Decannulation = 41 Ventilation liberation = NA Death = 6
32	Taboada [43], Spain (2021)	29	Multicentre, prospective, observational	Mean age: 69.59 ± 8.16 years 18 M, 11 F	–	Decannulation = NA Ventilation liberation = NA Death = 12
33	Schuler [44], Germany (2021)	18	Retrospective, observational	Age range: 42–87 years M 15, F 3	ST	Decannulation = 5 Ventilation liberation = 10 Death = 6
34	Arnold [45], USA (2021)	59	Retrospective	Median age: 66 (61–71) years M 40, F 19	PCT	Decannulation = 34 Ventilation liberation = 38 Death = 20
35	Ahn [46], Korea (2021)	27	Multicentre, prospective, observational	Mean age: 68.8 (range 26–85) years M 19, F 8	ST = 20 PCT = 7	Decannulation = 7 Ventilation liberation = 11 Death = 11
36	Cardasis [47], USA (2021)	24	Case series	Mean age: 61.1 years M 19, F 5	ST	Decannulation = 16 Ventilation liberation = 20 Death = 3

TABLE 1. Cont.

SN	Author/Country	n	Study settings	Population characteristics	Tracheostomy type	Outcomes
37	Sebastian [48], India (2021)	10	Retrospective	Age range: 38–67 years M 7, F 3	ST	Decannulation = NA Ventilation liberation = 5 Death = 5
38	Archer [49], UK (2021)	86	Prospective, observational cohort	Mean age: 56.8 ± 16.7 years	NA	Decannulation = 61 Ventilation liberation = NA Death = 7
39	Courtney [50], UK (2021)	20	Retrospective case series	Mean age 54 ± 8.6 years M 15, F 5	ST	Decannulation = 12 Ventilation liberation = NA Death = 0
40	Xu [51], China (2021)	8	Case series	Age range 55–74 years	ST	Decannulation = NA Ventilation liberation = NA Death = 6
41	Pradhan [52], India (2021)	12	Retrospective case series	Age range 22–85 years M 7, F 5	ST	Decannulation = NA Ventilation liberation = 10 Death = 2
42	Mata-Castro [53], Spain (2021)	29	Cross-sectional study	Mean age 66.4 ± 6.2 years M 23, F 26	ST	Decannulation = NA Ventilation liberation = NA Death = 9
43	Rovira [54], UK (2021)	201	Multicentre, retrospective, observational cohort	Mean age 55.6 ± 11.2 years M 142, F 59	PCT = 124 ST = 77	Decannulation = 163 Ventilation liberation = NA Death = 29
44	Ahmed [55], USA (2021)	64	Retrospective, observational cohort	Median age: 63 (54–70) years M 38, F 26	ST = 48 PCT = 16	Decannulation = 18 Ventilation liberation = 30 Death = 21
45	Sancho [56], Spain (2021)	11	Observational cohort study	Mean age: 67.18 ± 6.63 years M 9, F 2	PCT	Decannulation = 9 Ventilation liberation = 9 Death = 2
46	Murphy [57], USA (2021)	11	Observational case series	Age range: 25–77 years	PCT	Decannulation = 1 Ventilation liberation = 8 Death = 1
47	Rosano [58], Italy (2021)	121	Cohort study	Mean age: 65 ± 9 years M 93, F 28	PCT	Decannulation = 47 Ventilation liberation = NA Death = 55

ST – surgical tracheostomy, PCT – percutaneous tracheostomy, M – male, F – female, NA – not available, IQR – interquartile range

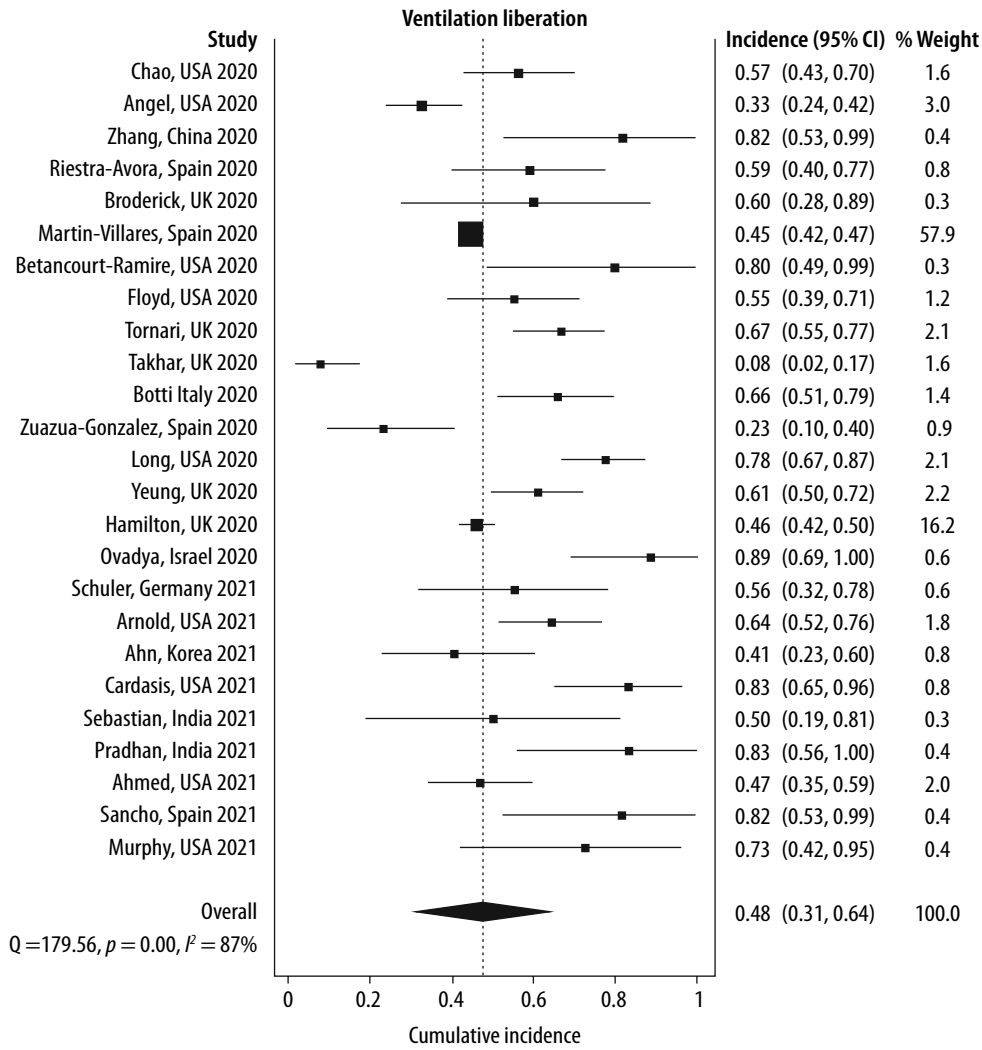


FIGURE 2. Forest plot of ventilation liberation rate after tracheostomy in COVID-19 patients in various studies

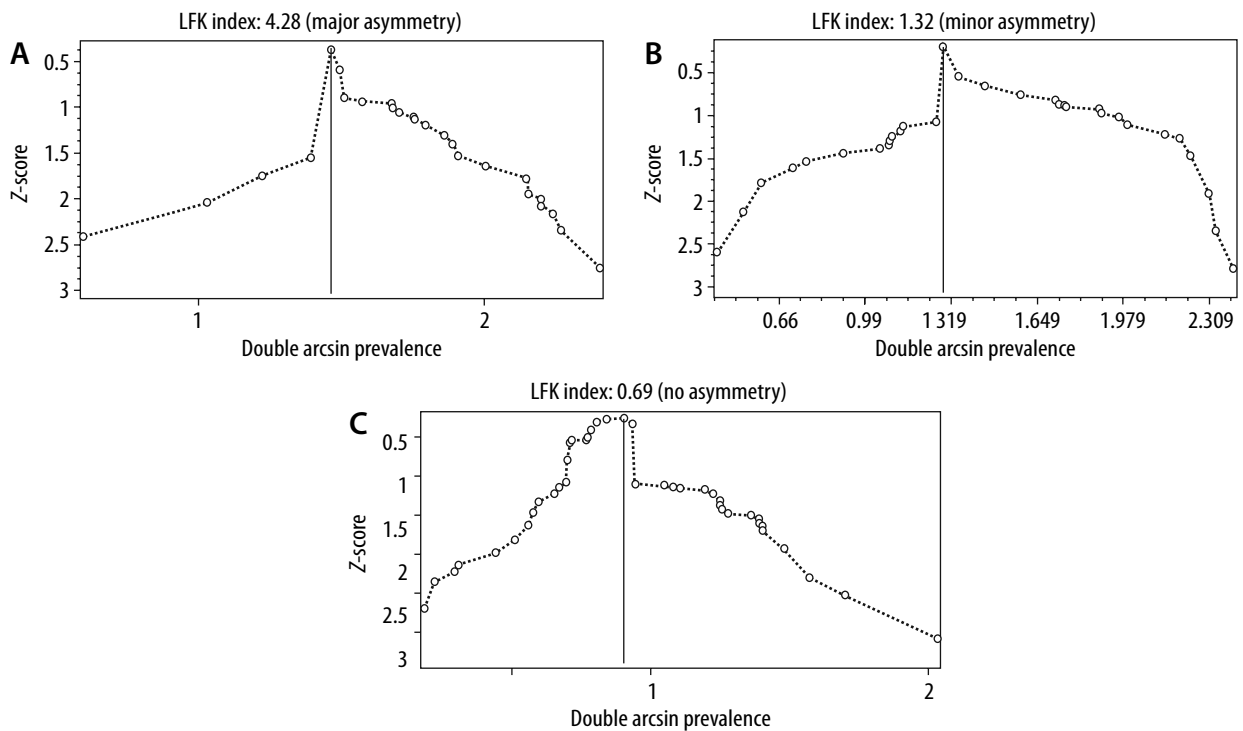


FIGURE 3. A) DOI plot of ventilation liberation. B) DOI plot of decannulation. C) DOI plot of mortality rate

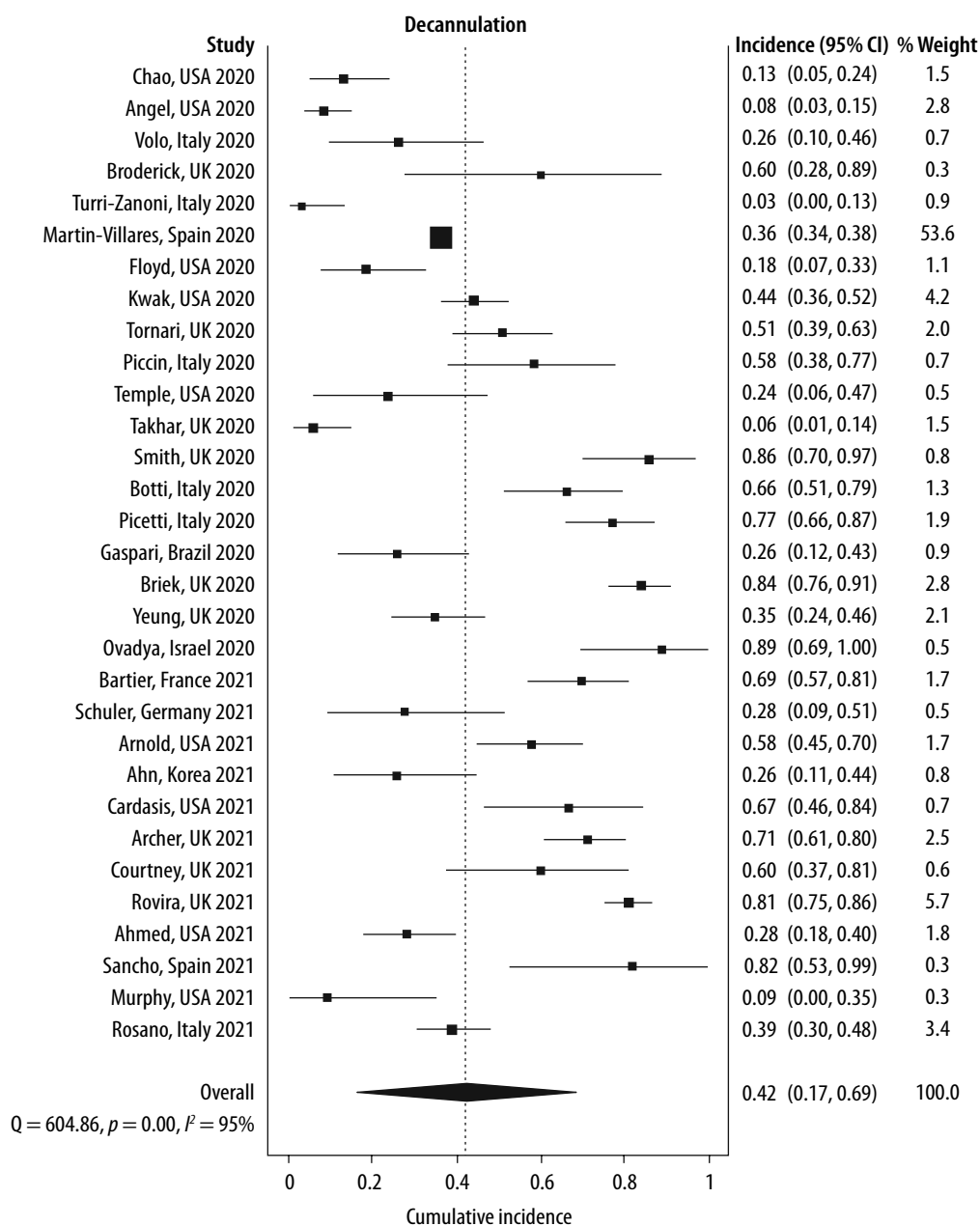


FIGURE 4. Forest plot of decannulation after tracheostomy in COVID-19 patients in various studies

The pooled proportion of hospital mortality was found to be 18% (95% CI: 9–28, I<sup>2</sup> = 84, n = 41 studies) (Figure 5, Supplementary Table 5). This can be considered a reasonable estimate of the available data due to less risk of publication bias as seen in the symmetrical DOI plot with an LFK index value of 0.69 (no asymmetry) (Figure 3C). Sensitivity analysis also did not appear to result in a significant change in the pooled estimate (Supplementary Table 6). On subgroup analysis, no significant difference was found in mortality between the PCT (17%; 95% CI: 6–30, n = 14 studies) and ST subgroups (19%; 95% CI: 12–27; n = 19 studies). The risk of bias is presented in Supplementary Table 7. In most of the reviewed articles, no spread of the disease among health care staff engaged in tracheostomy procedures was reported.

### DISCUSSION

COVID-19 patients can develop acute respiratory distress syndrome (ARDS) and pneumonia [59]. A substantial number of critically ill patients may require sustained mechanical ventilation. Many harmful effects, e.g. ventilator-associated pneumonia and the disuse myopathy, are related to prolonged mechanical ventilation. Tracheostomy is usually performed in individuals who need mechanical ventilation over long periods. The rising number of severe COVID-19 patients led to an imbalance between the volume of patients requiring intensive care and ICU beds and infrastructure provision [60]. As a result, the tracheostomy can provide a crucial measure for individuals' earlier discharge from the ICU to gene-



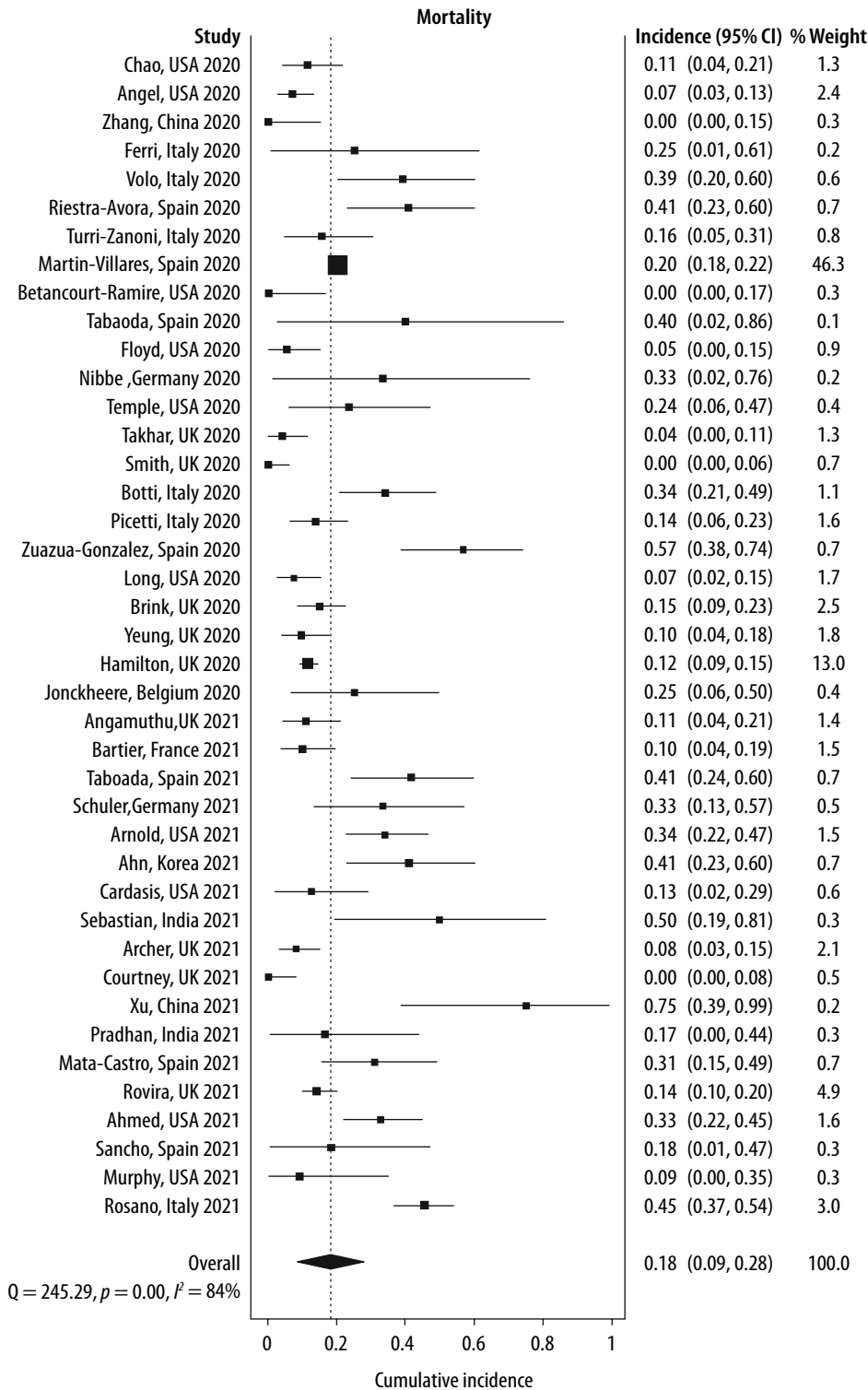


FIGURE 5. Forest plot of hospital mortality rate after tracheostomy in COVID-19 patients in various studies

ral care wards. Patients who are at the hospital with tracheostomy and do need mechanical ventilation can be managed with limited sedation in relatively low-intensity wards [61].

To the best of our knowledge, this is the second systematic review and meta-analysis of the results of tracheostomy in patients suffering from COVID-19. In the previous meta-analysis of tracheostomy out-

comes in COVID-19 patients by Benito *et al.* [62], 18 articles were included up to September 27, 2020. They found the pooled cumulative incidence of mortality to be 13.1% (95% CI: 8.5–18.4%) in these patients. Similarly, the present meta-analysis of 47 articles showed the mortality rate of 18% (95% CI: 9–28) in COVID-19 patients who have undergone a tracheostomy. Also, Shah *et al.* [63] noted a mortality rate of

19.2% in 113,653 tracheostomies in non-COVID-19 patients.

Benito *et al.* [62], in their meta-analysis, reported the cumulative incidence of decannulation as 34.9% (95% CI: 25.4–44.9%) and the ventilator weaning in patients with COVID-19 with tracheotomy as 54.9% (95% CI: 47.3–62.5%). In our meta-analysis, the rates of decannulation and ventilation liberation were 42% (95% CI: 17–69) and 48% (95% CI: 31–64), respectively.

Tracheostomy is an aerosol-producing surgery and can increase the risk of COVID-19 dissemination to healthcare staff [64]. In all the included studies, healthcare personnel (HCP) wore personal protective equipment (PPE) to protect against airborne, contact, and droplet exposures during the procedure [65]. In most of the articles, it is specifically mentioned that there were no cases where health care workers acquired COVID-19 infection after performing a tracheostomy in an infected patient. Out of 47 studies, only one study has reported COVID-19 infection in HCP performing tracheostomies. Angamuthu *et al.* [41] reported that out of 72 HCP who performed a total of 71 tracheostomies, eleven (15%, 11/72) had COVID-19 symptoms. Ten of these HCPs underwent a COVID-19 test, of whom three tested positive. However, none of the HCP required hospitalisation. This demonstrates that HCP can safely perform tracheostomies in COVID-19 patients.

Tracheostomies can be performed at the bedside without the patient being transferred to the operating room [32]. This is cost-effective and is linked to a lower risk for other patients and healthcare workers during the pandemic. Most of the included studies showed that most tracheostomies were either without complications or with minimal complications (especially minor bleeding). The minor bleeding can be associated with the use of low molecular weight heparin in most COVID-19 patients as a part of the treatment protocol [66].

## CONCLUSION

The ventilation liberation, decannulation, and mortality rates in COVID-19 patients undergoing tracheostomy were 48% (95% CI: 31–64), 42% (95% CI: 17–69) and 18% (95% CI: 9–28) respectively.

## ACKNOWLEDGEMENTS

1. Financial support and sponsorship: none.
2. Conflict of interest: none.

## REFERENCES

1. Zhu H, Wei L, Niu P. The novel coronavirus outbreak in Wuhan, China. *Glob Health Res Policy* 2020; 5: 6. doi:10.1186/s41256-020-00135-6.
2. Carter C, Osborn M, Agagah G, Aedy H, Notter J. COVID-19 disease: invasive ventilation. *Clinics in Integrated Care* 2020; doi:10.1016/j.jintcar.2020.100004.
3. Rovira A, Dawson D, Walker A et al. Tracheostomy care and decannulation during the COVID-19 pandemic. A multidisciplinary clinical practice guideline. *Eur Arch Otorhinolaryngol* 2020; doi: 10.1007/s00405-020-06126-0.
4. Bice T, Nelson JE, Carson SS. To trach or not to trach: uncertainty in the care of the chronically critically ill. *Semin Respir Crit Care Med* 2015; 36: 851-858. doi: 10.1055/s-0035-1564872.
5. Heyd CP, Desiato VM, Nguyen SA, et al. Tracheostomy protocols during COVID-19 pandemic. *Head Neck* 2020; 42: 1297-1302. doi: 10.1002/hed.26192.
6. Chao TN, Harbison SP, Braslow BM, et al. Outcomes after tracheostomy in COVID-19 patients. *Ann Surg* 2020; 272: e181-e186. doi: 10.1097/SLA.0000000000004166.
7. Angel L, Kon ZN, Chang SH, et al. Novel percutaneous tracheostomy for critically ill patients with COVID-19. *Ann Thorac Surg* 2020; 110: 1006-1011. doi: 10.1016/j.athoracsur.2020.04.010.
8. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* 2009; 339: b2535. doi: 10.1136/bmj.b2535.
9. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan – a web and mobile app for systematic reviews. *Syst Rev* 2016; 5: 210. doi: 10.1186/s13643-016-0384-4.
10. Downes MJ, Brennan ML, Williams HC, Dean RS. Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS). *BMJ Open* 2016; 6: e011458. doi: 10.1136/bmjopen-2016-011458.
11. Doi SA, Barendregt JJ, Khan S, Thalib L, Williams GM. Advances in the meta-analysis of heterogeneous clinical trials I: The inverse variance heterogeneity model. *Contemp Clin Trials* 2015; 45(Pt A): 130-138. doi: 10.1016/j.cct.2015.05.009.
12. Furuya-Kanamori L, Barendregt JJ, Doi SAR. A new improved graphical and quantitative method for detecting bias in meta-analysis. *Int J Evid Based Healthc* 2018; 16: 195-203. doi: 10.1097/XEB.0000000000000141.
13. Barendregt JJ, Doi SA, Lee YY, Norman RE, Vos T. Meta-analysis of prevalence. *J Epidemiol Community Health* 2013; 67: 974-978. doi: 10.1136/jech-2013-203104.
14. Zhang X, Huang Q, Niu X, et al. Safe and effective management of tracheostomy in COVID-19 patients. *Head Neck* 2020; 42: 1374-1381. doi: 10.1002/hed.26261.
15. Ferri E, Boscolo Nata F, Pedruzzi B, et al. Indications and timing for tracheostomy in patients with SARS CoV2-related. *Eur Arch Otorhinolaryngol* 2020; 277: 2403-2404. doi: 10.1007/s00405-020-06068-7.
16. Volo T, Stritoni P, Battel I, et al. Elective tracheostomy during COVID-19 outbreak: to whom, when, how? Early experience from Venice, Italy. *Eur Arch Otorhinolaryngol* 2020. doi: 10.1007/s00405-020-06190-6.
17. Riestra-Ayora J, Yanes-Diaz J, Penuelas O, Molina-Quiros C, Sanz-Fernández R, Martín-Sanz E. Safety and prognosis in percutaneous vs surgical tracheostomy in 27 patients with COVID-19. *Otolaryngol Head Neck Surg* 2020; 163: 462-464. doi: 10.1177/0194599820931801.
18. Broderick D, Kyzas P, Baldwin AJ, et al. Surgical tracheostomies in COVID-19 patients: a multidisciplinary approach and lessons learned. *Oral Oncol* 2020; 106: 104767. doi: 10.1016/j.oraloncology.2020.104767.
19. Turri-Zanoni M, Battaglia P, Czaczkes C, Pelosi P, Castelnovo P, Cabrini L. Elective tracheostomy during mechanical ventilation in patients affected by COVID-19: preliminary case series from Lombardy, Italy. *Otolaryngol Head Neck Surg* 2020; 163: 135-137. doi: 10.1177/0194599820928963.
20. Martín-Villares C, Pérez Molina-Ramírez C, Bartolome-Benito M, Bernal-Sprekelsen M; COVID ORL ESP Collaborative Group (\*). Outcome of 1890 tracheostomies for critical COVID-19 patients: a national cohort study in Spain. *Eur Arch Otorhinolaryngol* 2020. doi: 10.1007/s00405-020-06220-3.
21. Betancourt-Ramírez A, Yelon JA, Boland P, Amato M. A technique to minimize aerosolization during percutaneous tracheostomy in COVID-19 patients. *Am Surg* 2020; 86: 904-906. doi: 10.1177/0003134820943102.
22. Taboada M, Vazquez S, Regueira J, et al. Safe percutaneous dilational tracheostomy in 5 patients with ARDS by Covid-19. *J Clin Anesth* 2020; 67: 109977. doi: 10.1016/j.jclinane.2020.109977.
23. Floyd E, Harris SS, Lim JW, Edelstein DR, Filangeri B, Bruni M. Early data from case series of tracheostomy in patients with SARS-CoV-2. *Otolaryngol Head Neck Surg* 2020; 163: 1150-1152. doi: 10.1177/0194599820940655.
24. Kwak PE, Persky MJ, Angel L, Rafeq S, Amin MR. Tracheostomy in COVID-19 patients: why delay or avoid? *Otolaryngol Head Neck Surg* 2020; 18: 194599820953371. doi: 10.1177/0194599820953371.

25. Nibbe L, Jungehülsing M, Röber S, Ripberger G, Oppert M. „Hybrid-tracheostomie“ – ein risikoarmes Verfahren der Tracheostomie bei COVID-19-Patienten [“Hybrid tracheostomy”: a low risk procedure for tracheostomy in COVID-19 patients]. *Med Klin Intensivmed Notfmed* 2020; 115: 585-590. doi: 10.1007/s00063-020-00710-2.
26. Tornari C, Surda P, Takhar A, et al. Tracheostomy, ventilatory wean, and decannulation in COVID-19 patients. *Eur Arch Otorhinolaryngol* 2020. doi: 10.1007/s00405-020-06187-1.
27. Piccin O, Albertini R, Caliceti U, et al. Early experience in tracheostomy and tracheostomy tube management in Covid-19 patients. *Am J Otolaryngol* 2020; 41: 102535. doi: 10.1016/j.amjoto.2020.102535.
28. Temple B, Segal M, Singh VA, Galvin D, Kerr R, Zingale R. Implementation of a tracheostomy protocol during the COVID-19 pandemic. *Int J Cardiovasc Thorac Surg* 2020; 6: 38-43. doi: 10.11648/j.ijcts.20200603.11.
29. Takhar A, Tornari C, Amin N, et al. Percutaneous tracheostomy in COVID-19 pneumonitis patients requiring prolonged mechanical ventilation: initial experience in 51 patients and preliminary outcomes. *Authorea* 2020. doi: 10.22541/au.158801954.47538762.
30. Smith TG, Ahmad I, Takhar A, Surda P, El-Boghdadly K. Unconventional multidisciplinary team strategy for tracheostomy in COVID-19. *Anaesth Rep* 2020; 8: 176-180. doi: 10.1002/anr3.12074.
31. Botti C, Lusetti F, Peroni S, et al. The role of tracheostomy and timing of weaning and decannulation in patients affected by severe COVID-19. *Ear Nose Throat J* 2020; 9: 145561320965196. doi: 10.1177/0145561320965196.
32. Piccetti E, Fornaciari A, Taccone FS, et al. Safety of bedside surgical tracheostomy during COVID-19 pandemic: a retrospective observational study. *PLoS One* 2020; 15: e0240014. doi: 10.1371/journal.pone.0240014.
33. Gaspari CH, Assumpção I, Freire R, Silva A, Santoso C, Jaccoud AC. The first 60 days: physical therapy in a neurosurgical center converted into a COVID-19 center in Brazil. *Phys Ther* 2020; 100: 2120-2126. doi: 10.1093/ptj/pzaa175.
34. Zuazua-Gonzalez A, Collazo-Lorduy T, Coello-Casariago G, et al. Surgical tracheostomies in COVID-19 patients: indications, technique, and results in a second-level Spanish hospital. *OTO Open* 2020; 4: 2473974X20957636. doi: 10.1177/2473974X20957636.
35. Long SM, Chern A, Feit NZ, et al. Percutaneous and open tracheostomy in patients with COVID-19: comparison and outcomes of an institutional series in New York City. *Ann Surg* 2020. doi: 10.1097/SLA.0000000000004428.
36. Queen Elizabeth Hospital Birmingham COVID-19 airway team. Safety and 30-day outcomes of tracheostomy for COVID-19: a prospective observational cohort study. *Br J Anaesth* 2020; 125: 872-879. doi: 10.1016/j.bja.2020.08.023.
37. Yeung E, Hopkins P, Auzinger G, Fan K. Challenges of tracheostomy in COVID-19 patients in a tertiary centre in inner city London. *Int J Oral Maxillofac Surg* 2020; 49: 1385-1391. doi: 10.1016/j.ijom.2020.08.007.
38. COVIDTrach collaborative. COVIDTrach; the outcomes of mechanically ventilated COVID-19 patients undergoing tracheostomy in the UK: interim report. *Br J Surg* 2020; 107: e583-e584. doi: 10.1002/bjs.12020.
39. Jonckheere W, Mekeirele M, Hendrickx S, et al. Percutaneous tracheostomy for long-term ventilated COVID-19 patients: rationale and first clinical-safe for all-experience. *Anaesthesiol Intensive Ther* 2020; 52: 366-372. doi: 10.5114/ait.2020.101216.
40. Ovadya D, Bachar K, Peled M, Skudowitz M, Wollner A. Weaning of severe COVID-19 mechanically ventilated patients: experience within a dedicated unit in Israel. *Isr Med Assoc J* 2020; 22: 733-735.
41. Angamuthu N, Geraldine Gagasa E, Baker D, Tsui J, Evan D'Souza R. Transmission of infection among health care personnel performing surgical tracheostomies on COVID-19 patients. *Surgeon* 2021; 12: S1479-666X(21)00028-7. doi: 10.1016/j.surge.2021.01.007.
42. Bartier S, La Croix C, Evrard D, et al. Tracheostomies after SARS-CoV-2 intubation, performed by academic otorhinolaryngologists in the Paris area of France: preliminary results. *Eur Ann Otorhinolaryngol Head Neck Dis* 2021; 4: S1879-7296(21)00049-1. doi: 10.1016/j.anorl.2021.03.002.
43. Taboada M, Moreno E, Leal S, et al. Long-term outcomes after tracheostomy for COVID-19. *Arch Bronconeumol* 2021; 57 Suppl 2: 54-56. doi: 10.1016/j.arbres.2021.01.014.
44. Schuler PJ, Greve J, Hoffmann TK, et al. Surgical tracheostomy in a cohort of COVID-19 patients. *HNO* 2021; 69: 303-311. doi: 10.1007/s00106-021-01021-4.
45. Arnold J, Gao CA, Malsin E, et al. Outcomes of percutaneous tracheostomy for patients with SARS-CoV-2 respiratory failure. *medRxiv* 2021; 25: 2021.02.23.21252231. doi: 10.1101/2021.02.23.21252231.
46. Ahn D, Lee GJ, Choi YS, et al. Timing and clinical outcomes of tracheostomy in patients with COVID-19. *Br J Surg* 2021; 108: e27-e28. doi: 10.1093/bjs/znaa064.
47. Cardasis JJ, Rasamny JK, Berzofsky CE, Bello JA, Multz AS. Outcomes after tracheostomy for patients with respiratory failure due to COVID-19. *Ear Nose Throat J* 2021; 11: 145561321993567. doi: 10.1177/0145561321993567.
48. Sebastian SK, Amar PS, Sharma R, Gupta M, Ramesh S. Tracheostomy in COVID-19 patients: surgical concerns and considerations. *Indian J Otolaryngol Head Neck Surg* 2021. doi: 10.1007/s12070-021-02383-5.
49. Archer SK, Iezzi CM, Gilpin L. Swallowing and voice outcomes in patients hospitalized with COVID-19: an observational cohort study. *Arch Phys Med Rehabil* 2021; 30: S0003-9993(21)00089-7. doi: 10.1016/j.apmr.2021.01.063.
50. Courtney A, Lignos L, Ward PA, Vizcaychipi MP. Surgical tracheostomy outcomes in COVID-19-positive patients. *OTO Open* 2021; 5: 2473974X20984998. doi: 10.1177/2473974X20984998.
51. Xu K, Zhang XH, Long XB, Lu X, Liu Z. An environmental study of tracheostomy on eight COVID-19 patients. *J Otolaryngol Head Neck Surg* 2021; 50: 3. doi: 10.1186/s40463-021-00494-1.
52. Pradhan P, Mishra AK, Mittal Y, et al. Tracheostomy in the COVID19 patients: our experience in 12 cases. *Indian J Otolaryngol Head Neck Surg* 2021. doi: 10.1007/s12070-021-02375-5.
53. Mata-Castro N, Sanz-López L, Pinacho-Martínez P, Varillas-Delgado D, Miró-Murillo M, Martín-Delgado MC. Tracheostomy in patients with SARS-CoV-2 reduces time on mechanical ventilation but not intensive care unit stay. *Am J Otolaryngol* 2021; 42: 102867. doi: 10.1016/j.amjoto.2020.102867.
54. Rovira A, Tricklebank S, Surda P, et al. Open versus percutaneous tracheostomy in COVID-19: a multicentre comparison and recommendation for future resource utilisation. *Eur Arch Otorhinolaryngol* 2021. doi: 10.1007/s00405-020-06597-1.
55. Ahmed Y, Cao A, Thal A, et al. Tracheostomy outcomes in 64 ventilated COVID-19 patients at a high-volume center in Bronx, NY. *Laryngoscope* 2021. doi: 10.1002/lary.29391.
56. Sancho J, Ferrer S, Lahosa C, et al. Tracheostomy in patients with COVID-19: predictors and clinical features. *Eur Arch Otorhinolaryngol* 2021; 278: 3911-3919. doi: 10.1007/s00405-020-06555-x.
57. Murphy P, Holler E, Lindroth H, et al. Short-term outcomes for patients and providers after elective tracheostomy in COVID-19-positive patients. *J Surg Res* 2021; 260: 38-45. doi: 10.1016/j.jss.2020.10.013.
58. Rosano A, Martinelli E, Fusina F et al. Early percutaneous tracheostomy in coronavirus disease 2019: association with hospital mortality and factors associated with removal of tracheostomy tube at ICU discharge. A cohort study on 121 patients. *Crit Care Med* 2021; 49: 261-270. doi: 10.1097/CCM.0000000000004752.
59. Gibson PG, Qin L, Puah SH. COVID-19 acute respiratory distress syndrome (ARDS): clinical features and differences from typical pre-COVID-19 ARDS. *Med J Aust* 2020; 213: 54-56.e1. doi: 10.5694/mja.250674.
60. Phua J, Weng L, Ling L, et al. Intensive care management of coronavirus disease 2019 (COVID-19): challenges and recommendations. *Lancet Respir Med* 2020; 8: 506-517. doi: 10.1016/S2213-2600(20)30161-2.
61. 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: 252-259. doi: 10.4266/acc.2018.00248.
62. Benito DA, Bestouros DE, Tong JY, Pasick LJ, Sataloff RT. Tracheostomy in COVID-19 patients: a systematic review and meta-analysis of weaning, decannulation, and survival. *Otolaryngol Head Neck Surg* 2021; 5: 194599820984780. doi: 10.1177/0194599820984780.
63. Shah RK, Lander L, Berry JG, Nussenbaum B, Merati A, Roberson DW. Tracheostomy outcomes and complications: a national perspective. *Laryngoscope* 2012; 122: 25-29. doi: 10.1002/lary.21907.
64. Harding H, Broom A, Broom J. Aerosol-generating procedures and infective risk to healthcare workers from SARS-CoV-2: the limits of the evidence. *J Hosp Infect* 2020; 105: 717-725. doi: 10.1016/j.jhin.2020.05.037.
65. Valdez AM. Are you covered? Safe practices for the use of personal protective equipment. *J Emerg Nurs* 2015; 41: 154-157. doi: 10.1016/j.jen.2014.11.011.
66. Abdel-Maboud M, Menshawy A, Elgebaly A, Bahbah EI, El Ashal G, Negida A. Should we consider heparin prophylaxis in COVID-19 patients? a systematic review and meta-analysis. *J Thromb Thrombolysis* 2021; 51: 830-832. doi: 10.1007/s11239-020-02253-x.