



Ultrasound-guided percutaneous dilational tracheostomy versus bronchoscopy-guided percutaneous dilational tracheostomy in critically ill patients (TRACHUS): a randomized noninferiority controlled trial

André Luiz Nunes Gobatto^{1,4*}, Bruno A. M. P. Besen¹, Paulo F. G. M. M. Tierno², Pedro V. Mendes¹, Filipe Cadamuro², Daniel Joelsons³, Livia Melro¹, Maria J. C. Carmona⁴, Gregorio Santori⁵, Paolo Pelosi^{5,6}, Marcelo Park¹ and Luiz M. S. Malbouisson^{2,4}

© 2016 Springer-Verlag Berlin Heidelberg and ESICM

Abstract

Purpose: Percutaneous dilational tracheostomy (PDT) is routinely performed in the intensive care unit with bronchoscopy guidance. Recently, ultrasound has emerged as a potentially useful tool to assist PDT and reduce procedure-related complications.

Methods: An open-label, parallel, non-inferiority randomized controlled trial was conducted comparing an ultrasound-guided PDT with a bronchoscopy-guided PDT in mechanically ventilated critically ill patients. The primary outcome was procedure failure, defined as a composite end-point of conversion to a surgical tracheostomy, unplanned associated use of bronchoscopy or ultrasound during PDT, or the occurrence of a major complication.

Results: A total of 4965 patients were assessed for eligibility. Of these, 171 patients were eligible and 118 underwent the procedure, with 60 patients randomly assigned to the ultrasound group and 58 patients to the bronchoscopy group. Procedure failure occurred in one (1.7 %) patient in the ultrasound group and one (1.7 %) patient in the bronchoscopy group, with no absolute risk difference between the groups (90 % confidence interval, -5.57 to 5.85), in the “as treated” analysis, not including the prespecified margin of 6 % for noninferiority. No other patient had any major complication in either group. Procedure-related minor complications occurred in 20 (33.3 %) patients in the ultrasound group and in 12 (20.7 %) patients in the bronchoscopy group ($P = 0.122$). The median procedure length

*Correspondence: andregobatto@gmail.com

¹ Medical Intensive Care Unit, Emergency Department, Hospital das Clínicas, University of São Paulo Medical School, Rua Dr. Eneas Carvalho Aguiar, 255, Sixth Floor, Room 6040, São Paulo, Brazil
Full list of author information is available at the end of the article

Take home message: Ultrasound-guided percutaneous dilational tracheostomy (PDT) is easy, fast and safe compared with bronchoscopy-guided PDT.

was 11 [7–19] vs. 13 [8–20] min ($P = 0.468$), respectively, and the clinical outcomes were also not different between the groups.

Conclusions: Ultrasound-guided PDT is noninferior to bronchoscopy-guided PDT in mechanically ventilated critically ill patients.

Keywords: Ultrasound, Tracheostomy, Bronchoscopy

Introduction

Percutaneous dilatational tracheostomy (PDT) is a widely utilized technique in the intensive care unit (ICU) [1], with a safety profile that favorably compares to surgical tracheostomy [2, 3]. Although overall complication rates are low, severe adverse events, including death, are still reported [4]. Bronchoscopy guidance has traditionally been used as a safety adjunctive tool in order to define the appropriate site for the tracheal puncture, to guide the real-time entrance of the needle into the trachea, avoiding tracheal posterior wall injuries, and confirming the endotracheal tube placement [5, 6]. By contrast, bronchoscopy might not precisely identify the cervical anatomical structures and prevent complications such as vascular lesions or thyroid punctures.

Ultrasound has emerged as a potentially useful tool in assisting PDT. The potential advantages of ultrasound include the ability to identify the cervical vasculature [7], to help identify the most appropriate location for the tracheal puncture site, and to guide the needle insertion into the trachea, similar to the technique used in ultrasound-guided vascular punctures. Several studies have demonstrated the value of preprocedure cervical ultrasound in order to improve the safety of PDT [8–10]. In 1999, the first real-time ultrasound-guided PDT was described [11], followed by the publication of several case series and observational studies suggesting that the method was effective and safe [12–16].

Recently, three randomized controlled trials (RCTs) have demonstrated that the use of real-time ultrasound-guided PDT may significantly improve the rate of first-pass punctures, puncture accuracy, and reduce procedure-related complications, when compared to an anatomical landmark-guided PDT [17, 18] and bronchoscopy-guided PDT [19]. However, in the first two trials bronchoscopy was not evaluated and the last of these trials was underpowered to detect a difference in complication rates.

Therefore, we designed a noninferiority RCT in order to evaluate the safety and the efficacy of real-time ultrasound-guided PDT compared to bronchoscopy-guided PDT in mechanically ventilated patients in the ICU.

Methods

Trial design

The ultrasound-guided versus bronchoscopy-guided percutaneous dilatational tracheostomy trial (TRACHUS, NCT02084862) is an open-label, parallel, noninferiority RCT that was conducted at eight ICUs in the Hospital das Clínicas of São Paulo University. The study was conducted in accordance with the amended Declaration of Helsinki. Local institutional review boards approved the protocol (Comissão de Ética para Análise de Projetos de Pesquisa—CAPPesq, reference number 488506), and written informed consent was obtained from all of the patients or their legal surrogates.

Patients

Adult patients, intubated, mechanically ventilated, and indicated for a tracheostomy were considered eligible. Tracheostomy indication was at the discretion of the patient's attending physician. Patients were excluded if they had an unsuitable anatomy to undergo a PDT as judged by the patient attending physician (i.e., short neck, tracheal deviation, cervical anatomical anomaly, previous cervical surgery, cervical trauma, cervical tumors, or the inability to perform a neck extension) or the inability to get written informed consent.

Study intervention

Enrolled patients were randomized in a 1:1 ratio to ultrasound or bronchoscopy arms in random permuted blocks. None of the investigators or ICU staff members was aware of the randomization list prior to group allocation, as well as blocks numbers or blocks sizes at any moment, as the randomization was performed by using an automated third-party Internet-based service (Sealed Envelope, London, UK) in order to maintain allocation concealment. Treatment assignments could not be blinded to the ICU staff members. The patients were followed until hospital discharge.

Randomization was performed immediately before the procedure, as soon as all of the equipment and the PDT team were available. The procedures were performed according to standardized practices following hospital routines, as previously published [16]. Detailed procedure descriptions are available in supplemental materials.

Outcome measurements

Primary outcome

The primary outcome was procedure failure, defined as a composite end-point of conversion to a surgical tracheostomy, associated use of bronchoscopy in the case of ultrasound-guided PDT, associated use of ultrasound in the case of bronchoscopy-guided PDT, or the occurrence of a major complication.

The decision to proceed conversion to a surgical tracheostomy, associated use of bronchoscopy in the case of ultrasound-guided PDT, or associated use of ultrasound in the case of bronchoscopy-guided PDT was at discretion of the attending intensivist, during the procedure, without any interference of the investigators.

Major complications were defined as follows: procedure-related death, cardiac arrest, tracheal wall injury, false passage cannulation, pneumothorax, pneumomediastinum, tracheostomy cannula obstruction, esophageal injury, tracheoesophageal fistula, conversion to surgical tracheostomy, persistent hypotension (systolic blood pressure below 90 mmHg for more than 5 min and an associate intervention that was used to increase blood pressure using fluids, vasopressors infusion, or repeated vasopressors bolus), persistent acute hypoxemia (oxygen peripheral saturation below 90 % for more than 5 min as measured by a pulse oximeter), major bleeding (stomal, intratracheal, or trachea-vascular fistula causing hypoxemia and/or requiring an emergency transfusion and/or a surgical repair), tracheostomy-related sepsis (stoma infection as the only identifiable source).

Secondary outcomes

The secondary outcomes were the occurrence of a minor complication, procedure length, procedure difficulty, liberation from mechanical ventilation (breathing without ventilator assistance for at least 48 h), alive ventilation-free days at day 60 after hospital admission, days to ICU and hospital discharge, ICU mortality, and hospital mortality. Procedure difficulty was qualified as (1) easy, (2) somewhat difficult, (3) difficult, (4) very difficult, or (5) impossible [14] on the basis of subjective evaluation of the participating intensive care medicine residents about the procedure.

Minor complications were defined as follows: transient hypotension (systolic blood pressure below 90 mmHg for less than 5 min and an associate intervention that was used to increase blood pressure using fluids or vasopressors single bolus), transient acute hypoxemia (oxygen peripheral saturation below 90 % for less than 5 min as measured by a pulse oximeter), atelectasis, inadvertent cuff puncture, accidental decannulation, tracheostomy stoma infection, localized minor bleeding (stomal or intratracheal self-limiting bleeding or bleeding

successfully when treated with a local compression or by an instillation of topical vasoconstrictive agents), localized subcutaneous emphysema without any evidence of pneumothorax or pneumomediastinum, and local stomal infections not causing sepsis.

Statistical analysis

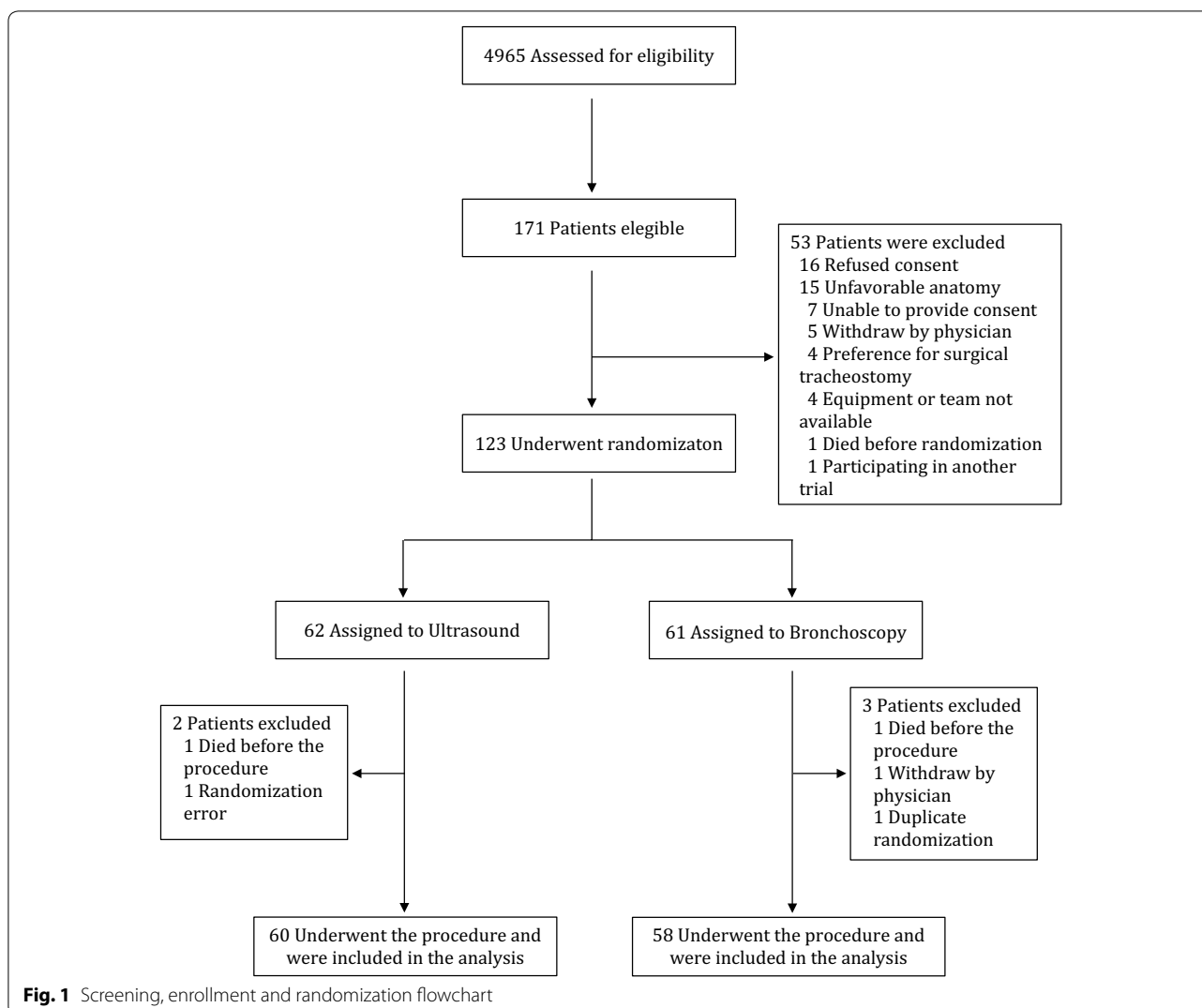
On the basis of the findings of both our previous observational study [16] and retrospective cohorts [20, 21], we estimated 1.2 % as being the primary outcome occurrence rate in the bronchoscopy-guided PDT group. Assuming an absolute noninferiority margin (Δ) of 6 %, at a one-sided α level significance of 0.05, we calculated that a sample size of 114 patients (57 per group) would be required to obtain a statistical power ($1 - \beta$) of 90 %. To assess for noninferiority we used the two one-sided test (TOST) method [22], where noninferiority is assumed, at the α significance level of 0.05, if the upper limit of a $(1 - 2\alpha) \times 100$ % confidence interval (CI) for the difference in efficacy is below Δ [23].

All analyses were performed on both an intention-to-treat and an “as treated” basis. As a noninferiority trial, data was presented mainly as an “as treated” population, because it is a stricter approach. No interim analysis was planned. For continuous variables, the Shapiro–Wilk test and kernel density estimation plots were used to assess normal distribution. Continuous variables were presented as a mean \pm standard deviation or as median and percentiles [25th–75th], according to the distribution, and they were compared by using the Student’s *t* test or the Wilcoxon–Mann–Whitney test. Categorical variables were presented as occurrences and their respective percentages, and they were compared by using the χ^2 or Fisher exact tests, as appropriate. Unadjusted Kaplan–Meier curves were used to assess the time from the endotracheal intubation to unassisted breathing within 28 days and were compared with a log-rank test, whereas an adjusted analysis was done by using Cox proportional hazards regression. A logistic regression was used to adjust for any significance between the groups on the baseline covariates. Statistical significance was assumed with a *P* value less than 0.05. In the Shapiro–Wilk test, the null hypothesis that the data are normally distributed was rejected with a *P* value less than 0.05. The statistical analysis was performed by using SPSS 21.0 software (SPSS Inc, Chicago, IL).

Results

Study patients

Between March 2014 and May 2015, a total of 4965 patients were assessed for eligibility. Of these, 171 patients were eligible and 123 were randomized. After exclusion of five patients before treatment for different



causes (death before the procedure, withdrawn by physician, and randomization errors), 118 patients underwent the procedure, with 60 patients randomly assigned to the ultrasound group and 58 patients to the bronchoscopy group (Fig. 1). Baseline characteristics were well balanced between the study groups, except for the Simplified Acute Physiology Score (SAPS) 3 (Table 1).

Procedure

The procedure was described as easy or somewhat difficult 88.3 % of the time in the ultrasound group and with a similar 86.2 % rate in the bronchoscopy group ($P = 0.960$). The median procedure length was similar in both groups, 11 [7–19] vs. 13 [8–20] minutes, respectively ($P = 0.468$). The puncture site was changed after the ultrasound procedure in 24 (23.3 %) patients in the ultrasound group (Table 2).

Outcomes

The primary outcome, procedure failure, occurred in one (1.7 %) patient in the ultrasound group and one (1.7 %) patient in the bronchoscopy group, with no absolute risk difference between the groups (90 % CI from -5.57 to 5.85) in the “as treated” analysis. In the intention-to-treat analysis, the absolute risk difference between the groups for the primary outcome was also none (90 % CI from -5.42 to 5.55). These confidence intervals did not include the prespecified margin of 6 %, meaning that the ultrasound-guided PDT met the prespecified criteria for non-inferiority when compared to the bronchoscopy-guided PDT (Fig. 2). An adjusted analysis for the primary outcome was not possible because of an insufficient number of events for a multivariate analysis.

In the ultrasound group, one patient had the tracheostomy tube inserted too low, between the fifth and sixth tracheal rings, with a subsequent tracheal laceration and

Table 1 General characteristics of the patients

Baseline characteristics	Ultrasound (n = 60)	Bronchoscopy (n = 58)	P value
Male, gender, n (%)	39 (65.0)	42 (72.4)	0.385
Age, years	49.9 (16.6)	46.9 (18.6)	0.330
Weight, kg	73.7 [65.0–83.8]	75 [61.8–80.0]	0.732
Height, cm	170 [164.2–175.8]	170 [164.5–178.0]	0.716
Body mass index, kg/m ²	25.1 [23.3–27.8]	25.2 [22.8–27.2]	0.720
SAPS 3 at ICU admission	61 [52–70]	55.5 [47–67]	0.027
Diagnosis on admission, n (%)			0.144
Traumatic brain injury	23 (38.3)	29 (50)	
Cerebrovascular disorder	12 (20)	8 (13.8)	
Pneumonia	2 (3.5)	1 (1.7)	
CNS infection	4 (6.7)	2 (3.4)	
Neurosurgery, except trauma	2 (3.3)	3 (5.2)	
Vascular surgery, except trauma	2 (3.3)	0	
Abdominal surgery, except trauma	1 (1.7)	2 (3.4)	
Peripheral neuropathy	4 (6.7)	4 (6.9)	
Cardiac arrest	2 (3.3)	2 (3.4)	
Metabolic encephalopathy	1 (1.7)	1 (1.7)	
Other	7 (11.7)	6 (10.3)	
Reason for Intubation, n (%)			0.852
Respiratory failure	9 (15)	8 (13.8)	
Inability to protect airway	51 (85)	50 (86.2)	
Reason for tracheostomy, n (%)			0.664
Difficult weaning	10 (16.7)	8 (13.8)	
Inability to protect airway	50 (83.3)	50 (86.2)	
Anatomical difficulties, n (%)			0.125
None	49 (81.7)	49 (84.5)	
Short neck	4 (6.7)	2 (3.4)	
Tracheal deviation	0	2 (3.4)	
Goiter	2 (3.3)	2 (3.4)	
Limited neck extension	4 (6.7)	0	
Others	0	2 (3.4)	
MV before tracheostomy, days	13 [8–18]	15 [9–17]	0.680

Values are expressed as the mean (standard deviation), median [25th–75th percentiles], or a number (percentage)

*PaO*₂ arterial oxygen pressure, *FiO*₂ fraction of inspired oxygen, *PDT* percutaneous dilational tracheostomy, *CNS* central nervous system, *MV* mechanical ventilation, *SAPS 3* Simplified Acute Physiology Score 3

mediastinitis. In the bronchoscopy group, one patient suffered from a tracheal anterior wall laceration during the tracheal dilation with a Griggs clamp and this was complicated with pneumomediastinum. No other major complication occurred in either group. Minor procedure-related complications were reported for a total of 32 (27.1 %) patients, 20 (33.3 %) patients in the ultrasound group and 12 (20.7 %) patients in the bronchoscopy group ($P = 0.122$) (Table 3). These results persisted after an adjusted analysis for the SAPS 3 score ($P = 0.148$).

Clinical outcomes were also not different between the ultrasound and the bronchoscopy groups. Forty-nine (81.7 %) patients achieved unassisted breathing in

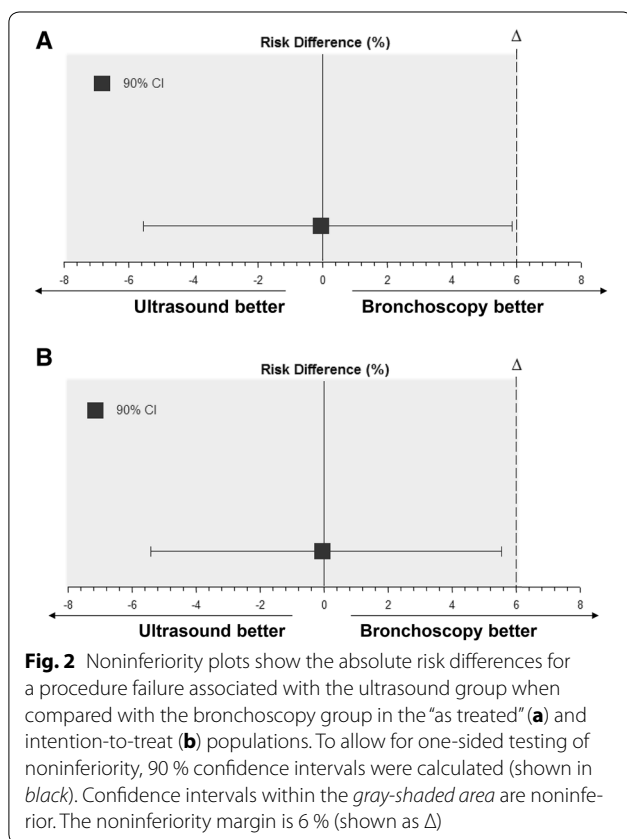
the ultrasound group when compared with 44 (75.9 %) patients in the bronchoscopy group ($P = 0.440$). The ventilation-free days were 38.5 [18–47] days vs. 38 [8–45] days ($P = 0.505$), and the time from tracheostomy to unassisted breathing was 3 [2–6] days vs. 4 [2.5–7] days ($P = 0.231$) in the ultrasound and the bronchoscopy groups, respectively. The time from tracheostomy to unassisted breathing within 30 days was also not different between the groups ($P = 0.972$, Fig. 3). A total of 52 (44 %) patients died during the hospital stay, 26 (44.8 %) patients in the ultrasound group and 26 (46.4 %) patients in the bronchoscopy group ($P = 0.864$) (Table 3).

Table 2 Procedure data

	Ultrasound (n = 60)	Bronchoscopy (n = 58)	P value
Procedure difficulty, n (%)			0.960
Easy	38 (63.3)	34 (58.6)	
Somewhat difficult	15 (25.0)	16 (27.6)	
Difficult	6 (10)	7 (12.1)	
Very difficult	1 (1.7)	1 (1.7)	
Impossible	0	0	
Tracheal punctures	2 [1–2]	2 [1–2]	0.724
Distance between skin and trachea, mm	8.9 (2.4)	NA	
Tracheal diameter, mm	22.2 (3.9)	NA	
Vessels beneath the puncture site, n (%)	10 (16.7)	NA	
Thyroid beneath the puncture site, n (%)	18 (30)	NA	
Change in the puncture site after US, n (%)	14 (23.3)	NA	
Procedure length (min)	11 [7–19]	13 [8–20]	0.468

Values are expressed as the mean (standard deviation), median [25th–75th percentiles], or a number (percentage)

US ultrasound, NA not applicable



Discussion

Ultrasound-guided PDT is noninferior to bronchoscopy-guided PDT in ICU mechanically ventilated patients. Furthermore, the major and minor complication rates were not statistically different between the groups, the

procedure length was the same in both groups, and ultrasound-guided PDT was described as being as easy as bronchoscopy-guided PDT.

Several studies evaluated the value of ultrasound in order to assist PDT [24, 25], and practice guidelines [26] have recommended its use to improve the safety of the technique. However, most of the studies were observational, and only three RCTs have been published to date comparing ultrasound-guided PDT to landmark- or bronchoscopy-guided PDT [17–19]. Despite significant methodological differences, all of these trials point out that ultrasound-guided PDT is safe, fast, and might improve procedure efficiency and reduce procedure-related complications when compared to landmark- or bronchoscopy-guided PDT.

Major complication rates are usually low. In the two largest retrospective cohorts previously published on the topic, including a total of 4162 patients in the analyses, the total major complication rates ranged from 0.38 to 1.4 % [4, 27], similar to the 1.7 % major complication rate in our trial.

Minor complications that were procedure related were reported for 20 (33.3 %) patients in the ultrasound group and 12 (20.7 %) patients in the bronchoscopy group. Total minor complications rate was higher in the ultrasound group, which might be related to higher baseline SAPS 3 score in the ultrasound group or less team experience with the new method. Nevertheless, this difference was not statistically significant, remaining nonsignificant after adjusted analysis and with an incidence similar to that previously reported [2, 28]. However, the study was not designed and might be underpowered to detect differences based on secondary outcomes.

Table 3 Complications and clinical outcomes

	Ultrasound (<i>n</i> = 60)	Bronchoscopy (<i>n</i> = 58)	<i>P</i> value
Procedure failure, <i>n</i> (%)	1 (1.7)	1 (1.7)	0.981
Transient hypotension, <i>n</i> (%)	7 (11.7)	6 (10.3)	0.819
Minor bleeding, <i>n</i> (%)	4 (6.7)	5 (8.6)	0.689
Transient acute hypoxemia, <i>n</i> (%)	2 (3.3)	0	0.496
Orotracheal cannula puncture, <i>n</i> (%)	3 (5.0)	1 (1.7)	0.619
Stoma infection, <i>n</i> (%)	2 (3.3)	0	0.496
Accidental decannulation, <i>n</i> (%)	1 (1.7)	2 (3.4)	0.615
Atelectasis, <i>n</i> (%)	5 (8.3)	1 (1.7)	0.207
Total minor complications, <i>n</i> (%)	20 (33.3)	12 (20.7)	0.122
Time to unassisted breathing, days	49 (81.7)	44 (75.9)	0.440
MV time, days	19 [12–28]	19 [13–24]	0.699
Time between tracheostomy and unassisted breathing, days	3 [2–6]	4 [2.5–7]	0.231
Ventilation-free days at day 60, days	38.5 [18–47]	38 [8–45]	0.505
ICU length of stay, days	26 [19–38]	24 [19–34]	0.819
Hospital length of stay, days	48 [29–70]	41 [27–66]	0.272
ICU mortality, <i>n</i> (%)	20 (33.3)	21 (36.2)	0.743
Hospital mortality, <i>n</i> (%)	26 (44.8)	26 (46.4)	0.864
ICU free days at day 60, <i>n</i> (%)	18 [0–36]	25 [0–38]	0.608

Values are expressed as the mean (standard deviation), median [25th–75th percentiles], or number (percentage)

MV mechanical ventilation, ICU intensive care unit

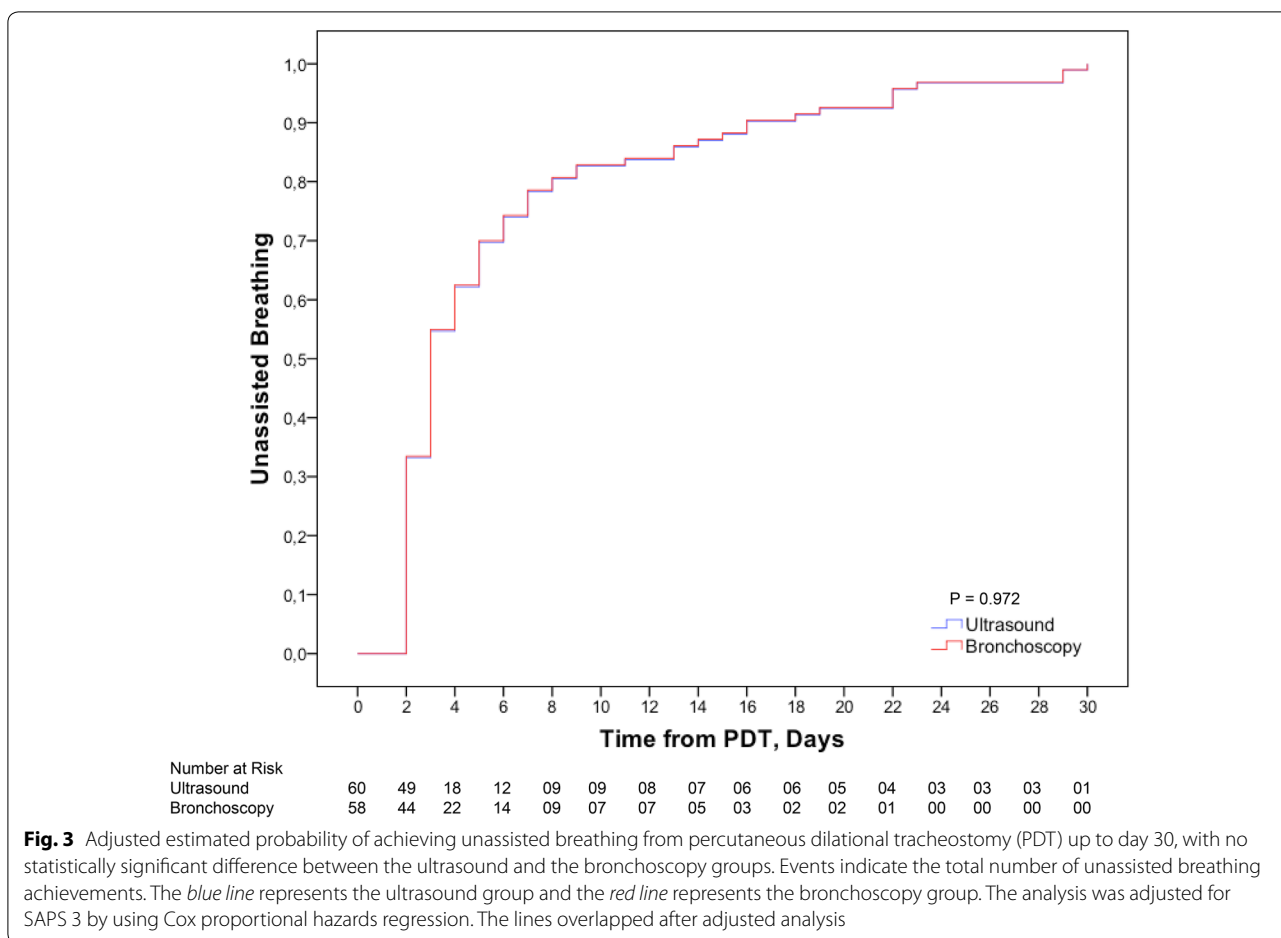
The complication rates in previous trials were highly variable, depending on the population and upon which complications were taken into account to elaborate the rate. In a meta-analysis comparing surgical with percutaneous tracheostomy, including 17 randomized trials with a total of 1212 patients, the overall incidence of bleeding in both of the groups was 5.7 % and the infection rate was 6.6 % [2]. In all three RCTs comparing ultrasound-guided PDT with bronchoscopy-guided PDT or landmark-guided PDT published to date, the total minor complication rates ranged from 11.52 to 56.75 % [17–19] and were not different between the groups. Additionally, in our previous retrospective cohort, the total minor complication rate was 30 % in both of the groups [16].

Bronchoscopy was chosen as the active comparator because, in our institution, a bronchoscopy-guided PDT has been the standard method for tracheostomy procedures over the past 15 years [29]. However, no RCTs comparing bronchoscopy-guided PDT to landmark-guided PDT (considered “placebo”) have been published to date. Therefore, the primary outcome occurrence rates and the noninferiority margins were estimated on the basis of retrospective cohorts comparing a bronchoscopy-guided PDT to a landmark-guided PDT [20, 21].

Furthermore, bronchoscopy has been traditionally recommended as an adjunctive tool to assist PDT and to help in preventing complications [5, 30, 31]. International surveys have revealed that 69.2–97.7 % routinely used

bronchoscopy guidance during PDT [1, 32], and that of the remaining, 1 % would opt for a bronchoscopy procedure in the presence of a difficult airway [32]. Moreover, several trials have shown the efficacy and the safety of a bronchoscopy-guided PDT, especially when compared to a surgical tracheostomy [2, 33]. Nevertheless, other reports have found no difference in the complication rates when a PDT was performed with or without bronchoscopy guidance, suggesting that its use is not routinely required and should be limited to selected cases [20, 21].

Since the introduction of ultrasound-guided PDT in our institution in 2013, it has become the preferred method for tracheostomy, accounting for more than 80 % of the tracheostomies performed in the ICU, when the patient was out of the clinical trial [16]. This increase could be related to the following: (1) the greater availability of ultrasound equipment than of bronchoscopy equipment in the ICU, (2) the ultrasound equipment cleaning is faster, it is much less labor intensive, it is less costly, and it does not require the removal of the ultrasound equipment from the ICU setting, (3) the need for fewer staff than a bronchoscopy, (4) a steep learning curve of ultrasound-guided PDT, and (5) confidence in the new method over time. However, bronchoscopy and ultrasound are not mutually exclusive and can be used in a combination to improve PDT efficacy and safety [34–36].



All the attending intensivists were previously trained in ultrasound-guided PDT, bronchoscopy-guided PDT, critical care ultrasound, and bronchoscopy. However, all the procedures were performed by inexperienced intensive care medicine residents, assisted by the attending intensivists. Furthermore, the ultrasound-guided PDT procedures were described as easy or somewhat difficult in 88.3 % of time by the participating residents. Although these data suggest that our results might be generalizable, similar results might not be obtained by less experienced teams.

The strengths of our trial include a prospective randomization, a strict maintenance of allocation concealment, a limited exclusion criterion, a high percentage of enrollments of eligible patients, a sample size calculation, and a prespecified noninferiority margin. The clinical outcomes were clinically relevant and the data analysis was blinded.

This study has important limitations. First, this is a single-center investigation, although it included eight ICUs, with a heterogeneous patient's population, and with many attending physicians with different backgrounds

before any critical care training (surgeons, anesthesiologists, and internal medicine). Second, this is a noninferiority trial, and the noninferiority margin of 6 % might be considerably high for the low primary outcome incidence rate. A rational decision about noninferiority margin should be prespecified on the basis of clinical factors and data from previous studies [37, 38]. The TRACHUS noninferiority margin was prespecified on the basis of 95 % CI from previous published observational cohorts on the topic [20, 21], clinically relevant, and similar to noninferiority margins used in recently published noninferiority RCTs evaluating surgical procedures [39, 40]. Third, the patients were followed only until hospital discharge and were not assessed for late complications such as tracheal stenosis, vocal abnormalities, or scar characteristics. Fourth, blinding was not possible because of the nature of the procedures and the outcome assessments were also not blinded. Fifth, the bronchoscopy procedure was performed by trained intensivists and not by the specialized bronchoscopy team. However, this is in line with the routine practice of most of the ICUs worldwide, which could improve external validity.

Conclusions

Our data indicates that ultrasound-guided PDT is non-inferior to bronchoscopy-guided PDT in mechanically ventilated patients in the ICU. Therefore, an ultrasound-guided PDT might be effectively and safely used as an alternative to a bronchoscopy-guided PDT.

Electronic supplementary material

The online version of this article (doi:[10.1007/s00134-016-4218-6](https://doi.org/10.1007/s00134-016-4218-6)) contains supplementary material, which is available to authorized users.

Abbreviations

CAPPesq: Comissão de Ética para Análise de Projetos de Pesquisa; CNS: Central nervous system; FiO₂: Fraction of inspired oxygen; ICU: Intensive care unit; MV: Mechanical ventilation; NA: Not applicable; PaO₂: Arterial oxygen pressure; PDT: Percutaneous dilatational tracheostomy; RCT: Randomized clinical trial; SAPS 3: Simplified Acute Physiology Score 3; US: Ultrasound.

Author details

¹ Medical Intensive Care Unit, Emergency Department, Hospital das Clínicas, University of São Paulo Medical School, Rua Dr. Eneas Carvalho Aguiar, 255, Sixth Floor, Room 6040, São Paulo, Brazil. ² Trauma Intensive Care Unit, Surgery Emergency Department, Hospital das Clínicas, University of São Paulo Medical School, São Paulo, Brazil. ³ Intensive Care Unit, Infectious Disease Department, Hospital das Clínicas, University of São Paulo Medical School, São Paulo, Brazil. ⁴ Surgical Intensive Care Unit, Anesthesiology Department, Hospital das Clínicas, University of São Paulo Medical School, São Paulo, Brazil. ⁵ Department of Surgical Sciences and Integrated Diagnostics, University of Genoa, Genoa, Italy. ⁶ Department of Surgical Sciences and Integrated Diagnostics, IRCCS AOU San Martino IST, Genoa, Italy.

Acknowledgments

We would like to thank the nursing staff, the respiratory therapists, the intensive care medicine residents, and all of the attending physicians from the ICU departments for performing treatment for our patients and for their cooperation in the trial. Special acknowledgments are due to Dr. Mino Cestari whose collaboration was indispensable to the trial.

Compliance with ethical standards

Conflicts of interests

The authors have no relevant conflict of interest to disclose. The study was not financially supported by any funding source. The design, collection, analysis, and the interpretation of data, plus the writing and the publication of the manuscript, were done by the authors without participation or influence from any funding source.

Received: 16 November 2015 Accepted: 9 January 2016

Published online: 1 February 2016

References

- Vargas M, Sutherland Y, Antonelli M, Brunetti I, Corcione A, Laffey JG, Putensen C, Servillo G, Pelosi P (2015) Tracheostomy procedures in the intensive care unit: an international survey. *Crit Care* 19:291
- Delaney A, Bagshaw SM, Nalos M (2006) Percutaneous dilatational tracheostomy versus surgical tracheostomy in critically ill patients: a systematic review and meta-analysis. *Critical Care* 10: R55
- Putensen C, Theuerkauf N, Guenther U, Vargas M, Pelosi P (2014) Percutaneous and surgical tracheostomy in critically ill adult patients: a meta-analysis. *Crit Care* 18:544
- Dennis BM, Eckert MJ, Gunter OL, Morris JA Jr, May AK (2013) Safety of bedside percutaneous tracheostomy in the critically ill: evaluation of more than 3,000 procedures. *J Am Coll Surg* 216:858–865 (discussion 865–857)
- Hinerman R, Alvarez F, Keller CA (2000) Outcome of bedside percutaneous tracheostomy with bronchoscopic guidance. *Intensive Care Med* 26:1850–1856
- Fernandez L, Norwood S, Roettger R, Gass D, Wilkins H 3rd (1996) Bedside percutaneous tracheostomy with bronchoscopic guidance in critically ill patients. *Arch Surg* 131:129–132
- Flint AC, Midde R, Rao VA, Lasman TE, Ho PT (2009) Bedside ultrasound screening for pretracheal vascular structures may minimize the risks of percutaneous dilatational tracheostomy. *Neurocrit Care* 11:372–376
- Singh M, Chin KJ, Chan VW, Wong DT, Prasad GA, Yu E (2010) Use of sonography for airway assessment: an observational study. *J Ultrasound Med* 29:79–85
- Bonde J, Nørgaard N, Antonsen K (1999) Implementation of percutaneous dilation tracheotomy—value of preincisional ultrasonic examination? *Acta Anaesthesiol Scand* 43:163–166
- Kollig E, Heydenreich U, Roetman B, Hopf F, Muhr G (2000) Ultrasound and bronchoscopic controlled percutaneous tracheostomy on trauma ICU. *Injury* 31:663–668
- Sustic A, Zupan Z, Eskinja N, Dirlic A, Bajek G (1999) Ultrasonographically guided percutaneous dilatational tracheostomy after anterior cervical spine fixation. *Acta Anaesthesiol Scand* 43:1078–1080
- Rajajee V, Fletcher JJ, Rochlen LR, Jacobs TL (2011) Real-time ultrasound-guided percutaneous dilatational tracheostomy: a feasibility study. *Crit Care* 15:R67
- Rezende-Neto JB, Oliveira AJ, Neto MP, Botoni FA, Rizoli SB (2011) A technical modification for percutaneous tracheostomy: prospective case series study on one hundred patients. *World J Emerg Surg* 6:35
- Guinot PG, Zogheib E, Petiot S, Marienne JP, Guerin AM, Monet P, Zaatar R, Dupont H (2012) Ultrasound-guided percutaneous tracheostomy in critically ill obese patients. *Crit Care* 16:R40
- Rajajee V, Williamson CA, West BT (2015) Impact of real-time ultrasound guidance on complications of percutaneous dilatational tracheostomy—a propensity score analysis. *Crit Care* 19:198
- Gobatto AL, Besen BA, Tierno PF, Mendes PV, Cadamuro F, Joelsons D, Melro L, Park M, Malbouisson LM (2015) Comparison between ultrasound- and bronchoscopy-guided percutaneous dilatational tracheostomy in critically ill patients: a retrospective cohort study. *J Crit Care* 30:220. e213–220.e227
- Yavuz A, Yilmaz M, Goya C, Alimoglu E, Kabaalioglu A (2014) Advantages of US in percutaneous dilatational tracheostomy: randomized controlled trial and review of the literature. *Radiology* 273:927–936
- Rudas M, Seppelt I, Herkes R, Hislop R, Rajbhandari D, Weisbrodt L (2014) Traditional landmark versus ultrasound guided tracheal puncture during percutaneous dilatational tracheostomy in adult intensive care patients: a randomised controlled trial. *Crit Care* 18:514
- Ravi PR, Vijay MN (2015) Real time ultrasound-guided percutaneous tracheostomy: is it a better option than bronchoscopy guided percutaneous tracheostomy? *Med J Armed Forces India* 71:158–164
- Jackson LS, Davis JW, Kaups KL, Sue LP, Wolfe MM, Bilello JF, Lemaster D (2011) Percutaneous tracheostomy: to bronch or not to bronch—that is the question. *J Trauma* 71:1553–1556
- Abdulla S, Conrad A, Vielhaber S, Eckhardt R, Abdulla W (2013) Should a percutaneous dilatational tracheostomy be guided with a bronchoscope? *B-ENT* 9:227–234
- Schuirman DJ (1987) A comparison of the two one-sided tests procedure and the power approach for assessing the equivalence of average bioavailability. *J Pharmacokinet Biopharm* 15:657–680
- Walker E, Nowacki AS (2011) Understanding equivalence and noninferiority testing. *J Gen Intern Med* 26:192–196
- Rudas M, Seppelt I (2012) Safety and efficacy of ultrasonography before and during percutaneous dilatational tracheostomy in adult patients: a systematic review. *Crit Care Resusc* 14:297–301
- Alansari M, Alotair H, Al Aseri Z, Elhoseny MA (2015) Use of ultrasound guidance to improve the safety of percutaneous dilatational tracheostomy: a literature review. *Critical Care* 19:229
- Madsen KR, Guldager H, Rewers M, Weber SO, Kobke-Jacobsen K, White J (2015) Danish guidelines 2015 for percutaneous dilatational tracheostomy in the intensive care unit. *Dan Med J* 61(3):pii B5042
- Kornblith LZ, Burrell CC, Moore EE, Haenel JB, Kashuk JL, Biffi WL, Barnett CC, Johnson JL (2011) One thousand bedside percutaneous

- tracheostomies in the surgical intensive care unit: time to change the gold standard. *J Am Coll Surg* 212:163–170
28. Higgins KM, Punthakee X (2007) Meta-analysis comparison of open versus percutaneous tracheostomy. *Laryngoscope* 117:447–454
 29. Park M, Brauer L, Sanga RR, Amaral ACK-B, Ladeira JP, Azevedo LCPd, Taniguchi LU, Cruz-Neto LMd (2004) Traqueostomia percutânea no doente crítico: a experiência de uma unidade de terapia intensiva clínica. *J Bras Pneumol* 30:237–242
 30. Polderman KH, Spijksstra JJ, de Bree R, Christiaans HM, Gelissen HP, Wester JP, Girbes AR (2003) Percutaneous dilatational tracheostomy in the ICU: optimal organization, low complication rates, and description of a new complication. *Chest* 123:1595–1602
 31. Tomsic JP, Connolly MC, Joe VC, Wong DT (2006) Evaluation of bronchoscopic-assisted percutaneous tracheostomy. *Am Surg* 72:970–972
 32. Kluge S, Baumann HJ, Maier C, Klose H, Meyer A, Nierhaus A, Kreymann G (2008) Tracheostomy in the intensive care unit: a nationwide survey. *Anesth Analg* 107:1639–1643
 33. Kost KM (2005) Endoscopic percutaneous dilatational tracheotomy: a prospective evaluation of 500 consecutive cases. *Laryngoscope* 115:1–30
 34. Dinh VA, Farshidpanah S, Lu S, Stokes P, Chrissian A, Shah H, Giri P, Hecht D, Nguyen HB (2014) Real-time sonographically guided percutaneous dilatational tracheostomy using a long-axis approach compared to the landmark technique. *J Ultrasound Med* 33:1407–1415
 35. Chacko J, Gagan B, Kumar U, Mundlapudi B (2015) Real-time ultrasound guided percutaneous dilatational tracheostomy with and without bronchoscopic control: an observational study. *Minerva Anesthesiol* 81:166–174
 36. Chacko J, Nikahat J, Gagan B, Umesh K, Ramanathan M (2012) Real-time ultrasound-guided percutaneous dilatational tracheostomy. *Intensive Care Med* 38:920–921
 37. Siegel JP (2000) Equivalence and noninferiority trials. *Am Heart J* 139:S166–S170
 38. Snapinn SM (2004) Alternatives for discounting in the analysis of noninferiority trials. *J Biopharm Stat* 14:263–273
 39. Stevenson AR, Solomon MJ, Lumley JW, Hewett P, Clouston AD, Gebiski VJ, Davies L, Wilson K, Hague W, Simes J, ALaCaRT Investigators (2015) Effect of laparoscopic-assisted resection vs open resection on pathological outcomes in rectal cancer: the ALaCaRT randomized clinical trial. *JAMA* 314:1356–1363
 40. Bonjer HJ, Deijen CL, Haglind E, COLOR II Study Group (2015) A randomized trial of laparoscopic versus open surgery for rectal cancer. *N Engl J Med* 373:194