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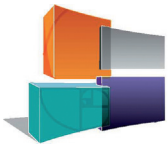

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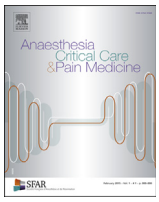

Original Article

Learning curve for real-time ultrasound-guided percutaneous tracheostomy

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ABSTRACT

Objectives: The objective of this study was to demonstrate and quantify the ultrasound-guided percutaneous tracheostomy (UPDT) learning curve in a single team since the first UPDT.
Study design and patients: This was a cohort of all consecutive patients undergoing UPDT in the Amiens teaching hospital surgical intensive care unit between 2010 and 2014.
Methods: The learning process was evaluated according to three aspects: duration of the various steps involved in UPDT, incidence of consecutive complications, and procedure difficulty.
Results: During the study period, 85 consecutive patients underwent UPDT with no deaths. The mean total procedure time was 22 (10) minutes (range: 7 to 60). Analysis of mean cumulative UPDT procedure times showed that total UPDT time decreased to a stable duration of 25 minutes after 54 procedures. Complications were observed in 24 (28%) of the 85 patients. The overall complication rate decreased to below a stable percentage of 30% after 70 procedures. The minor complication rate decreased below 25% after 64 procedures. The moderate complication rate decreased to below a stable percentage of 10% after 10 procedures. The major complication rate decreased to below a stable percentage of 5% after 20 procedures. Most complications were observed in the first 50 patients (25 [50%] versus 6 [13%], $P < 0.05$).
Conclusions: Our study demonstrated that UPDT is associated with a fairly long learning curve. At least 50 procedures are necessary to perform UPDT with an acceptable complication rate and procedure time.
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1. Introduction

Since the original description of percutaneous dilatational tracheostomy (PDT) by Ciaglia in 1985, this technique has become increasingly popular [1] and is now commonly used at the bedside in critical care medicine. Since ultrasound (US) has become a widely used tool in the critical care unit, several studies have recently assessed the feasibility of real-time ultrasound-guided tracheostomy [2–4]. Numerous interventional tasks have been reported to be improved by US guidance in the literature, such as real-time US-guided central venous catheter placement [5]. Several studies have demonstrated the safety of real-time US-guided percutaneous tracheostomy (UPDT), even in obese patients [2,3] and have reported low complication rates with no life-threatening complications based on improved visualization of neck anatomy before and during the procedure [2]. However, UPDT is a new technique, used by only a few teams and no data are available about the UPDT learning curve. The objective of this prospective study was to demonstrate and quantify the UPDT learning curve in a single team.

2. Methods

This study included all consecutive patients undergoing PDT in the Amiens teaching hospital surgical intensive care unit between 2010 and 2014. The study was approved by the local ethics committee (*Comité de protection des personnes Nord Ouest, CHU d'Amiens*,[1] number 2010/29 and 2014/73), and all patients were provided with written information and gave their informed consent. Exclusion criteria were age under 18 years, clotting disorder (international normalized ratio > 2, activated partial thromboplastin time [APTT] > 1.5, and platelet

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count $< 50 \times 10^9$/L), puncture site infection and emergency tracheostomy.

2.1. Percutaneous tracheostomy technique

Percutaneous tracheostomy was performed using the single-step, progressive Ciaglia Blue Rhino technique, as previously described [6,7]. The PCT set consisted of a puncture needle, a guide wire, a small dilator, a curved dilator with a hydrophilic coating and a tracheostomy tube (Tracoe® expert dilatation set from Pouret Medical, Clichy, France).

2.2. Critical care team

The same team composed of two physicians performed each UPDT procedure. Both physicians had more than 5 years of experience with point-of-care US. They also performed other ultrasound-guided invasive procedures such as central venous catheter placement and/or nerve blocks. Both had performed more than 50 PDT procedures according to the modified Ciaglia technique. However, they had no prior experience with the UPDT technique.

2.3. Ultrasound guidance

The UPDT procedure was performed at the bedside under deep sedation, analgesia and muscle relaxation using the same US machine and probe (Envisor® point-of-care system or Cx 50 CompactXtrem with a 12- to 3-MHz linear array probe [Philips Medical Systems, Best, The Netherlands]). The patient was ventilated under controlled ventilation with 100% FIO_2. The UPDT procedure required three persons: one person to manage the airway, and two operators performing UPDT. The procedure was always performed according to the same protocol. First, the two operators, in sterile gowns, performed sterile draping of the neck, skin disinfection and sterile draping of the US probe. Point-of-care US was performed at the patient's bedside. An US examination of the neck area was performed, using transverse and longitudinal views [2]. Transverse sections identified arteries, veins, thyroid, trachea, endotracheal tube and measured skin thickness over the anterior tracheal wall. The longitudinal view identified the various tracheal rings and guided the level of puncture. After this step, the physician standing at the patient's head withdrew the endotracheal tube balloon to near the vocal cords under direct laryngoscopic guidance. The modified Ciaglia technique under ultrasound guidance was then initiated using a modified Blue Rhino dilator Tracoe® (Pouret medical, Clichy, France) [1]. A puncture needle with a saline-filled syringe was introduced perpendicularly to the skin and advanced until the needle was seen to pass the anterior tracheal wall during inspiration. The needle was then angled caudally to prevent retrograde passage of the guide wire. The needle was visualized in "out-of-plane" mode (i.e., the needle path was determined by the presence of a distinct acoustic shadow ahead of the needle) on a transverse section of the neck. The guide wire was introduced, the needle was removed, and a small horizontal incision was made at the point of puncture. The guide wire was visualized as a hyperechoic signal on transverse and longitudinal sections. The small dilator was then used to create the initial stoma, followed by the single-stage curve dilator over the guide wire. The tracheostomy tube fitted over an appropriate loading tube was passed through the stoma. US guidance allowed the operator to check the correct positioning of the puncture site and guide wire before dilatation of the trachea followed by tracheostomy tube placement.

2.4. Data collection

Demographic and clinical data were collected, including gender, age (years), height (metres), weight (kilograms), body mass index (BMI), Simplified acute physiology score II (SAPS II), admission diagnosis, duration of mechanical ventilation prior to PCT (days), and indication for tracheostomy. An anatomical criterion of difficult tracheostomy was noted: presence of a short neck. The following US data were also recorded: level of the thyroid, presence of tracheal deviation, aberrant vessels, puncture site, subcutaneous tissue thickness (centimetres) defined by the distance between the skin and the anterior tracheal wall measured perpendicularly to the skin at the puncture site, tracheal diameter (centimetres). The difficulty of the US-guided technique was scored on a simple numerical scale; 1: easy; 2: minor difficulties in identifying anatomical structures and tracheostomy tube placement; 3: moderate difficulties in identifying anatomical structures; 4: very difficult; and 5: impossible [2].

2.5. Definition of complications

Complications occurring between the beginning of UPDT and decannulation were recorded. Bronchoscopy was performed before decannulation in order to detect any long-term complications. Complications were classified in two ways:

- according to their severity as minor (irrelevant for the patient), moderate (potentially harmful) and major complications (harmful and requiring immediate treatment) (Table 1);
- according to their chronology as technical, intra-procedural and post-procedural [2].

2.6. Construction of the learning curve

The learning curve was based on three aspects of UPDT. First, we evaluated the duration of the various steps of UPDT: installation

Table 1
Classification of complications. SpO_2, oxygen saturation as measured by pulse oximetry.

Minor	Moderate	Major
Bleeding not requiring compression or administration of packed red blood cells	Bleeding requiring compression without blood transfusion	Bleeding requiring administration of packed red blood cells
Hypoxaemia (SpO_2 of less than 90%) and/or hypotension (systolic blood pressure less than 100 mmHg) for less than 5 minutes	Posterior tracheal wall injury not requiring surgical repair	Oesophageal injury
Difficult puncture or multiple punctures (more than three)	Subglottic stenosis	Posterior tracheal wall injury requiring surgical repair
Puncture of the tracheal tube cuff	Granuloma	Pneumothorax
Peristomal infection not requiring antibiotic therapy	Malposition of the tracheostomy tube (pretracheal or paratracheal insertion)	Peristomal infection requiring local care or antibiotic therapy or both
Atelectasis		Loss of airway
		Surgical conversion
Tracheal ring fracture		Cardiac arrest
		Death

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