

## UPDATE IN INTENSIVE CARE MEDICINE: HEMODYNAMIC MONITORIZATION IN THE CRITICAL PATIENT

### Percutaneous tracheostomy in the ventilated patient<sup>☆</sup>

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#### KEYWORDS

Tracheostomy;  
Percutaneous tracheostomy;  
Prolonged mechanical ventilation

**Abstract** The medical indications of tracheostomy comprise the alleviation of upper airway obstruction; the prevention of laryngeal and upper airway damage due to prolonged translaryngeal intubation in patients subjected to prolonged mechanical ventilation; and the facilitation of airway access for the removal of secretions. Since 1985, percutaneous tracheostomy (PT) has gained widespread acceptance as a method for creating a surgical airway in patients requiring long-term mechanical ventilation. Since then, several comparative trials of PT and surgical tracheostomy have been conducted, and new techniques for PT have been developed. The use of percutaneous dilatation techniques under bronchoscopic control is now increasingly popular throughout the world. Tracheostomy should be performed as soon as the need for prolonged intubation is identified. However a validated model for the prediction of prolonged mechanical ventilation is not available, and the timing of tracheostomy should be individualized. The present review analyzes the state of the art of PT in mechanically ventilated patients – this being regarded by many as the technique of choice in performing tracheostomy in critically ill patients.

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#### PALABRAS CLAVE

Traqueotomía;  
Traqueotomía percutánea;  
Ventilación mecánica prolongada

#### Traqueotomía percutánea en el paciente ventilado

**Resumen** Las indicaciones para la realización de la traqueotomía se pueden resumir en: 1. obstrucción de la vía aérea superior, 2. prevención del daño laríngeo y de la vía aérea alta por intubación prolongada en pacientes sometidos a ventilación mecánica prolongada, y 3. permitir un fácil acceso a la vía aérea para la eliminación de secreciones. Desde 1985 la traqueotomía percutánea (TP) se ha ido consolidando como la técnica para establecer una vía aérea quirúrgica en los pacientes que necesitan ventilación prolongada. Desde entonces, se han publicado diferentes estudios comparativos entre TP y traqueotomía quirúrgica, se han desarrollado

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nuevas modalidades de TP y el uso de las técnicas por dilatación con control endoscópico continúa extendiendo su popularidad por todo el mundo. La traqueotomía debe realizarse tan pronto como se identifica la necesidad de tener un paciente ventilado de forma prolongada, sin embargo no hay modelos para predecir tal situación y el momento para su realización debe individualizarse. En el presente artículo analizaremos el estado actual de la TP en los pacientes ventilados mecánicamente, considerada para muchos la técnica de elección para la realización de la traqueotomía en el enfermo crítico.

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## Introduction

Tracheostomy is one of the most common techniques used in the Intensive Care Unit (ICU). Although the procedure is assumed to be thousands of years old, modern tracheostomy was introduced with the description of surgical tracheostomy (ST) by Jackson in 1909.<sup>1</sup> In that period, inflammatory or tumor processes causing airway obstruction were the main indication of the technique. With advances in the fields of surgery, critical care and positive pressure mechanical ventilation, tracheostomy received a new indication: prolonged mechanical ventilation. For years this was a feared technique, often associated with serious and even fatal complications; physicians therefore attempted to avoid the procedure, and patients remained intubated for weeks and even months.<sup>2</sup> In 1985, Bishop et al.<sup>3</sup> published an experimental study on the consequences of prolonged intubation, and that same year Ciaglia et al.<sup>4</sup> described percutaneous dilatation tracheostomy (PDT), which proved simple, rapid and safe. Furthermore, the technique could be performed at the patient bedside, leading to a new way of viewing surgical access to the airway in the critically ill patient.

## Types of percutaneous tracheostomy

Five years after the description of PDT by Ciaglia et al.,<sup>4</sup> Griggs et al.<sup>5</sup> introduced tracheostomy using guide wire dilating forceps (GWDF) (Portex Limited, Hythe, Kent, United Kingdom). With this technique the tracheostoma is opened using blunt-tipped forceps (designed with a cannulated internal margin through which a metal guide wire can be inserted) previously advanced over the metal guide in the tracheal lumen. In 1998 the classical technique of Ciaglia was modified using a single dilator<sup>6</sup> (Ciaglia Blue Rhino [CBR], Cook Critical Care, Bloomington, IN, USA). With respect to the original technique, this modification offered the advantage that the stoma is produced by a single dilatation, thereby avoiding the need for successive dilatations. Fantoni and Ripamonti<sup>7</sup> in turn developed the translaryngeal technique (Mallinckrodt, Mirandola, Italy) – a complex system in which the stoma is made by exteriorizing a dilator from within the trachea, using a specially designed tracheostomy cannula and a rigid bronchoscope. In 2002, Frova and Quintel<sup>8</sup> described the PercuTwist technique (Rüsch GmbH, Kernen, Germany), in which the tracheostoma is made using a rotation system. Another modification of

the classical technique of Ciaglia was introduced in 2008 (Ciaglia Blue Dolphin [CBD], Cook Critical Care, Bloomington, IN, USA), involving dilatation performed by insufflating a balloon.<sup>9</sup>

The techniques most widely used in Spain in the early years of the last decade were the Griggs technique, the Ciaglia PDT, and the Ciaglia Blue Rhino.<sup>10</sup> At that time the balloon dilatation technique had not been developed, and the PercuTwist procedure was being introduced. An additional 5 European surveys have evaluated the use of percutaneous tracheostomy (PT) in the ICU, and their results are shown in Fig. 1.<sup>11–15</sup>

## Indications and contraindications of percutaneous tracheostomy

The indications of tracheostomy can be summarized as follows: (1) need for airway permeation; (2) prevention of laryngotracheal damage caused by prolonged intubation; and (3) maintenance of adequate tracheobronchial hygiene, facilitating the aspiration of secretions in patients with spontaneous secretion clearing problems.

The classical contraindications of PT have been obesity, a short neck, gout or neck deformities, coagulation disorders (INR > 1.5) or thrombopenia (platelet count < 50,000/mm<sup>3</sup>), children under 16 years of age, the need to establish an emergency surgical airway, probable or confirmed cervical spine damage, previous neck surgery or tracheostomy, infection in the surgical zone, and high oxygen and PEEP requirements.<sup>16–18</sup>

As experience with PT has increased, so has clinician confidence with the technique, while the restrictions in high risk patients have decreased. Nevertheless, it must be taken into account that young children, cervical injury and infection of the surgical zone remain absolute contraindications. Some risk groups and the pediatric population deserve special mention.

## Children

Toursarkissian et al.<sup>19</sup> evaluated PDT in 11 children and adolescents between 10 and 20 years of age, with good results. They recorded an intraoperative and a postoperative complication in the same patient that were easily recognized and treated, and in no case was tracheal stenosis observed in 8 decannulated patients during a follow-up period of 43 ± 30 weeks. More recently, Raju et al.<sup>20</sup> have

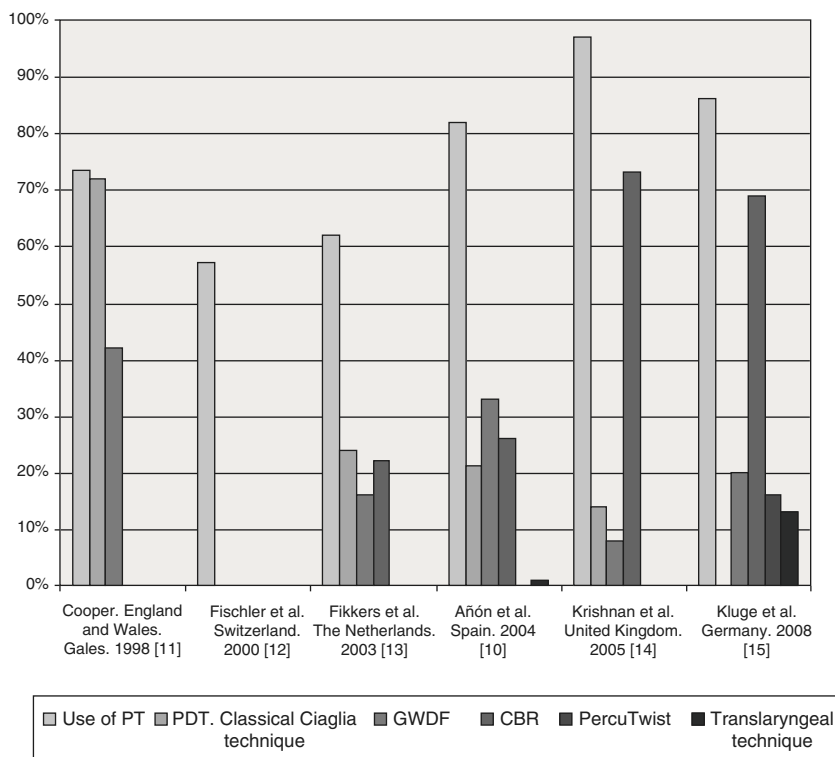


Figure 1 Use of percutaneous tracheostomy (PT) in European Intensive Care Units.

compared ST with PT in pediatric trauma patients. The mean age of both groups was 14.2 and 15.5 years for ST and PT, respectively. No significant differences were observed, and the authors concluded that PT is a safe option in older children.

However, the characteristics of the trachea in children may make them more susceptible to certain serious complications. There is not enough experience in this population, and it is ethically questionable to conduct randomized trials to evaluate a technique in which the risks of a learning curve would have to be accepted in a population (pediatric patients) for which it was not designed.<sup>21,22</sup> At this time there are no guides or recommendations warranting its application in children.

**Obesity**

Few studies have examined the safety of PT in obese patients, and the existing data are moreover contradictory. Mansharamani et al.<sup>23</sup> published their experience in 13 patients with a body mass index (BMI) > 27 kg/m<sup>2</sup>. They described a false passage and a case of balloon rupture, with no fatalities attributable to the technique. The latter was thus considered safe in this population. Byhahn et al.<sup>24</sup> obtained different results in a cohort of 73 patients with BMI > 27.5 kg/m<sup>2</sup> in which PT was performed under endoscopic control using one of the following methods: classical PDT, CBR and the translaryngeal technique. There were complications in 43% of the 73 patients classified as obese, versus in 18% of the 401 patients without obesity. A total of 9.6% of the obese subjects suffered serious complications (defined as problems with an impact upon morbidity and

mortality), versus 0.7% in the other group. The serious complications in the obese patients included posterior tracheal wall damage and anterior esophageal tearing, as well as accidental decannulation.

Although obesity is currently not an absolute contraindication to PT, it is a condition that does require a number of precautions. Anatomical localization may prove more difficult in some cases, and longer tracheostomy cannulas are probably required in the last step of the technique. Successful performance of the procedure is conditioned by the degree of obesity, with the need for reasonable identification of the puncture zone; the experience of the medical team; and the safety measures adopted.

**Previous tracheostomy**

Previous tracheostomy has been a classical contraindication to PT. To date only one study involving a small sample and with a lack of follow-up has reported no serious complications with ‘‘retracheostomy’’ in 14 subjects. The authors defend the safety of the procedure.<sup>25</sup> Although the technique is an attractive alternative to ST in these cases, its application must be conditioned to the characteristics of the patient and the experience of the team performing the procedure.

**Thrombopenia**

Kluge et al.<sup>26</sup> published the results of a retrospective study on the safety of PT using the Griggs technique in ventilated patients with platelet counts of under 50,000/mm<sup>3</sup>.

The mean platelet count was 26,400/mm<sup>3</sup>, and the number of platelet units transfused before PT was  $6 \pm 2.5$ . Only two patients (5%) suffered bleeding that required suturing after the procedure. Both presented prolongation of activated partial thromboplastin time due to heparin treatment. The authors concluded that the technique has a low complication rate when performed by experienced personnel, and provided prior platelet transfusion has been carried out. However, suspension of heparin infusion was considered necessary before performing the procedure. It should be noted that before the publication of the study by Kluge et al.,<sup>26</sup> some studies had already considered that the contraindications related to coagulation disorders are conditioned to the possibility of correcting such disorders. The results obtained are important in that they offer information not previously available, reinforcing the relative nature of such contraindications.

### High fraction of inspired oxygen and positive end-expiratory pressure requirements

High fraction of inspired oxygen (FiO<sub>2</sub>) and positive end-expiratory pressure (PEEP) requirements has been the exclusion criteria in different studies, with values that vary over a broad range. Once again, however, there are few studies on this subject, and no recommendations have been established. In order to evaluate the impact upon oxygenation of PDT under endoscopic guidance, Beiderlinden et al.<sup>27</sup> compared the technique in two groups of patients with PEEP > 10 mmHg and with PEEP ≤ 10 mmHg. Oxygenation was not found to worsen one and 24 h after performing PDT, and the authors did not experience changes in the patients with the greatest alteration in gas exchange. The authors therefore concluded that acute respiratory failure with high FiO<sub>2</sub> and PEEP levels should not be regarded as a contraindication to PT.

### Complications of percutaneous tracheostomy

A number of reasons make it difficult to obtain a rigorous estimate of the perioperative complications of PT: (1) the baseline conditions of the patient may play a predisposing role; (2) the complications are directly conditioned to the degree of experience, which has been evaluated in only a few studies to date; (3) some of the more serious complications of PT can be avoided by adopting adequate safety measures, though these have not been widely used in the comparative studies; and (4) the definition of each event varies considerably among the different studies. In this regard, standardization of these aspects would allow us to obtain more objective and homogeneous information on the acute complications of the different types of PT. In this regard we propose the definitions of the complications of PT shown in Table 1, modified from Durbin.<sup>28</sup>

Surgical tracheostomy has been the gold standard for comparison with PT. Table 2 shows the results of the randomized studies<sup>29-42</sup> that have compared ST and PT (predominantly PDT). Only two studies found the incidence of intra- or postoperative complications to be significantly greater with PDT than with ST.

Few studies have focused on the late complications (some of which are inherent to tracheostomy, regardless of the technique used) of PT, and the existing publications moreover involve small samples due to the high in-hospital and middle-term mortality among critical patients susceptible to PT. This makes it difficult to obtain representative samples for study (Table 3).<sup>43-54</sup> The most feared complications are fistula of the innominate artery, tracheomalacia, tracheoesophageal fistula and tracheal stenosis. Other less serious complications are tracheocutaneous fistula, hoarseness and/or voice changes, or esthetic alterations. In relation to the more serious complications, the following should be noted: (1) tracheal stenosis causes no symptoms until 50–75% of the lumen is obliterated, and most cases therefore can be subclinical (Fig. 2); (2) the mortality rate associated with fistula of the innominate artery is close to 100%, and the preventive measures include not performing tracheostomy too low, in order to avoid resting of the cannula on the artery, and avoiding excessive movements on the part of the patient; (3) a tracheoesophageal fistula may be produced when performing PT, secondary to posterior tracheal wall damage, or on a delayed basis as a consequence of excessive balloon insufflation or posterior wall damage caused by continuous trauma produced by the tracheostomy cannula tip; and (4) tracheomalacia is a result of damage to the tracheal cartilage, causing the trachea to become distensible, and in acute ventilated patients the tracheomalacia zone must be passed by introducing a longer tracheostomy tube while waiting definitive treatment.

### Are some types of percutaneous tracheostomy better than others?

Each type or modality of PT has its own characteristics, and this has led to the conduction of comparative studies in search of the safest option. However, these studies have been heterogeneous and with small samples. Table 4 summarizes the prospective and randomized studies published to date.<sup>55-64</sup>

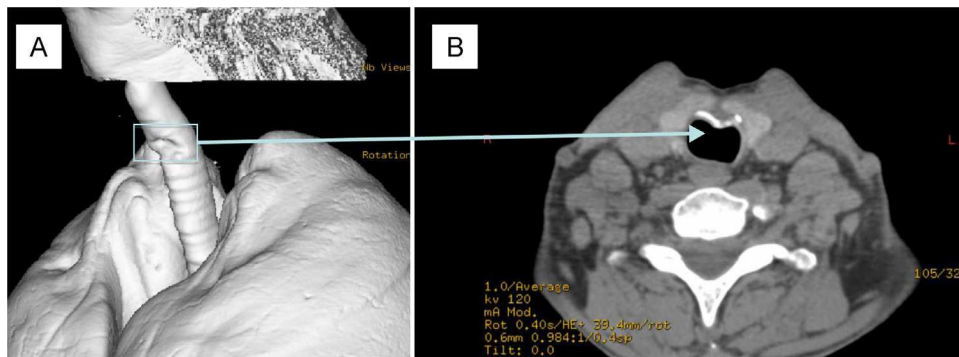
### Percutaneous dilatation tracheostomy versus guide wire dilating forceps

Three randomized studies have compared PDT versus GWDF. In a series of 100 patients, Nates et al.<sup>55</sup> observed increased technical difficulty and a higher incidence of bleeding with GWDF – the balance of the global complications being favorable to PDT. Van Heurn et al.,<sup>58</sup> in 127 patients (63 randomized to PDT and 64 to GWDF), likewise recorded a higher incidence of complications in the GWDF group. Although the authors specified that all the techniques were performed or assisted by experienced personnel, they described cannula insertion difficulties in 8 patients in the GWDF group – thus suggesting that discrete changes in the operating group could have avoided some of the observed complications. In a more recent comparative study, Kaiser et al.<sup>63</sup> randomized 48 patients to PDT and 52 to GWDF. In this case, the incidence of minor and major complications was significantly greater in the PDT group than in the GWDF series. Of note is the high presence of certain complications such as bleeding in both groups, and a large number of anesthetic

**Table 1** Proposed definitions for the perioperative complications of percutaneous tracheostomy (PT).

Complication	Definition
Hypoxemia	SaO <sub>2</sub> by pulseoximetry ≤90% during >30 s
Severe hypoxemia	SaO <sub>2</sub> by pulseoximetry ≤90% during >60 s or ≤85% any duration
Loss of airway control	Failure to access airway for more than 20 s
Bronchospasm	Bronchoconstriction related to performance of the technique
Mild arrhythmia	Bradycardia or tachycardia without effects upon blood pressure
Severe arrhythmia	Ventricular tachycardia, ventricular fibrillation, asystolia or any arrhythmia with hemodynamic impairment
Difficulty inserting the tracheostomy cannula	Need for more than two attempts to insert the cannula
Balloon rupture	Impossibility of keeping balloon insufflated as the result of maneuvering while performing the technique
Hypotension	Decrease in blood pressure of at least 20% with respect to baseline
Moderate hypotension	Hypotension requiring treatment with the infusion of <1000 ml of fluids during the procedure
Severe hypotension	Hypotension requiring treatment with vasopressors or >1000 ml of fluids during the procedure
Bleeding	<i>Mild:</i> bleeding that subsides with digital pressure and is estimated to be <20 ml <i>Moderate:</i> bleeding estimated to be >20 ml <i>Severe:</i> bleeding with reperfusion upon hematocrit (≥3 points), and requiring surgical repair or transfusion
Barotrauma	<i>Mild:</i> subcutaneous emphysema <i>Moderate:</i> mediastinal emphysema <i>Severe:</i> pneumothorax
False passage	Dilatation or insertion of the tracheostomy cannula outside the tracheal lumen
Damage of the posterior tracheal wall	Damage of the posterior tracheal wall caused by the needle, guide or dilator
Tracheal tearing	Tracheal wall tearing during the dilatation procedure
Atelectasis	Total or partial lung collapse not present before the technique, and evidenced at postoperative control
Flexion of the metal guide	Guide cannot be moved into the tracheal lumen
Trapping of the metal guide	Metal guide cannot be removed
Failure in completing the technique	Need for a second (different) team to complete the technique, or need for ST to complete the procedure
Lateralization of the stoma	Stoma outside the anterior quadrant of the tracheal wall
Tracheal ring fracture	Tracheal ring rupture during any phase of the procedure
Death	Death related to complications of the technique

Modified from Durbin.<sup>28</sup>  
ST, surgical tracheostomy.



**Figure 2** Finding (in the context of protocolized follow-up) in an asymptomatic patient 6 months after percutaneous tracheostomy using the Ciaglia Blue Dolphin technique. (A) Spiral CAT reconstruction showing anteroposterior displacement of the tracheal cartilage, and (B) causing 15% stenosis of the tracheal lumen.

**Table 2** Comparative randomized studies between surgical tracheostomy (ST) and percutaneous tracheostomy (PT).

	ST/type of PT	n	Bleeding	Infection	Intraoperative complications	Postoperative complications	p
Hazard et al. <sup>29</sup>	ST/PDT	46	4/1	8/1	NA	11/3	<0.05
Crofts et al. <sup>30</sup>	ST/PDT	53	3/3	1/0	NA	6/4	NA
Friedman et al. <sup>31</sup>	ST/PDT	53	7/5	4/0	11/9	12/3*	0.008*
Holdgaard et al. <sup>32</sup>	ST/PDT	60	36/9*	19/3*	26/19	30/7	<0.01*
Porter and Ivatury <sup>33</sup>	ST/PDT	24	0/0	0/0	1/5	0/0	NA
Gysin et al. <sup>34</sup>	ST/PDT	70	4/4	3/4	4/14*	8/15	0.01*
Heikkinen et al. <sup>35</sup>	ST/GWDF	56	1/5	0/0	0/5	1/1	NS <sup>a</sup>
Freeman et al. <sup>36</sup>	ST/PDT	80	2/0	NA	NA	2/0	ND <sup>a</sup>
Massick et al. <sup>37</sup>	ST/PDT	100	0/2	0/1	1/4	1/9*	<0.05*
Melloni et al. <sup>38</sup>	ST/PDT	50	1/2	7/0*	0/2	9/1	<0.001*
Sustić et al. <sup>39</sup>	ST/GWDF	16	1/1	2/0	1/1	2/0	NS
Wu et al. <sup>40</sup>	ST/PDT	83	4/3	3/1	1/4	7/3	NS
Antonelli et al. <sup>41</sup>	ST/TLT	139	6/0	6/6	7/7	26/13*	0.02*
Silvester et al. <sup>42</sup>	ST/PDT	200	1/4	14/4*	2/5	14/13	0.04*

GWDF, guide wire dilating forceps; NA, not available; NS, nonsignificant; TLT, translaryngeal tracheostomy; PT, percutaneous tracheostomy; PDT, percutaneous dilatation tracheostomy (classical Ciaglia technique); ST, surgical tracheostomy.

<sup>a</sup> Lesser cost of PT compared with ST ( $p < 0.001$ ).

\* Indicates the variables for which statistical significance is observed.

complications in the PDT group. This could have a number of explanations: (1) failure to use endoscopic guidance, which possibly could have contributed to avoid some of the described complications (damage to the posterior tracheal wall, loss of airway control); (2) strict definition of the complications (as could be the case of the definition of minor bleeding); and (3) lack of experience of the personnel performing the technique. The authors discard this latter factor, since the team was experienced with both techniques (at least 20 operations with each of them). Although many studies fail to mention the degree of experience of the physicians performing the procedure, it is difficult to say how many performed interventions suffice to guarantee extensive expertise, and the degree of experience is generally left to the authors to define.

### Percutaneous dilatation tracheostomy versus Ciaglia Blue Rhino

Two studies have compared PDT with CBR. In one of them, Johnson et al.<sup>57</sup> observed no significant differences between the two procedures in a series of 50 patients, while in the other study, likewise involving 50 patients, Byhahn et al.<sup>56</sup> recorded 7 complications with PDT (3 of them of a serious nature) and a greater incidence of tracheal cartilage damage with CBR. They concluded that the latter is more applicable than PDT, since they recorded no serious complications with CBR.

### Guide wire dilating forceps versus Ciaglia Blue Rhino

Two studies have compared GWDF with CBR. Ambesh et al.,<sup>61</sup> in a sample of 60 patients, reported greater technical difficulty and bleeding with GWDF, as well as over-dilatation of the stoma. The patients randomized to CBR had a greater

incidence of tracheal cartilage damage and elevated airway pressure. In our experience<sup>62</sup> with 53 patients (27 randomized to CBR and 26 to GWDF), we observed no significant differences between the two techniques in terms of complications, though in coincidence with the findings of other authors,<sup>58</sup> we recorded greater technical problems with GWDF – fundamentally referred to as difficulties in inserting the cannula.

### Ciaglia Blue Rhino versus PercuTwist

A randomized, prospective study of 70 patients has compared CBR with the PercuTwist technique.<sup>59</sup> Greater technical difficulty was reported with the PercuTwist, together with two cases of tearing of the posterior tracheal wall. The authors acknowledged heterogeneous experience with the two techniques. Specifically, the team was familiarized with CBR, but had no prior experience with PercuTwist. It therefore can be affirmed that the study was carried out in the course of the learning curve of the PercuTwist technique – this representing a clear source of bias that limits the conclusions drawn.

### Ciaglia Blue Dolphin versus Ciaglia Blue Rhino

Cianchi et al.<sup>64</sup> compared CBR with CBD under endoscopic guidance in the context of a randomized prospective study of 70 critical patients in which the results were favorable to the former technique. The authors found CBR to be faster to perform, and with a lesser frequency of bleeding (mild tracheal mucosal bleeding evidenced by endoscopy 6 h after the procedure), while insertion of the tracheostomy cannula proved more difficult with CBD. Their comparatively lesser familiarity with CBD may have influenced the results. Despite the observed differences, the authors concluded that CBD is indicated in the ICU. In view of the recent introduction of the

**Table 3** Late complications of percutaneous tracheostomy (PT).

Author/year/design	Type	n	Follow-up	Evaluation	Tracheal stenosis	Others	Surgical wound	Symptoms
Hill et al. <sup>43</sup> Prospective	PDT	258/353 <sup>a</sup>	10 ± 7 months	Interview and clinical evaluation	Stenosis requiring revision n = 5 (2.3%)	Excessive granulation tissue in stoma: n = 1 (0.4%) Sore retraction		Hoarseness: n = 1 (0.4%) Dysphagia: n = 1 (0.4%) Voice changes: n = 12 No
Van Heurn et al. <sup>44</sup> Prospective	PDT	66	16 months (3–39)	Tomography (n = 54)	Stenosis >10% n = 14 (26%)			
Law et al. <sup>45</sup> Not specified	PDT	41	Minimum 6 months after decannulation	LT	Stenosis >10% n = 4 (9.7%)			
Rosenbower et al. <sup>46</sup> Prospective	PDT	55/95	Minimum one year	Clinical (n = 55) and LT (n = 9)	Subglottic stenosis after decannulation (n = 2) <sup>a</sup>	Tracheocutaneous fistula (n = 1)		Minimum voice changes. Respiratory impairment <sup>a</sup> Breathing difficulty, stridor <sup>a</sup>
Walz et al. <sup>47</sup> Prospective	PDT	106	9.9 ± 5.6 months	Conventional X-rays (2 planes)	Stenosis >10% n = 46 (43.4%) Stenosis 50% n = 4 (3.7%) (n = 1 symptomatic) <sup>a</sup> n = 1 symptomatic tracheal stenosis before revision			
Leonard et al. <sup>48</sup> Prospective	GWDF	39/49	6 months	RFT (n = 13) LT (n = 10)				Minimum voice changes. No respiratory impairment
Steele et al. <sup>49</sup> Retrospective	GWDF	25	> 6 months	CAT	0	Tracheal dilatation, n = 8 (32%)		Permanent hoarseness (n = 2). Voice changes (n = 9)
Norwood et al. <sup>50</sup> Not specified	PDT	100	30 ± 25 months	CAT (n = 48) and LT (n = 38)	CAT: stenosis >10% n = 15 <sup>b</sup> LT <sup>c</sup> n = 1 (10%) >50%		n = 15 cosmetic revision of sore considered	Voice changes: 27% Persistent hoarseness: 2%
Dollner et al. <sup>51</sup> Retrospective	GWDF	19	17 months (r: 11–23)	LT	Stenosis >10% n = 12 (63%) n = 2 stenosis >25%	Cricoid cartilage damage, n = 7 (32%)		No
Fikkers et al. <sup>52</sup> Prospective	GWDF	106/171	2.5 years (minimum: 14 months)	Laryngoscopy	Subglottic stenosis n = 1 (0.9%) Required stent		Cosmetic problems n = 10 (9.4%). Two required corrective surgery	Hoarseness or voice changes (n = 9)-without anomalies at indirect laryngoscopy Stridor: n = 1

Table 3 (Continued)

Author/year/design	Type	n	Follow-up	Evaluation	Tracheal stenosis	Others	Surgical wound	Symptoms
Carrer et al. <sup>53</sup> Prospective	n = 181; PDT (n = 48; 26.5%)/Per-cutTwist (133; 73.5%) PDT	141	3, 6, 12 months	Fibroscopy	Tracheal stenosis n = 1 (0.7%)	Recurrent granulo ma in stoma n = 2 (1.4%)		
Karvandian et al. <sup>54</sup> Prospective	PDT	20/140	4 months	Fibroscopy and CAT	Subglottic stenosis n = 17 (85%)	Tracheo mediastinal fistula n = 1		

RFT, respiratory function tests; GWDF, guide wire dilating forceps; LT, laryngotracheoscopy; CAT, computed axial tomography; PDT, percutaneous dilatation tracheostomy (classical Ciaglia technique).

<sup>a</sup> 356 procedures in 353 patients.

<sup>b</sup> Mild: 11–25%, n = 10; moderate: 26–50%, n = 4 [2 respiratory problems after decannulation]; severe: >50%, n = 1.

<sup>c</sup> LT, laryngeal granuloma n = 1; vocal cord anomalies n = 4; laryngeal edema and erythema n = 2; severe tracheomalacia and stenosis n = 1.

technique, further randomized studies are needed, involving comparisons made by teams with equivalent experience in the use of both modalities.

## Metaanalyses

Cabrini et al.<sup>65</sup> have recently published a meta-analysis of all the randomized studies that have compared at least two PT techniques. They included 13 publications, of which 7 made use of endoscopic control. The authors found all the techniques to be equivalent, with the exception of the Fantoni technique, which was associated with more serious complications and with a greater need to convert to another tracheostomy technique compared with GWDF or CBR. The latter technique in turn was associated with fewer failures than PercuTwist, and with fewer mild complications than CBD or GWDF. They therefore concluded that CBR is the safest option and offers the highest success rate – though no recommendations for specific groups can be made. This has been the first meta-analysis to compare the most widely used PT modalities, though it is limited by the heterogeneous nature of the reviewed studies. One of the included studies was a letter to the Editor, while another consisted of a comparative trial of three techniques (ST, PDT and the translaryngeal procedure), primarily designed to assess the effects of the procedures upon intracranial pressure, cerebral perfusion pressure, and cerebral oxygen extraction. The authors point to the need for randomized comparative studies.

Given the equivalence among the different modalities, it is difficult to recommend a concrete technique as being better than the rest. As a result, the choice is conditioned more by professional preferences than by objective criteria.

## Safety methods

Fibrobronchoscopy is the most widely used safety method, though its application as a routine coadjuvant technique is heterogeneous. In effect, while in Spain fibrobronchoscopy is reportedly used in 16% of the ICUs,<sup>10</sup> its application in other countries in our setting varies between 36%<sup>13</sup> and 98%.<sup>15</sup> The routine use of fibrobronchoscopy has been the subject of controversy, since the endoscopic guide produces a rise in airway pressure, hypoventilation and an increase in intracranial pressure – a situation that contraindicates its utilization in patients with acute neurological damage. Moreover, fibrobronchoscopy increases the cost of the procedure – causing some authors to consider its use only in cases with anatomical difficulties or in the context of learning curves.<sup>57</sup> Nevertheless, the technique is simple and is recommended by some guides<sup>66</sup> in the absence of contraindications, with a view to preventing serious complications such as false passage or damage to the posterior tracheal wall.

Capnography is useful for confirming the intratracheal location of the needle at the time of puncture. Mallick et al.<sup>67</sup> have compared capnography with fibrobronchoscopy in 55 patients subjected to PT using the CBR technique. Twenty-nine patients were randomized to endoscopic control and 26 to capnographic control. The authors found capnography to be comparable to bronchoscopy in



**Table 4** Comparison between different percutaneous tracheostomy (PT) modalities. Prospective and randomized studies.

Author/year	Type PT	EG	n	ETI time before PT	Bleeding	Pneumothorax or emphysema	Technical difficulty	Airway obstruction	Tracheal tearing	Tracheal ring fracture	CRA	False passage	AC	p
Nates et al. <sup>55</sup>	PDT/GWDF	NA	50/50	6/6.5	1/7	-	1.3/1.8 <sup>a</sup>	0/4	-	-	-	0/2	5/6	0.02 <sup>b</sup>
Byhahn et al. <sup>56</sup>	PDT/CBR	Yes	25/25	7.5/7.2	1/0	1/0	-	-	2/0	2/9 <sup>§</sup>	-	-	1/2	<0.05 <sup>§</sup>
Johnson et al. <sup>57</sup>	PDT/CBR	No	25/25	NA	3/4	-	5/2	-	-	-	-	-	5/6	NS
Van Heurn et al. <sup>58</sup>	PDT/GWDF	No	63/64	14.3/13.6	4/7	-	0/6	-	-	-	-	0/2	-	0.03 <sup>c</sup>
Byhahn et al. <sup>59</sup>	CBR/PTwist	Yes	35/35	9.5/NA	3/2	1/0	0/6 <sup>*</sup>	-	0/1	1/1	0/1	0/1	0/1	<0.05 <sup>*</sup>
Cantais et al. <sup>60</sup>	GWDF/TLT	Yes	53/47	18	12/2	1/1	0/11	-	1/2 <sup>d</sup>	-	-	-	0/7	0.001 <sup>e</sup>
Ambesh et al. <sup>61</sup>	CBR/GWDF	No	30/30	9/8	1/5 <sup>†</sup>	1/3 <sup>f</sup>	2/9 <sup>f</sup>	-	2/3	9/0 <sup>†</sup>	-	-	2/0	<0.05 <sup>†</sup>
Añon et al. <sup>62</sup>	CBR/GWDF	No	27/26	17.4/20.3	2/1	-	0/3	-	-	-	-	-	-	NS
Kaiser et al. <sup>63</sup>	PDT/GWDF	No	48/52	7/9	17/6	1/0	-	-	1/0 <sup>§</sup>	-	-	-	6/0	0.0001 <sup>h</sup> 0.008
Cianchi et al. <sup>64</sup>	CBR/CBD	Yes	35/35	2/2.5	12/24	-	3/10	-	-	2/3	-	-	-	<0.01 <sup>i</sup> 0.02

AC, anesthetic complications; CBR, Ciaglia Blue Rhino; GE, endoscopic guide; GWDF, guide wire dilating forceps; ETI, endotracheal intubation; n, number of randomized patients; NA, not available; NS, nonsignificant; CRA, cardiorespiratory arrest; PTwist, PercuTwist; TLT, translaryngeal tracheostomy (Fantoni technique); PT, percutaneous tracheostomy; PDT, percutaneous dilatation tracheostomy (classical Ciaglia technique).

Anesthetic complications: loss of airway control, arterial hypotension, desaturation or arrhythmias.

<sup>a</sup> Technical difficulty rated by the supervising physician: (1) easy, (2) some difficulty, (3) very difficult, (4) requires the professional of greatest experience, or the technique cannot be completed ( $p=0.01$ ).

<sup>b</sup> Level of significance for the total complications favorable to PDT.

<sup>c</sup> Level of significance for the total complications favorable to PDT.

<sup>d</sup> Damage of the posterior tracheal wall.

<sup>e</sup> Level of significance for serious complications favorable to GWDF.

<sup>f</sup> 1 pneumothorax, 3 emphysemas.

<sup>§</sup> Damage of the posterior tracheal wall with emphysema.

<sup>h</sup> Level of significance for mild (0.0001) and serious complications (0.008) favorable to GWDF.

<sup>i</sup> Level of significance for bleeding (<0.01) – mild bleeding evidenced by endoscopy 6 h after the procedure – and technical difficulty (0.02) favorable to CBR.

<sup>§</sup> Statistical significance due to tracheal ring fracture.

<sup>\*</sup> Statistical significance due to technical difficulty.

<sup>†</sup> Statistical significance due to technical difficulty and tracheal ring fracture.

**Table 5** Results of randomized prospective studies that have compared early versus delayed tracheostomy.

Author	Type of patients	Number of patients	Timing of tracheostomy	Results
Dunham and LaMonica <sup>69</sup>	Trauma	74	Early: 3–4 days Late: >14 days	Without differences in laryngotracheal disease
Rodriguez et al. <sup>70</sup>	Trauma	106	Early: ≤7 days Late: >7 days	Shorter duration of MV, stay in ICU, in hospital and even pneumonia if tracheostomy is performed before 3 days
Sugerman et al. <sup>71</sup>	Trauma/non-trauma	157 (potential)	1st randomization: 3–5 days 2nd randomization: 10–14 days	Without differences in duration of stay (ICU and in hospital), frequency of pneumonia and death
Saffle et al. <sup>72</sup>	Burns	44	Early: next day available Late: 14 days <sup>a</sup>	Without differences in ventilation support, duration of stay, incidence of pneumonia or survival
Bouderka et al. <sup>73</sup>	TBI	62	Early: 5 days Late: prolonged intubation	Shorter duration of MV (for the early tracheostomy group)
Rumbak et al. <sup>74</sup>	Clinical	120	Early: 2 days Late: 14–16 days	Shorter duration of MV, stay in ICU, lesser pneumonia and mortality (for the early tracheostomy group)
Blot et al. <sup>75</sup>	Polyvalent	123	Early: 4 days Late: > 7 days	Without differences in mortality, pneumonia, days without MV, stay in ICU
Terragni et al. <sup>76</sup>	Polyvalent without pneumonia	600	Early: 6–8 days Late: 13–15 days	Without differences in incidence of VAP

VAP, ventilator associated pneumonia; TBI, traumatic brain injury; ICU, Intensive Care Unit; MV, mechanical ventilation.

<sup>a</sup> Early: next day available after burn trauma (mean: 4 days). Delayed: mean 14.8 days.

confirming the location of the needle in the tracheal lumen, and concluded that it may be an alternative to endoscopic guidance when the latter cannot be used or is contraindicated. The disadvantage of capnography is the lack of direct visualization of the precise position of the needle and metal guide within the trachea.

Cervical ultrasound can be useful for locating aberrant vascular structures that may cause bleeding. Kollig et al.<sup>68</sup> performed PDT in 72 patients, initially using cervical ultrasound, followed by bronchoscopy. Based on the ultrasound findings, the puncture site had to be modified in 24% of the cases. There were no cases of damage to the posterior tracheal wall or bleeding. In this respect, ultrasound is a noninvasive procedure and may prove useful in selected patients.

### Timing of tracheostomy in the ventilated patient

The optimum timing of tracheostomy in the ventilated patient remains the subject of debate. The difficulty lies in defining prolonged mechanical ventilation and predicting which patients are going to need it.

The comparative studies of early versus delayed tracheostomy have been unable to draw firm conclusions.

There has been heterogeneity in defining the term prolonged mechanical ventilation, and difficulty in defining which patients are candidates for such ventilation, as well as heterogeneity in the type of patients included, randomization defects, and consequently heterogeneity of the results obtained. Since 1984, a total of 8 randomized prospective studies have been published<sup>69–76</sup> (Table 5). Two of them<sup>71,72</sup> found no advantages with early tracheostomy versus the delayed technique. One of these studies<sup>71</sup> reported important difficulties in performing randomization, while the other<sup>72</sup> was carried out in critical burn patients. The results of the three most recent studies are contradictory. While Rumbak et al.<sup>74</sup> found early tracheostomy (within the first 48 h of mechanical ventilation) to involve a shorter duration of mechanical ventilation, a shorter stay in the ICU, and lesser pneumonia and mortality, Blot et al.<sup>75</sup> observed no differences in terms of mortality, pneumonia, days without mechanical ventilation or stay in the ICU between the patients subjected to tracheostomy in the first four days (early) versus those in which the technique was carried out after more than 7 days (delayed). In the latest and also the largest randomized prospective trial, designed to assess the incidence of ventilation associated pneumonia among patients subjected to early (6–8 days) or delayed tracheostomy (13–15 days), Terragni et al.<sup>76</sup> observed no differences between the two groups.

Three meta-analyses have addressed this issue. The study by Maziak et al.<sup>77</sup> included two retrospective studies and three randomized trials with a total of 396 trauma patients with neutropenia and acute respiratory failure. The results do not suggest that the timing of tracheostomy influences the duration of mechanical ventilation or laryngeal damage. The limitations result from the heterogeneity of the included studies, heterogeneity in timing, a lack of information on how randomization was carried out, defective randomizations, and the inclusion of studies predating the PT era. In their meta-analysis, Griffiths et al.<sup>78</sup> included 5 randomized studies comprising 406 clinical, surgical, trauma and burn patients. The timing of early tracheostomy was 0–7 days after the start of ventilation or admission to the ICU. The authors concluded that early tracheostomy results in a lesser duration of mechanical ventilation and a shorter stay in the ICU, but they recorded no differences in terms of pneumonia or mortality. Dunham and Ransom<sup>79</sup> in turn included trauma patients in a meta-analysis comprising four retrospective studies and 5 randomized trials. The results showed no influence of early tracheostomy upon the development of pneumonia or patient mortality. Here again, the heterogeneity of the included studies did not allow the drawing of firm conclusions.

The literature suggests that early tracheostomy affords no advantages in terms of ventilation associated pneumonia or mortality, though it seems reasonable to use the technique in patients who are likely to require prolonged mechanical ventilation, in view of its benefits compared with intubation in terms of well-being, stay in the ICU and time on mechanical ventilation.

The term prolonged mechanical ventilation is characterized by important variability, and its definition is conditioned by the setting in which it is used. In our proposal of a prolonged ventilation probability model,<sup>80</sup> we established a period of 7 days, on the grounds that this is the time limit for the possible appearance of laryngeal damage secondary to endotracheal intubation.<sup>3</sup> Other studies have aimed to identify groups of patients with a high probability of requiring prolonged mechanical ventilation in both selected populations<sup>81–83</sup> and in the general population.<sup>84</sup> All of them have limitations, and no validated model is available. Therefore, considering the lack of tools that could help in the decision-making process, the timing of PT should be established on an individualized basis.

## Conclusions

Tracheostomy is one of the most common techniques in the ICU, and PT is a widespread practice in our setting. The popularity of the technique is based on its safety, easy execution, and the fact that it can be performed at the patient bedside. Fibrobronchoscopy has gained acceptance and is now recommended as a safety technique. Although it is difficult to define the incidence of perioperative complications (which should be analyzed for each individual PT modality), it can be regarded as no greater than that associated with ST. Nevertheless, the incidence of late complications has been little studied to date, and surveys involving larger patient samples are therefore needed to clarify this aspect. The contraindications of PT have become relativized as confidence

with the technique has increased, though it must be taken into account that children, neck injuries and infection of the surgical zone remain absolute contraindications. The optimum timing of tracheostomy in the ventilated patient remains the subject of debate. The results of randomized studies contrasting early versus delayed tracheostomy are heterogeneous. Consequently, it can only be affirmed that the timing of PT should be established on an individualized basis.

## Conflicts of interest

The authors state that they have no conflicts of interest.

## References

1. Jackson C. Tracheostomy. *Laryngoscope*. 1909;19:285–90.
2. Byhahn C, Westphal K, Zwissler B. Percutaneous tracheostomy: past present and future perspectives. In: Vincent JL, editor. *Year book of intensive care and emergency medicine*. Berlin: Springer; 2005. p. 30–8.
3. Bishop MJ, Hibbard AJ, Fink BR, Vogel AM, Weymuller EA. Laryngeal injury in a dog model of prolonged endotracheal intubation. *Anesthesiology*. 1985;62:770–3.
4. Ciaglia P, Firsching R, Syniec C. Elective percutaneous dilatational tracheostomy: a new simple bedside procedure: preliminary report. *Chest*. 1985;87:715–9.
5. Griggs WM, Worthley LIG, Gilligan JE, Thomas PD, Myburg JA. A simple percutaneous tracheostomy technique. *Surgery*. 1990;170:543–5.
6. Byhahn C, Lischke V, Halbig S, Scheifler G, Westphal A. Ciaglia blue rhino: a modified technique for percutaneous dilatation tracheostomy. *Technique and early clinical results*. *Anaesthest. 2000;49:202–6*.
7. Fantoni A, Ripamonti D. A non-derivative, non-surgical tracheostomy: the translaryngeal method. *Intensive Care Med*. 1997;23:386–92.
8. Frova G, Quintel M. A new simple method for percutaneous tracheostomy: controlled rotating dilation. A preliminary report. *Intensive Care Med*. 2002;28:299–303.
9. Gromann TW, Birkelbach O, Hetzer R. Balloon dilatational tracheostomy: initial experience with the Ciaglia Blue Dolphin method. *Anesth Analg*. 2009;108:1862–6.
10. Añón JM, Escuela MP, Gómez V, García de Lorenzo A, Montejo JC, López J. Use of percutaneous tracheostomy in intensive care units in Spain. Results of a national survey. *Intensive Care Med*. 2004;30:1212–5.
11. Cooper RM. Use and safety of percutaneous tracheostomy in intensive care. Report of a postal survey of ICU practice. *Anaesthesia*. 1998;53:1209–12.
12. Fischler L, Erhart S, Kleger G, Frutiger A. Prevalence of tracheostomy in ICU patients. A nation-wide survey in Switzerland. *Intensive Care Med*. 2000;26:1428–33.
13. Fikkers BG, Franssen GA, van der Hoeven JG, Briede IS, van den Hoogen FJ. Tracheostomy for long-term ventilated patients: a postal survey of ICU practice in The Netherlands. *Intensive Care Med*. 2003;29:1390–3.
14. Krishnan K, Elliot SC, Mallick A. The current practice of tracheostomy in the United Kingdom: a postal survey. *Anaesthesia*. 2005;60:360–4.
15. Kluge S, Baumann HJ, Maier C, Klose H, Meyer A, Nierhaus A, et al. Tracheostomy in the intensive care unit: a nationwide survey. *Anesth Analg*. 2008;107:1639–43.

16. Anderson HL, Bartlett RH. Elective tracheostomy for mechanical ventilation by percutaneous technique. *Clin Chest Med*. 1991;12:555–60.
17. Groves DS, Durbin CG. Tracheostomy in the critically ill: indications, timing and techniques. *Curr Opin Crit Care*. 2007;13:90–7.
18. Al-Ansari MA, Hijazi MH. Percutaneous dilatational tracheostomy. *Crit Care*. 2006;10:202.
19. Toursarkissian B, Fowler C, Zweng T, Kearney P. Percutaneous dilatational tracheostomy in children and teenagers. *J Pediatr Surg*. 1994;29:1421–4.
20. Raju A, Joseph DK, Diarra C, Ross SE. Percutaneous versus open tracheostomy in the pediatric trauma population. *Am Surg*. 2010;76:276–8.
21. Scott CJ, Darowski M, Crabbe DC. Complications of percutaneous dilatational tracheostomy in children. *Anaesthesia*. 1998;53:477–80.
22. Bell MD. Percutaneous dilatational tracheostomy in children. *Anaesthesia*. 1998;53:931.
23. Mansharamani NG, Koziel H, Garland R, LoCicero 3rd J, Critchlow J, Ernst A. Safety of bedside percutaneous dilatational tracheostomy in obese patients in the ICU. *Chest*. 2000;117:1426–9.
24. Byhahn C, Lischke V, Meininger D, Halbig S, Westphal A. Perioperative complications during percutaneous tracheostomy in obese patients. *Anaesthesia*. 2005;60:12–5.
25. Meyer M, Critchlow J, Mansharamani N, Angel LF, Garland R, Ernst A. Repeat bedside percutaneous dilatational tracheostomy is a safe procedure. *Crit Care Med*. 2002;30:986–8.
26. Kluge S, Meyer A, Kuhnelt P, Baumann HJ, Kreymann G. Percutaneous tracheostomy is safe in patients with severe thrombocytopenia. *Chest*. 2004;126:547–51.
27. Beiderlinden M, Groeben H, Peters J. Safety of percutaneous dilatational tracheostomy in patients ventilated with high positive end-expiratory pressure (PEEP). *Intensive Care Med*. 2003;29:944–8.
28. Durbin CG. Early complications of tracheostomy. *Respir Care*. 2005;50:511–5.
29. Hazard P, Jones C, Benitone J. Comparative clinical trial of standard operative tracheostomy with percutaneous tracheostomy. *Crit Care Med*. 1991;19:1018–24.
30. Crofts SL, Alzeer A, McGuire GP, Wong DT, Charles D. A comparison of percutaneous and operative tracheostomies in intensive care patients. *Can J Anaesth*. 1995;42:775–97.
31. Friedman Y, Fildes J, Mizock B, Samuel J, Patel S, Appavu S, et al. Comparison of percutaneous and surgical tracheostomies. *Chest*. 1996;110:480–5.
32. Holdgaard HO, Pedersen J, Jensen RA, Outzen KE, Midtgaard T, Johansen LV, et al. Percutaneous dilatational tracheostomy versus conventional surgical tracheostomy. A clinical randomized study. *Acta Anaesthesiol Scand*. 1998;42:545–50.
33. Porter JM, Ivatury RR. Preferred route of tracheostomy—percutaneous versus open at the bedside: a randomized, prospective study in the surgical intensive care unit. *Am Surg*. 1999;65:142–6.
34. Gysin C, Dulguerov P, Guyot JP, Perneger TV, Abajo B, Chevrolet JC. Percutaneous versus surgical tracheostomy: a double blind randomized trial. *Ann Surg*. 1999;230:708–14.
35. Heikkinen M, Aarnio P, Hannukainen J. Percutaneous dilatational tracheostomy or conventional surgical tracheostomy? *Crit Care Med*. 2000;28:1399–402.
36. Freeman BD, Isabella K, Cobb JP, Boyle WA, Schmiege Jr RE, Kolleff MH, et al. A prospective, randomized study comparing percutaneous with surgical tracheostomy in critically ill patients. *Crit Care Med*. 2001;29:926–30.
37. Massick DD, Yao S, Powell DM, Griesen D, Hobgood T, Allen JN, et al. Bedside tracheostomy in the intensive care unit: a prospective randomized trial comparing open surgical tracheostomy with endoscopically guided percutaneous dilatational tracheostomy. *Laryngoscope*. 2001;111:494–500.
38. Melloni G, Muttini S, Gallioli G, Carretta A, Cozzi S, Gemma M, et al. Surgical tracheostomy versus percutaneous dilatational tracheostomy. A prospective-randomized study with long-term follow-up. *J Cardiovasc Surg (Torino)*. 2002;43:113–21.
39. Sustić A, Krstulović B, Eskinja N, Zelić M, Ledić D, Turina D. Surgical tracheostomy versus percutaneous dilatational tracheostomy in patients with anterior cervical spine fixation: preliminary report. *Spine*. 2002;27:1942–5.
40. Wu JJ, Huang MS, Tang GJ, Shih SC, Yang CC, Kao WF, et al. Percutaneous dilatational tracheostomy versus open tracheostomy—a prospective, randomized, controlled trial. *J Chin Med Assoc*. 2003;66:467–73.
41. Antonelli M, Michetti V, di Palma A, Conti G, Pennisi MA, Arcangeli A, et al. Percutaneous translaryngeal versus surgical tracheostomy: a randomized trial with 1-yr double-blind follow-up. *Crit Care Med*. 2005;33:1015–20.
42. Silvester W, Goldsmith D, Uchino S, Bellomo R, Knight S, Seevanayagam S, et al. Percutaneous versus surgical tracheostomy: a randomized controlled study with long-term follow-up. *Crit Care Med*. 2006;34:2145–52.
43. Hill BB, Zweng TN, Maley RH, Charash WE, Toursarkissian B, Kearney PA. Percutaneous dilatational tracheostomy: report of 356 cases. *J Trauma*. 1996;41:238–43.
44. Van Heurn LW, Goei R, de Ploeg I, Ramsay G, Brink PR. Late complications of percutaneous dilatational tracheostomy. *Chest*. 1996;110:1572–6.
45. Law RC, Carney AS, Manara AR. Long-term outcome after percutaneous dilatational tracheostomy. Endoscopic and spirometry findings. *Anaesthesia*. 1997;52:51–6.
46. Rosenbower TJ, Morris Jr JA, Eddy VA, Ries WR. The long-term complications of percutaneous dilatational tracheostomy. *Am Surg*. 1998;64:82–6.
47. Walz MK, Peitgen K, Thürauf N, Trost HA, Wolfhard U, Sander A, et al. Percutaneous dilatational tracheostomy – early results and long-term outcome of 326 critically ill patients. *Intensive Care Med*. 1998;24:685–90.
48. Leonard RC, Lewis RH, Singh B, van Heerden PV. Late outcome from percutaneous tracheostomy using the Portex kit. *Chest*. 1999;115:1070–5.
49. Steele AP, Evans HW, Afaq MA, Robson JM, Dourado J, Tayar R, et al. Long-term follow up of Griggs percutaneous tracheostomy with spiral CT and questionnaire. *Chest*. 2000;117:1430–3.
50. Norwood S, Vallina VL, Short K, Saigusa M, Fernandez LG, McLarty JW. Incidence of tracheal stenosis and other late complications after percutaneous tracheostomy. *Ann Surg*. 2000;232:233–41.
51. Dollner R, Verch M, Schweiger P, Deluigi C, Graf B, Wallner F. Laryngotracheoscopic findings in long-term follow-up after Griggs tracheostomy. *Chest*. 2002;122:206–12.
52. Fikkers BG, van Heerbeek N, Krabbe PF, Marres HA, van den Hoogen FJ. Percutaneous tracheostomy with the guide wire dilating forceps technique: presentation of 171 consecutive patients. *Head Neck*. 2002;24:625–31.
53. Carrer S, Basilico S, Rossi S, Bosu A, Bernorio S, Vaghi GM. Outcomes of percutaneous tracheostomy. *Minerva Anesthesiol*. 2009;75:607–15.
54. Karvandian K, Jafarzadeh A, Hajipour A, Zolfaghari N. Subglottic stenosis following percutaneous tracheostomy: a single centre report as a descriptive study. *Acta Otorhinolaryngol Ital*. 2011;31:239–42.
55. Nates JL, Cooper J, Myles PS, Scheinkestel CD, Tuxen DV. Percutaneous tracheostomy in critically ill patients: a prospective, randomized comparison of two techniques. *Crit Care Med*. 2000;28:3734–9.
56. Byhahn C, Wilke H, Halbig S, Lischke V, Westphal K. Percutaneous tracheostomy: Ciaglia Blue Rhino versus the basic Ciaglia

- technique of percutaneous dilational tracheostomy. *Anesth Analg.* 2000;91:882–6.
57. Johnson JL, Cheatham ML, Sagraves SG, Block EFJ, Nelson LD. Percutaneous dilational tracheostomy: a comparison of single versus multiple-dilator techniques. *Crit Care Med.* 2001;29:1251–4.
  58. Van Heurn LWE, Mastboom WBJ, Scheeren CIE, Brink PRG, Ramsay G. Comparative clinical trial of progressive dilatational and forceps dilatational tracheostomy. *Intensive Care Med.* 2001;27:292–5.
  59. Byhahn C, Westphal K, Meininger D, Gürke B, Kessler P, Lischke V. Single-dilator percutaneous tracheostomy: a comparison of PercuTwist and Ciaglia Blue Rhino techniques. *Intensive Care Med.* 2002;28:1262–6.
  60. Cantais E, Kaiser E, Le-Goff Y, Palmier B. Percutaneous tracheostomy: prospective comparison of the translaryngeal technique versus the forceps-dilatational technique in 100 critically ill adults. *Crit Care Med.* 2002;30:815–9.
  61. Ambesh SP, Pandey CK, Srivastava S, Agarwal A, Sing DK. Percutaneous tracheostomy with single dilatation technique: a prospective, randomized comparison of Ciaglia Blue Rhino versus Griggs' Guidewire Dilating Forceps. *Anesth Analg.* 2002;95:1739–45.
  62. Añón JM, Escuela MP, Gómez V, Moreno A, López J, Díaz R, et al. Percutaneous tracheostomy. Ciaglia Blue Rhino versus Griggs' Guide Wire Dilating Forceps. A prospective randomized trial. *Acta Anaesthesiol Scand.* 2004;48:451–6.
  63. Kaiser E, Cantais E, Gourtorbe P, Salinier L, Palmier B. Prospective randomized comparison of progressive dilational vs forceps dilational percutaneous tracheostomy. *Anaesth Intensive Care.* 2006;34:51–4.
  64. Cianchi G, Zagli G, Bonizzoli M, Batacchi S, Cammelli R, Biondi S, et al. Comparison between single-step and balloon dilatational tracheostomy in intensive care unit: a single-centre, randomized controlled study. *Br J Anaesth.* 2010;104:728–32.
  65. Cabrini L, Monti G, Landoni G, Biondi-Zoccai G, Boroli F, Mamo D, et al. Percutaneous tracheostomy, a systematic review. *Acta Anaesthesiol Scand.* 2012;56:270–81.
  66. De Leyn P, Bedert L, Delcroix M, Depuydt P, Lauwers G, Sokolov Y, et al. Tracheotomy: clinical review and guidelines. *Eur J Cardiothorac Surg.* 2007;32:412–21.
  67. Mallick A, Venkatanath D, Elliot SC, Hollins T, Nanda Kumar CG. A prospective randomised controlled trial of capnography vs. bronchoscopy for Blue Rhino percutaneous tracheostomy. *Anaesthesia.* 2003;58:864–8.
  68. Kollig E, Heydenreich U, Roetman B, Hopf F, Muhr G. Ultrasound and bronchoscopic controlled percutaneous tracheostomy on trauma ICU. *Injury.* 2000;31:663–8.
  69. Dunham CM, LaMonica C. Prolonged tracheal intubation in the trauma patient. *J Trauma.* 1984;24:120–4.
  70. Rodriguez JL, Steinberg SM, Luchetti FA, Gibbons KJ, Taheri PA, Flint LM. Early tracheostomy for primary airway management in the surgical critical care setting. *Surgery.* 1990;108:655–9.
  71. Sugerma HJ, Wolfe L, Pasquale MD, Rogers FB, O'Malley KF, Knudson M, et al. Multicenter, randomized, prospective trial of early tracheostomy. *J Trauma.* 1997;43:741–7.
  72. Saffle JR, Morris SE, Edelman L. Early tracheostomy does not improve outcome in burn patients. *J Burn Care Rehabil.* 2002;23:431–8.
  73. Boudierka MA, Fakhir B, Bouaggad A, Hmamouchi B, Hamoudi D, Harti A. Early tracheostomy versus prolonged endotracheal intubation in severe head injury. *J Trauma.* 2004;57:251–4.
  74. Rumbak MJ, Newton M, Truncate T, Schwartz SW, Adams JW, 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;32:1689–94.
  75. Blot F, Similowski T, Trouillet JL, Chardon P, Korach JM, Costa MA, et al. Early tracheotomy versus prolonged endotracheal intubation in unselected severely ill ICU patients. *Intensive Care Med.* 2008;34:1779–87.
  76. Terragni PP, Antonelli M, Fumagalli R, Facciano C, Bernardino 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;303:1483–9.
  77. Maziak DE, Meade MO, Todd TR. The timing of tracheotomy: a systematic review. *Chest.* 1998;114:605–9.
  78. Griffiths J, Barber VS, Morgan L, Young JD. Systematic review and meta-analysis of studies of the timing of tracheostomy in adult patients undergoing artificial ventilation. *BMJ.* 2005;330:1243.
  79. Dunham CM, Ransom KJ. Assessment of early tracheostomy in trauma patients: a systematic review and meta-analysis. *Am Surg.* 2006;72:276–81.
  80. Añón JM, Gómez-Tello V, Gonzalez-Higueras E, Oñoro JJ, Córcoles V, Quintana M, et al. Modelo de probabilidad de ventilación mecánica prolongada. *Med Intensiva.* 2012;36:488–95.
  81. Ross BJ, Barker DE, Russell WL, Burns RP. Prediction of long-term ventilatory support in trauma patients. *Am Surg.* 1996;62:19–25.
  82. Sellers BJ, Davis BL, Larkin PW, Morris SE, Saffle JR. Early prediction of prolonged ventilator dependence in thermally injured patients. *J Trauma.* 1997;43:899–903.
  83. Gajic O, Afessa B, Thompson BT, Frutos-Vivar F, Malinchoc M, Rubenfeld GD, et al. Prediction of death and prolonged mechanical ventilation in acute lung injury. *Crit Care.* 2007;11:R53.
  84. Seneff MG, Zimmerman JE, Knaus WA, Wagner DP, Draper E. Predicting the duration of mechanical ventilation: the importance of disease and patient characteristics. *Chest.* 1996;110:469–79.