Timing of tracheotomy in ICU patients: a systematic review of randomized controlled trials

Koji Hosokawa1*, Masaji Nishimura2, Moritoki Egì3 and Jean-Louis Vincent1

Abstract

Introduction: The optimal timing of tracheotomy in critically ill patients remains a topic of debate. We performed a systematic review to clarify the potential benefits of early versus late tracheotomy.

Methods: We searched PubMed and CENTRAL for randomized controlled trials that compared outcomes in patients managed with early and late tracheotomy. A random-effects meta-analysis, combining data from three a priori-defined categories of timing of tracheotomy (within 4 versus after 10 days, within 4 versus after 5 days, within 10 versus after 10 days), was performed to estimate the weighted mean difference (WMD) or odds ratio (OR).

Results: Of the 142 studies identified in the search, 12, including a total of 2,689 patients, met the inclusion criteria. The tracheotomy rate was significantly higher with early than with late tracheotomy (87 % versus 53 %, OR 16.1 (5.7-45.7); p <0.01). Early tracheotomy was associated with more ventilator-free days (WMD 2.12 (0.94, 3.30), p <0.01), a shorter ICU stay (WMD -5.14 (-9.99, -0.28), p = 0.04), a shorter duration of sedation (WMD -5.07 (-10.03, -0.10), p <0.05) and reduced long-term mortality (OR 0.83 (0.69-0.99), p = 0.04) than late tracheotomy.

Conclusions: This updated meta-analysis reveals that early tracheotomy is associated with higher tracheotomy rates and better outcomes, including more ventilator-free days, shorter ICU stays, less sedation, and reduced long-term mortality, compared to late tracheotomy.

Keywords: Early tracheotomy, Systematic review, Mortality

Introduction

Tracheotomy has a number of advantages in patients requiring prolonged mechanical ventilation [1–3], including improved lung mechanics [4, 5], easier oral hygiene, diminished noisive stimuli on the larynx or trachea, decreased need for sedatives, enhanced communication, and the fact that the head and neck are free of equipment [6–8]. Tracheotomy, however, also has adverse effects, including procedure-related complications and later cosmetic concerns [9–11].

Because of the relatively complex procedure, tracheotomy was in the past reserved for patients who had been intubated for a long time [12]. However, technological improvements, including simplification and decreased invasiveness of the procedure, have encouraged some to consider a more liberal use of tracheotomy. Some earlier studies in ICU patients suggested that early tracheotomy was associated with better outcomes than late tracheotomy [13–16], but more recent, rigorously designed randomized controlled trials (RCTs) did not show a significant survival benefit [17–19]. The five most recent systematic reviews of RCTs comparing early and late tracheotomy yielded conflicting results [20–24]. However, these meta-analyses combined studies using different timings of early (within 48 hours [16], within 4 days [19], and between 6 and 8 days [17]) versus late interventions, so that the results were difficult to interpret. A meta-
analysis in which only studies with early tracheotomy performed within 4 days or 7 days were included reported no significant differences between early and late tracheotomy [24].

Since the most recent systematic reviews were conducted, results from an RCT by Diaz-Prieto et al., which included about 500 patients, have been published [25]. We therefore conducted an updated systematic review and meta-analysis to evaluate the impact of early tracheotomy compared to late tracheotomy on outcome. To investigate whether very early (within 4 days) tracheotomy has a greater impact on outcome than relatively early (within 10 days) tracheotomy, we also evaluated possible differences between very early, relatively early and late tracheotomy.

**Methods**

This systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) statement [26].

Two authors (KH and ME) searched PubMed and the Cochrane Central Register of Controlled Trials (CENTRAL) on 3 July 2015 using relevant terms (Additional file 1: Table S1). They also independently examined the reference lists from related articles or systematic reviews. Disagreements about eligibility were resolved by consensus. Articles eligible for inclusion were RCTs that compared outcomes associated with early and late tracheotomy. The definition of timing was not specified in the selection step. Studies on pediatric patients, reviews, conference abstracts, quasi-randomized prospective trials and non-English-language articles were excluded. The quality of studies was examined using the method recommended by a Cochrane Collaboration tool for assessing risk of bias in the included RCTs [27].

From the included articles, two of the authors (KH and ME) extracted timing of tracheotomy, number of participating centers, type and number of ICUs, number of patients and the inclusion and exclusion criteria, major disease categories, severity scores, the rate of tracheotomy, the rate of percutaneous dilatation procedures, duration of mechanical ventilation and/or ventilator-free days (VFDs), duration of ICU stay and/or ICU-free days, duration of sedation and/or sedation-free days, the rate of acquired pneumonia, and short-term (defined a priori as ≤2 months) and long-term (defined a priori as >2 months and in hospital) term mortality rates. We also recorded complication rates related to tracheotomy and unplanned extubation. No attempts were made to contact the authors of included studies to obtain missing/unreported data.

Meta-analysis was performed using Review Manager (ver. 5.3, The Nordic Cochrane Center, Copenhagen, Denmark). When continuous values were described by median and IQR or range instead of mean and SD, the following formula was used for approximations:

\[\text{Mean} = \text{Median}; \quad \text{SD} = 1.35 \times \text{IQR}; \quad \text{if} \quad 15 < n < 70, \quad \text{SD} = (b-a)/4, \quad \text{(Minimum (a), Maximum (b))}; \quad \text{if} \quad n > 70, \quad \text{SD} = (b-a)/6 [27, 28].\]

All pooled data were assessed using a random-effects model with an inverse variance method. The estimation of combined continuous values and dichotomous values was described by weighted mean difference (WMD) or odds ratios (OR), respectively, with 95% CI. We first performed analysis by dividing the data into three groups of studies defined a priori according to the definitions used by the original articles for early versus late timings (within 4 versus after 10 days, within 4 versus after 5 days, or within 10 versus after 10 days) and then combined the results to give an overall estimation of early versus late tracheotomy. Heterogeneity among the included studies was assessed using Tau², Chi² and I² tests. A p value <0.05 was considered significant.

**Results**

Among 142 citations initially identified, 34 studies were selected for full-text reading (see Additional file 1: Fig. S1). Of these, 13 studies were excluded because they were systematic reviews. Nine others were excluded because of unclear inclusion criteria [29], inadequate randomization [30, 31], randomization at different timings and re-allocation to different groups [32], missing patient data before randomization [33, 34], inadequate outcome assessment [35], and non-English-language articles [36, 37]. A total of 12 eligible RCTs [16–19, 25, 38–44] including 2,689 patients were therefore included (Additional file 1: Fig. S1). The studies were similar in terms of quality assessment (Additional file 1: Fig. S2).

The definitions of early and late tracheotomy varied among the studies (Table 1). Seven studies used very early tracheotomy (within 4 days) [16, 19, 25, 38–43] and five used early tracheotomy (within 10 days) [17, 18, 25, 39, 44]. Late tracheotomy was defined as after 10 days in 10 RCTs [16–19, 25, 38–41, 44] and as after 5 days in 2 studies [42, 43]. The studies included different patient populations, including patients with intracranial disease [43], trauma [39], burns [38], and postoperative patients [18, 41, 42] (Table 1). Some studies excluded patients with pneumonia [17, 41, 42, 44]. Tracheotomy was performed primarily using percutaneous methods in 9 of the 11 studies [16–19, 25, 41–44] that provided this information (Table 1). The reported incidence of complications...
Table 1 Summary of the included randomized controlled trials of early versus late tracheotomy

| Study                  | Definition of early versus late tracheotomy (days) | Type of ICU; number of ICUs | Number of patients, early versus late groups | Inclusion criteria | Excluded Major disease category | APACHE II/SAPS II Tracheotomy rate (number (%)) in early versus late groups | Percutaneous dilatation tracheotomy (number (%)) in early versus late groups |
|------------------------|---------------------------------------------------|-----------------------------|---------------------------------------------|-------------------|--------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Saffle et al. (2002)   | 2-4 vs. 14–16                                     | Burn; 1                     | 21 vs. 23                                   | High predicted probability of prolonged MV | Burn (100 %) | NA                             | 21 (100 %) vs. 16 (70 %)                                                        | NA                                                                            |
| Rumbak et al. (2004)   | ≤2 vs. >14                                        | Medical; 2                  | 60 vs. 60                                   | exp. >14 d MV; APACHE II >25 | Respiratory failure (100 %), severe sepsis (88 %) | 26.9                                                                                  | 60 (100 %) vs. 50 (83 %)                                                      | All in both groups |
| Barquist et al. (2006) | <8 vs. >28                                        | Trauma; 1                   | 29 vs. 31                                   | GCS >4 with no head injury; GCS >9 with head injury | Trauma (100 %) | 12.6                                                                  | 27 (93 %) vs. 11 (35 %)                                                         | 0/27 (0 %) vs. 0/11 (0 %) |
| Blot et al. (2008)     | ≤4 vs. >14                                        | Medical and surgical; 25    | 61 vs. 62                                   | exp. >7 d MV | Irreversible neurological disease | NA/50.4                                                                                   | 145 (69 %) vs. 119 (57 %)                                                      | 141/145 (97 %) vs. 113/119 (95 %) |
| Terragni et al. (2010) | 6-8 vs. 13–15                                     | NA; 12                      | 209 vs. 210                                 | SAPS II = 35–65; SOFA ≥5; worsening respiratory conditions; unchanged/worse SOFA sore | Respiratory failure (33 %), neurology (23 %), trauma (19 %) | NA/50.4                                                                                   | 109 (100 %) vs. 29 (27 %)                                                      | All in both groups |
| Trouillet et al. (2011) | <5-7 vs. >19                                      | Surgical; 1                 | 109 vs. 107                                 | exp. >7 d MV | Irreversible neurologic disorder | Post-cardiac surgery (100 %) | NA/46.5                                                                                   | 109 (100 %) vs. 29 (27 %)                                                      | All in both groups |
| Zheng et al. (2012)    | 3 vs. 15                                          | Surgical; 1                 | 58 vs. 61                                   | PaO2/FiO2 <200; APACHE II >15; SOFA ≥5; CPIS >6; exp. >14 d MV | Pulmonary infection (CPIS >6) | NA                                                                                      | 58 (100 %) vs. 51 (84 %)                                                        | All in both groups |
| Koch et al. (2012)     | ≤4 vs. ≥6                                         | Surgical; 1                 | 50 vs. 50                                   | exp. >21 d MV | Pneumonia | Neurosurgical (28 %), trauma (25 %) | 22                                                                                                    | All in both groups |
| Young et al. (2013)    | ≤4 vs. >10                                        | General; 70 and surgical; 2 | 451 vs. 448                                 | exp. >7 d MV | Respiratory failure due to chronic neurological disease | Pulmonary (60 %), gastrointestinal (19 %) | 19.8                                                                                      | 418 (93 %) vs. 204 (46 %)                                                      | 378/418 (90 %) vs. 176/204 (86 %) |
| Bösel et al. (2013)    | ≤3 vs. 7–14                                       | Neuro; 1                    | 30 vs. 30                                   | ICH; SAH; or AIS; exp. >14 d MV | Severe chronic cardiopulmonary disease; extensive brainstem lesions | Non-traumatic neurology (100 %) | 17                                                                                       | 30 (100 %) vs. 18 (60 %)                                                        | 27/30 (90 %) vs. 16/18 (89 %) |
| Study               | Start vs. End | APACHE ≥15 | Pneumonia | TBI (43 %), CVA (25 %) | Respiratory insufficiency (60 %), coma (22 %) | All in both groups | Notes |
|---------------------|---------------|------------|-----------|------------------------|-----------------------------------------------|-------------------|-------|
| Mohamed et al. (2014) | ≤10 vs. >10   | 20 vs. 20  | APACHE ≥15| TBI (43 %), CVA (25 %) | Respiratory insufficiency (60 %), coma (22 %) | All in both groups |       |
| Diaz-Prieto et al. (2014) | <8 vs. >14    | 245 vs. 244| 1, exp. >7 d MV; 2, attending physician’s acceptance at 3–5 d | All in both groups | All in both groups |       |

Values are shown as days from the initiation of mechanical ventilation, except one that used days from ICU admission [19]. AIS: acute ischemic stroke, APACHE: acute physiology and chronic health evaluation, COPD: chronic obstructive pulmonary disease, CPIS: clinical pulmonary infection score, CVA: cerebrovascular accident, d: days, exp: expected, GCS: Glasgow coma scale, ICH: intracerebral hemorrhage, MV: mechanical ventilation, NA: not available, PaO2/FiO2: partial pressure arterial oxygen/fraction of inspired oxygen, RCT: randomized controlled trial, SAH: subarachnoid hemorrhage, SAPS: simplified acute physiology score, SOFA: sequential organ failure assessment.
related to tracheotomy ranged from 0 % to 39 %, with the most frequent reported complication being bleeding (data not shown).

**Meta-analysis results**

**Tracheotomy rate**

The rate of tracheotomy was significantly higher with early than with late tracheotomy in studies comparing timings of within 4 versus after 10 days (95 % versus 52 %, OR 24.08) and in those comparing within 10 versus after 10 days (76 % versus 51 %, OR 5.32, Fig. 1). When the data were combined for the 12 studies [16–19, 25, 38–44], the rates were 87 % for early versus 53 % for late tracheotomy (OR 16.12 (5.68, 45.74), p <0.01; I² 92 %, p heterogeneity <0.01).

**Mechanical ventilation**

The duration of mechanical ventilation was reported in eight studies [16, 18, 19, 38, 40, 42–44] (Table 2) and did not differ significantly between the early and late tracheotomy groups in any of the three predefined groups of studies or overall (Fig. 2a). VFDs were reported in five studies [17, 18, 25, 39, 41] (Table 2) and were greater with early than with late tracheotomy in one of the predefined groups of studies (within 10 versus after 10 days; WMD 2.10 (0.44, 3.76), p <0.01; I² 55 %, p heterogeneity = 0.09; Fig. 2b) and overall (WMD 2.12 (0.94, 3.30), p <0.01; I² 40 %, p heterogeneity = 0.16; Fig. 2b).

**ICU stay**

The duration of ICU stay was reported in seven studies [16, 18, 19, 25, 42–44] (Table 2) and was significantly shorter with early than with late tracheotomy overall (WMD −5.14 (−9.99, −0.28), p = 0.04; I² 96 %, p heterogeneity <0.01; Additional file 1: Figure S3a). Three studies reported ICU-free days [17, 39, 41]; there were no significant differences with early compared to late tracheotomy overall (Additional file 1: Figure S3b).

**Sedation**

The duration of sedation was reported in four studies [16, 18, 19, 25] (Table 2) and was shorter with early than with late tracheotomy in one of the predefined groups of studies (within 10 versus after 10 days) and overall (WMD −5.07 (−10.03, −0.10), p <0.05; I² 99 %, p heterogeneity <0.01; Fig. 3a). The number of sedation-free days was reported in three studies [18, 40, 41] and was larger with early than with late tracheotomy in two of the predefined groups of studies (within 4 versus after 10 days, and within 10 versus after 10 days) and overall (WMD 3.68 (2.93, 4.44), p <0.01; I² 0 %, p heterogeneity = 0.82; Fig. 3b).

**Acquired pneumonia**

The risk of acquired pneumonia was reported in 10 studies [16–18, 25, 38–42, 44] (Table 2) and did
Table 2 Reported outcomes in the included randomized controlled trials

| Study            | Duration of mechanical ventilation (days) | Number of ventilator-free days in 28 days, early versus late groups (days) | Number of ICU stay, early versus late groups (days) | Duration of ICU stay, early versus late groups (days) | Number of ventilator-free days in 28 days, early versus late groups (days) | Duration of sedation, early versus late groups (days) | Number of sedation-free days in 28 days, early versus late groups (days) | Acquired pneumonia, early versus late groups | Mortality (≤2 months), early versus late groups | Mortality (>2 months), early versus late groups | Other outcomes, early versus late groups |
|------------------|-------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------------|--------------------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Saffle et al. (2002) [38] | 35.3 (4.5) vs. 31.4 (5.2) (p = NA) | NA                                                                       | NA                                                  | NA                                                  | NA                                                                       | NA                                                  | NA                                                                       | 21 (100%) vs. 22 (96%) (p = 0.16) | 17 (81%) vs. 17 (74%) (p = 0.58) | NA                                            | Successfully extubated, 1 (5%) vs. 6 (26%) (p <0.01) |
| Rumbak et al. (2004) [16] | 7.6 (4.0) vs. 17.4 (5.3) (p <0.01) | NA                                                                       | 4.8 (1.4) vs. 16.2 (3.8) (p <0.01) | NA                                                  | 3.2 (0.4) vs. 14.1 (2.9) (p <0.01) | NA                                                  | 3 (5%) vs. 15 (25%) (p <0.05) | 19 (32%) vs. 37 (62%) (p <0.05) (at 30 d) | NA                                            | Damage to the larynx and lips, rated 0–1 vs. 2–3 |
| Barquist et al. (2006) [39] | NA                                         | 8.57 (7.9) vs. 8.83 (9) (in 30 d) (p = 0.9) | NA                                                  | 5.0 (6.0) vs. 5.5 (5.5) (in 30 d) (p = 0.8) | NA                                                                       | 28 (97%) vs. 28 (90%) (p = 0.6) | NA                                                                       | 2 (6.9%) vs. 5 (16%) (p = 0.4) | NA                                            |                                              |                                              |
| Blot et al. (2008) [40] | 14 (2–28) vs. 16 (3–28) (p = 0.62) | NA                                                                       | NA                                                  | NA                                                  | NA                                                                       | 18 (0–27) vs. 15 (0–27) (p = 0.94) | 30 (49%) vs. 31 (50%) (p = 0.94) | 12 (20%) vs. 15 (24%) (at 28 d) | 16 (27%) vs. 15 (24%) (at 60 d) | NA                                            | Laryngeal symptoms, 1 (2%) vs. 7 (11%) (p = 0.01) |
| Terragni et al. (2010) [17] | NA                                         | 11 (0–21) vs. 6 (0–17) (p = 0.02)                                       | 0 (0–13) vs. 0 (0–8) (p = 0.02) | NA                                                  | 30 (14%) vs. 44 (21%) (p = 0.07) | 55 (26%) vs. 66 (31%) (p = 0.25) (at 28 d) | 72/144 (50%) vs. 75/138 (57%) (p = 0.25) (in 1 year) | NA                                            |                                              |                                              | Successful weaning, 161 (77%) vs. 142 (68%) (p = 0.02) |
| Trouillet et al. (2011) [18] | 17.9 (14.9) vs. 19.3 (16.9) (p = 0.55) | 10.0 (8.8) vs. 9.2 (10.2) (p = 0.52)                                       | 23.9 (21.3) vs. 25.5 (22.2) (p = 0.85) | NA                                                  | 64.5 (5.9) vs. 9.6 (7.3) (p <0.01) | 19.0 (9.1) vs. 15.5 (9.3) (p <0.01) | 50 (46%) vs. 47 (44%) (p = 0.77) | 17 (16%) vs. 23 (21%) (p = 0.30) (at 30 d) | 12/74 (16%) vs. 17/74 (23%) (p = 0.49) (in 2.4 years median) | ADL, anxiety, depression, or PTSD similar |
| Zheng et al. (2012) [41] | NA                                         | 9.6 (5.6) vs. 7.4 (6.2) (p = 0.05)                                       | 8.0 (5.0–12.0) vs. 3.0 (0–12.0) (p <0.01) | NA                                                  | 20.8 (2.4) vs. 17.1 (2.3) (p <0.01) | 17 (29%) vs. 30 (49%) (p = 0.03) | 8 (14%) vs. 6 (10%) (p = 0.55) (at 28 d) | NA                                            |                                              |                                              |                                              |
| Koch et al. (2012) [42]  | 15.3 (9.1–19.8) vs. 21.1 (13.5–27.9) (p ≤0.01) | NA                                                                       | 21.5 (15.0–30.0) vs. 30.6 (22.0–37.0) (p ≤0.01) | NA                                                  | NA                                                                       | NA                                                  | 19 (38%) vs. 32 (64%) (p <0.01) | 9 (18%) vs. 7 (14%) (p = 0.79) (in ICU) | 10 (20%) vs. 11 (22%) (p = 0.81) (in hospital) |                                              |
| Young et al. (2013) [19] | 13.6 (12.0) vs. 15.2 (14.4) (p = 0.06) | NA                                                                       | 13.0 (8.2–19.1) vs. 13.1 (7.4–23.6) (p = 0.74) in survivors; 9.3 (4.2–16.0) vs. NA | 5 (3–9) vs. 8 (4–12) (p <0.01) in survivors; 5 (3–9) vs. 6 (4–10) | NA                                                                       | 139 (31%) vs. 141 (32%) (p = 0.89) (at 30 d) | 168 (40%) vs. 180 (41%) (p = 0.63) (in hospital); 207 (46%) vs. 217 (49%) (p = 0.38) (1 year) | Antibiotic use, 5 (1–8) vs. 5 (1–10) (p = 0.95) (in 30 d) |                                              |                                              |                                              |
Table 2: Reported outcomes in the included randomized controlled trials (Continued)

| Study                        | ADL, mean (SD) or median (IQR) | p-value | Sedation use, % | p-value | Excluded by attending physician, % | p-value |
|------------------------------|--------------------------------|---------|-----------------|---------|-----------------------------------|---------|
| Bösel et al. (2013) [43]     | 10.4 (6.0–19.7) (p = 0.16)     |         | 3 (10 %) vs. 14 (47 %) (p <0.01) (in ICU) |         | 284 (58 %)                         |         |
| Mohamed et al. (2014) [44]   | 20.6 (13.0) vs. 32.2 (10.5) (p <0.01) |         | 4 (20 %) vs. 8 (40 %) (in hospital) |         |                                   |         |
| Diaz-Prieto et al. (2014) [25] | 11 (0–22) vs. 9 (0–22) (p = 0.05) |         | 33 (13 %) vs. 23 (9 %) (p = 0.02) |         |                                   |         |

The values are presented as number (%), mean with (SD) or median with (IQR). The values indicate early tracheostomy versus late tracheostomy. ADL: activities of daily living, d: days, NA: not available, PTSD: posttraumatic stress disorder, RCT: randomized controlled trial.
not differ in any of the predefined groups of studies, or overall (OR 0.69 (0.45, 1.06), \( p = 0.09 \); \( I^2 = 60\% \), \( p_{\text{heterogeneity}} < 0.01 \); Additional file 1: Figure S4).

Mortality

Short-term (≤2 months) mortality rates were reported in 11 studies [16–19, 25, 38–43] (Table 2) and did not differ in any of the predefined groups of studies or overall (OR 0.74 (0.55, 1.00), \( p = 0.05 \); \( I^2 = 48\% \), \( p_{\text{heterogeneity}} = 0.04 \); Fig. 4a). Long-term (>2 months) mortality rates were reported in seven studies [17–19, 25, 42–44] and did not differ in any of the predefined groups of studies but were significantly lower with early than with late tracheotomy overall (OR 0.83 (0.69, 0.99), \( p = 0.04 \); \( I^2 = 0\% \), \( p_{\text{heterogeneity}} = 0.45 \); Fig. 4b).

Discussion

Our analysis indicated that early (versus late) tracheotomy was associated with a larger number of VFDs, shorter ICU stay, shorter duration of sedation and lower long-term mortality rates.

Fig. 2 a Duration of mechanical ventilation. Meta-analysis of the eight studies providing this information. b Ventilator-free days. Meta-analysis of the five studies providing this information. I-V inverse variance
early (within 4 days) tracheotomy was compared to relatively early (after 5 days) tracheotomy [42]. We also included the study by Bösel et al., who compared very early tracheotomy (within 1–3 days after intubation) to what the authors called "standard" timing (between days 7 and 14) [43]. These studies would have been excluded if we had limited the late tracheotomy group to more than 7 or 10 days. Moreover, our cutoffs for the timing of tracheotomy produced some interesting findings in the differences between very early and moderately early procedures.

Tracheotomy rates were generally lower in the late tracheotomy than in the early tracheotomy groups, likely because patients will have recovered or died by the later time point. In addition, there is no reliable means of predicting the likely length of mechanical ventilation. The differences in tracheotomy rates between the early and late group were much larger in the predefined group of studies comparing within 4 days versus after 10 days than that comparing within 10 versus after 10 days.

Our results showed that early tracheotomy was associated with a larger number of VFDs in the group of studies comparing tracheotomy within 10 versus after 10 days. This seems to contradict the policy that tracheotomy should be delayed until after 14 days [7], but does support several reviews that suggest that the need for tracheotomy should be assessed on a daily basis with a definite decision being taken as early as 4–7 days after endotracheal intubation [9, 45, 46].

As in previous meta-analyses [20, 21], early tracheotomy was associated with a shorter duration of sedation. Some [47–49], but not all [50], retrospective observational studies have also reported that early tracheotomy allows a shorter duration of sedation. These differences may be related to the sedation strategies used in these studies.

Our analysis has several limitations. First, there was marked heterogeneity among studies for some of the outcome measures, likely related to the diverse patient groups and characteristics and the different timings of tracheotomy, which are inherent in all systematic reviews on this topic, and the fact that respiratory management may have changed between 2002 and 2015, the dates of publication of the included studies. Second, early tracheotomy may be particularly beneficial in selected groups of patients, such as those with head or spinal cord injury or massive stroke [6, 51], but our meta-analysis could not address this question. Third, adverse effects and cost-effectiveness were not assessed. Finally, the statistical plan included the estimation of WMD using approximate SD values calculated from the IQR.

Fig. 3 a Duration of sedation. Meta-analysis of the four studies providing this information. b Sedation-free days. Meta-analysis of the three studies providing this information. I-V inverse variance
Conclusions
This updated meta-analysis reveals that early tracheotomy is associated with a significantly higher rate of tracheotomy and a larger number of VFDs, shorter duration of sedation and lower long-term mortality rates than late tracheotomy. The assessment restricted to groups of studies with different time cutoffs did not provide enough information to be able to draw conclusions about differences between very early (within 4 days) and moderately early (within 10 days) tracheotomy.

Key messages
- Early tracheotomy was associated with significantly higher rates of tracheotomy than late tracheotomy
- Early tracheotomy is associated with a larger number of VFDs, shorter ICU stays, shorter duration of sedation and lower long-term mortality rates than late tracheotomy
- In the group of studies that compared tracheotomy within 10 versus after 10 days, early tracheotomy was associated with more VFDs than late tracheotomy
Additional file

Additional file 1: Table S1. Electronic database search strategy and results. Fig. S1 Preferred reporting items for systematic reviews and meta-analyses (PRISMA) study flow chart. Fig. S2 The quality assessment of included studies. Fig. S3 a Duration of ICU stay. Meta-analysis of the seven studies providing this information. b ICU-free days. Meta-analysis of the three studies providing this information. CI confidence interval, I2 inverse variance, SD standard deviation. Fig. S4 The incidence of acquired pneumonia. Meta-analysis of the 10 studies providing this information. (DOCX 1069 kb)

Abbreviations

ADL: activities of daily living; AIS: acute ischemic stroke; APACHE: acute physiology and chronic health evaluation; CENTRAL: Cochrane Central Register of Controlled Trials; CI: confidence interval; COPD: chronic obstructive pulmonary disease; CPIS: clinical pulmonary infection score; CVA: cerebrovascular accident; GCS: Glasgow coma scale; ICU: intensive care unit; IQR: interquartile range; MV: mechanical ventilation; OR: odds ratio; PaO2/FiO2: partial pressure arterial oxygen/fraction of inspired oxygen, PRISMA: preferred reporting items for systematic reviews and meta-analyses; PTSD: posttraumatic stress disorder; RCT: randomized controlled trial; SAH: subarachnoid hemorrhage; SAPS: simplified acute physiology score; SD: standard deviation; SOFA: sequential organ failure assessment; VFD: ventilator-free day; WMD: weighted mean difference.

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

KH had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the analysis. KH contributed to the study concept and design, data acquisition, data analysis and interpretation, drafting of the manuscript, critical revision of the manuscript for important intellectual content and final approval of the manuscript. MN and ME contributed to the study concept and design, data analysis and interpretation, critical revision of the manuscript for important intellectual content and final approval of the manuscript. Funding was from institutional funds only.

Author details

1Department of Intensive Care, Erasme University Hospital, Université Libre de Bruxelles, Route de Lennik 808, 1070 Brussels, Belgium. 2Department of Emergency and Critical Care Medicine, Tokushima University Hospital, Tokushima, Japan. 3Department Intensive Care, Kobe University Hospital, Kobe-city, Hyogo, Japan.

Received: 7 August 2015 Accepted: 17 November 2015

Published online: 04 December 2015

References

1. West JB. The physiological challenges of the 1952 Copenhagen poliomyelitis epidemic and a renaissance in clinical respiratory physiology. J Appl Physiol. 2005;99(2):242–32.
2. Severinghaus JW, Astrup P, Murray JF. Blood gas analysis and critical care medicine. Am J Respir Crit Care Med. 1998;157(4 Pt 2):14–122.
3. Heffner JE. Medical indications for tracheotomy. Chest. 1989;96(1):178–90.
4. Diehl JL, El Atrous S, Touchard D, Lemaire F, Brochard L. Changes in the work of breathing induced by tracheotomy in ventilator-dependent patients. Am J Respir Crit Care Med. 1999;159(2):383–8.
5. Davis JR, Campbell RS, Johannigman JA, Valente JF, Branson RD. Changes in respiratory mechanics after tracheostomy. Arch Surg. 1999;134(1):59–62.
6. Cheung NH, Napolitano LM. Tracheostomy: epidemiology, indications, timing, technique, and outcomes. Respir Care. 2014;59(6):895–915.
7. Freeman BD, Morris PE. Tracheostomy practice in adults with acute respiratory failure. Crit Care Med. 2012;40(10):2890–6.
8. Heffner JE, Miller KS, Sahn SA. Tracheostomy in the intensive care unit. Part 1: Indications, technique, management. Chest. 1988;93(2):269–74.
9. Rana S, Pendem S, Pogodzinski MS, Hubmayr RD, Gajic O. Tracheostomy in critically ill patients. Mayo Clin Proc. 2005;80(12):1632–8.
10. Epstein SK. Late complications of tracheostomy. Respir Care. 2005;50(4):542–9.
11. Stauffer JL, Olson DE, Petty TL. Complications and consequences of endotracheal intubation and tracheotomy. A prospective study of 150 critically ill adult patients. Am J Med. 1981;70(1):65–76.
12. Plummer AL, Gracey DR. Consensus conference on artificial airways in patients receiving mechanical ventilation. Chest. 1989;96(1):78–80.
13. Brook AD, Sherman G, Malen J, Kollef MH. Early versus late tracheostomy in patients who require prolonged mechanical ventilation. Am J Crit Care. 2000;9(5):352–9.
14. Arabi Y, Haddad S, Shitawi N, Al SA. Early tracheostomy in intensive care trauma patients improves resource utilization: a cohort study and literature review. Crit Care. 2004;8(5):R347–52.
15. Griffiths J, Barber V, Morgan L, Young JD. Systematic review and meta-analysis of studies of the timing of tracheostomy in adult patients undergoing artificial ventilation. BMJ. 2005;330(7502):1243.
16. Rumbak MJ, Newton M, Truncale T, Schwartz SW, Adams JS, Hazard PB. A prospective, randomized, study comparing early percutaneous dilational tracheotomy to prolonged translaryngeal intubation (delayed tracheotomy) in critically ill medical patients. Crit Care Med. 2004;32(8):1689–94.
17. Terragni PP, Antonelli M, Fumagalli R, Faggiano C, Berardino M, Pallavicini FB, et al. Early vs late tracheotomy for prevention of pneumonia in mechanically ventilated adult ICU patients: a randomized controlled trial. JAMA. 2010;303(15):1483–9.
18. Trouillet JL, Luyt CE, Guiguet M, Ouattara A, Vaisser E, Makri R, et al. Early percutaneous tracheotomy versus prolonged intubation of mechanically ventilated patients after cardiac surgery: a randomized trial. Ann Intern Med. 2011;154(6):373–83.
19. Young D, Harrison DA, Cuthbertson BH, Rowan K, Tracman Collaborators. Effect of early vs late tracheostomy placement on survival in patients receiving mechanical ventilation: the Trachman randomized trial. JAMA. 2013;309(20):2121–9.
20. Meng L, Wang CM, Li JX, Zhang J. Early versus late tracheotomy in critically ill patients: a systematic review and meta-analysis. Clin Respir J. 2015. doi:10.1111/crj.12286.
21. Szakmany T, Russell P, Wilkes AR, Hall JE. Effect of early tracheostomy on resource utilization and clinical outcomes in critically ill patients: meta-analysis of randomized controlled trials. Br J Anaesth. 2015;114(3):396–405.
22. Andriolo BN, Andriolo RB, Saconato H, Atallah AN, Valente O. Early versus late tracheotomy for critically ill patients. Cochrane Database Syst Rev. 2015(1), CD007271.
23. Siempos II, Ntabou TK, Filippidou FT, Choi AM. Effect of early versus late or no tracheostomy on mortality and pneumonia of critically ill patients receiving mechanical ventilation: a systematic review and meta-analysis. Lancet Respir Med. 2015;3(2):150–8.
24. Huang H, Li Y, Ariani F, Chen X, Lin J. Timing of tracheotomy in critically ill patients: a meta-analysis. PLoS One. 2014;9(3), e92981.
25. Diaz-Prieto A, Mateu A, Goritz M, Ortega B, Trucero C, Sampietro N, et al. A randomized clinical trial for the timing of tracheostomy in critically ill patients: factors precluding inclusion in a single center study. Crit Care. 2014;18(5):585.
26. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gartszte PC, Ioannidis JP, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS Med. 2009;6(7), e1000100.
27. Higgins J, Green S. Cochrane Handbook for Systematic Reviews of Interventions (Ver. 5.1.0.). 2011.
28. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. BMC Med Res Methodol. 2005;5:13.
29. Dunham CM, LaMonica C. Prolonged tracheal intubation in the trauma patient. J Trauma. 1984;24(2):120–4.
30. El-Naggar M, Sadagopan S, Levine H, Kantor H, Collins VJ. Factors influencing choice between tracheostomy and prolonged translaryngeal intubation in acute respiratory failure: a prospective study. Anesth Analg. 1976;55(2):195–201.
31. Rodríguez JL, Steinberg SM, Luchetti FA, Gibbons KJ, Tahan PA, Flint LM. Early tracheostomy for primary airway management in the surgical critical care setting. Surgery. 1990;108(6):635–9.
32. Sugerman HJ, Wolfe L, Pasquale MD, Rogers FB, O’Malley KF, Knudson M, et al. Multicenter, randomized, prospective trial of early tracheostomy. J Trauma. 1997;43(5):741–7.

33. Boulker MA, Fakhir B, Bouaggad A, Hmamouchi B, Hamoudi D, Harti A. Early tracheostomy versus prolonged endotracheal intubation in severe head injury. J Trauma. 2004;57(2):251–4.

34. Dunham CM, Cutrona AF, Gruber BS, Calderon JE, Ransom KJ, Flowers LL. Early tracheostomy in severe traumatic brain injury: evidence for decreased mechanical ventilation and increased hospital mortality. Int J Burns Trauma. 2014;4(1):14–24.

35. Bylappa K, Mohiyudin A, Delphine W, Silvia CR, Krishnamurthy D, Pyarajan MS. A comparative study of early and late tracheostomy in patients requiring prolonged tracheal intubation. World J Surg. 2011;4(2). http://www.wajnt.org/archives/2011/Vol4-2/20111215-Tracheostomy-Intubation/late-trachotomy.htm

36. Sabouri M, Esmaili TM, Hosseini B. The effects of early tracheostomy on outcomes of patients with severe head injury. J Isfahan Med School. 2009;27(95):211–6.

37. Lu W, Xia Z, Chén YL. Clinical study on the comparison of prophylactic tracheotomy with emergent tracheotomy after inhalation injury. Chin J Burns (Zhonghua shao shang za zhi). 2003;19(4):233–5.

38. Saffle JR, Morris SE, Edelman L. Early tracheostomy does not improve outcome in burn patients. J Burn Care Rehabil. 2002;23(6):491–8.

39. Barquist ES, Amortegui J, Hallal A, Giannotti G, Whinney R, Alzamel H, et al. Tracheostomy in ventilator dependent trauma patients: a prospective, randomized intention-to-treat study. J Trauma. 2006;60(1):91–7.

40. Blok F, Similowski T, Trouillet JL, Chardon P, Korach JM, Costa MA, et al. Early tracheostomy versus prolonged endotracheal intubation in unselected severely ill ICU patients. Intensive Care Med. 2008;34(10):1779–87.

41. Zheng Y, Si F, Chen XZ, Zhang GC, Wang XW, Zhao S, et al. Early versus late percutaneous dilatational tracheostomy in critically ill patients anticipated requiring prolonged mechanical ventilation. Chin Med J. 2012;125(1):1925–30.

42. Koch T, Hecker B, Hecker A, Brench F, Preuss M, Schmelzer T, et al. Early tracheostomy decreases ventilation time but has no impact on mortality of intensive care patients: a randomized study. Langenbecks Arch Surg. 2012;397(6):1001–8.

43. Mohamed KAE, Moussa AY, ElSawy AS, Saleem AM. Early versus late percutaneous tracheostomy in critically ill adult mechanically ventilated patients. Egyptian J Chest Dis Tuberc. 2014;63(2):443–8.

44. Bittner EA, Schmidt UH. The ventilator liberation process: update on technique, timing, and termination of tracheostomy. Respir Care. 2012;57(10):1626–34.

45. King C, Moores LK. Controversies in mechanical ventilation: when should a tracheotomy be placed? Clin Chest Med. 2008;29(2):253–63.

46. Gandía-Martínez F, Martínez-Gil I, Andaluz-Ojeda D, Bobillo de Lamo F, Parra-Morais L, Díez-Gutiérrez F, et al. Analysis of early tracheostomy and its impact on development of pneumonia, use of resources and mortality in neurocritically ill patients. Neurocrit Care. 2010;12(3):211–21.

47. Veelo DP, Dongelmans DA, Binnekade JM, Korevaar JC, Vroom NB, Schultz MJ. Tracheostomy does not affect reducing sedation requirements of patients in intensive care—a retrospective study. Crit Care. 2006;10(4):R99.

48. Nieszowska A, Combès A, Luyt CE, Kobi H, Trouillet JL, Gibert C, et al. Impact of tracheostomy on sedative administration, sedation level, and comfort of mechanically ventilated intensive care unit patients. Crit Care Med. 2005;33(11):2527–33.

49. Scales DC, Thruchelvam D, Kiss A, Redelmeier DA. The effect of tracheostomy timing during critical illness on long-term survival. Crit Care Med. 2008;36(9):2547–57.