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Advantages of US in Percutaneous Dilatational Tracheostomy: Randomized Controlled Trial and Review of the Literature[1]

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Purpose: To compare procedure times and complication rates of preincisional ultrasonographic (US) evaluation and perioperative US guidance in percutaneous dilatational tracheostomy (PDT) with those of the current standard of care, PDT performed without image guidance.

Materials and Methods: Between December 2007 and January 2011, 341 patients were included in this institutional review board–approved study after informed consent was obtained from the patients or their relatives. The patients were divided randomly into two groups. In group A (n = 166), the possible causes of complications, such as aberrations of tracheal, thyroidal, and vascular structures, were determined with US, and tracheal measurements were performed by using US. The clinician's initial considerations at physical examination were compared with the US findings. PDT was subsequently performed with US guidance in suitable cases. In group B (n = 175), PDT was performed solely on the basis of physical landmarks. The procedure times and complication rates were compared across groups by using the Fisher exact test.

Results: In group A, the puncture sites designated at the physical examination were reconsidered in 39 (23.8%) of 164 cases. The perioperative complication rates were slightly lower in group A (7.8% [12 of 154]) than in group B (15.0% [25 of 167]); however, the difference did not achieve statistical significance (P = .054). The mean procedure times for groups A and B were 24.09 minutes ± 8.05 (standard deviation) (range, 14–68 minutes) and 18.62 minutes ± 6.34 (range, 12–81 minutes), respectively (P = .001), and the numbers of patients in each group who required multiple puncture attempts were six (3.9%) of 154 and 23 (13.6%) of 169 (P = .003), respectively.

Conclusion: The use of US guidance before and during PDT could render the procedure easier and safer, with fewer complications but a slightly longer procedure time.

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Percutaneous dilatational tracheostomy (PDT) has been used as an effective method for many patients in the intensive care unit (ICU) since its first description by Ciaglia et al (1). The most appropriate level for puncturing the trachea for PDT is not entirely clear; however, most authors hypothesize that the location of choice for seeking needle entry should be between the first and second tracheal rings (2). The main problem appears to be the disparity between the intended level and the actual puncture site. Dexter (3) reported that in cadavers, nine of 20 insertions were correctly placed at the level planned for the PDT. Theoretically, the physical landmarks of the neck should be clearly identified to assess a suitable puncture location for PDT; in practice, this method is not possible for all patients in the ICU. Short necks, deviated tracheas, massive goiters, previous neck surgery, obesity, edema, subcutaneous emphysema, and difficulties in the positioning of unconscious patients are the principal complicating factors. Results of previous studies (4–8) have demonstrated the benefits of ultrasonographic (US) imaging during the PDT procedure; however, to our knowledge, no randomized controlled trials comparing the current standard care with US-assisted PDT have been reported. We aimed to compare procedure times and complication rates of preincisional US evaluation and perioperative US guidance in PDT compared with those of the current standard of care, PDT without image guidance.

Advances in Knowledge

- Preoperative US examination of the neck demonstrated conditions, including tracheal, thyroidal, or vascular aberrations, that might complicate percutaneous dilatational tracheostomy (PDT) in 38 (23.2%) of 164 patients.
- The incidence of risky conditions for a PDT procedure was significantly higher in patients with short necks (distance between cricoid cartilage and sternal notch, ≤3 cm) than in other patients, at 21 (52.5%) of 40 patients and 17 (13.7%) of 124 patients, respectively (P = .001).
- The mean procedure time for US-guided PDT was higher than that for standard PDT, at 24.09 minutes ± 8.05 (standard deviation) (range, 14–68 minutes) and 18.62 minutes ± 6.34 (range, 12–81 minutes), respectively (P = .001).
- The rate for the requirement of multiple puncture attempts to accomplish the PDT procedure was significantly higher for the standard PDT procedure than for the US-guided PDT procedure (P = .003).
- The total perioperative complication rates of the PDT procedure for patients with short necks were significantly higher than those for the patients with normal-length necks (P = .001).

Implications for Patient Care

- In PDT procedures, US could be used to identify the intended level of seal penetration, even in patients with complicated situations; US could also be utilized to confirm the withdraw level of the endotracheal tube cuff to prevent cuff perforation during the initial puncturing.
- In PDT procedures, posterior tracheal wall damage could be prevented by the estimation of the penetration length of the seeking needle according to the US-quantified tracheal depth.
- US could help ensure the caudal advancement of the guidewire when it is introduced through the seeking needle at PDT; thus, cranial guidewire migration could be eliminated.
- Physicians should be alerted to the possibility of existing anatomic abnormalities that might complicate the PDT procedure in short-necked patients.

Materials and Methods

Study Design and Patients

This prospective study had approval from the institutional review board of Dicle University Hospital, and written informed consent was obtained from the patients or their relatives.

Between December 2007 and January 2011, 341 critically ill patients in the ICU were included in this prospective randomized controlled trial. Patients in the pediatric age group (0–16 years of age) and those with high or unstable intracranial pressures, severe coagulation disorders, and/or evident cervical spine precautions were excluded. The patients were randomly separated into two groups at the time that the decision to perform PTD was made. This was prior to physical examination of the neck. In group A (n = 166; mean age, 59.56 years ± 14.87 [standard deviation]; age range, 18–89 years; 71 women, 95 men), preoperative US examinations of the puncture area were performed by a single radiologist (A.Y., with 10 years of experience in neck US examinations and 5 years of experience in US-guided interventional procedures). All measured tracheal dimensions were recorded, and any conditions that may complicate a PDT procedure were noted. No visible mark was applied to the skin

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Abbreviations:
ICU = intensive care unit
PDT = percutaneous dilatational tracheostomy

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Guarantors of integrity of entire study, A.Y., M.Y.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, C.G., E.A., A.K.; clinical studies, A.Y., M.Y.; statistical analysis, A.Y., C.G.; and manuscript editing, A.Y., E.A., A.K.

Conflicts of interest are listed at the end of this article.

of the neck at the initial US evaluation to avoid the possibility of influencing the clinician. The initial physical examination assessments were performed by a clinician (M.Y., with 300-case experience with the PDT procedure) who was blinded to the US findings. These assessments, including the feasibility of PDT and the estimated puncture locations, were then recorded for each patient. After the insertion point, which depended on the physical examination findings, was decided and marked by the clinician, the US check was immediately repeated. The insertion point, which was determined by a radiologist (A.Y.) with the assistance of US, was again marked, and two marks that were consecutively placed were compared in terms of unity. The necessity for a puncture site revision was considered and recorded in detail. The clinician's estimation of the puncture point was considered inaccurate when the distance from the midline of the trachea to the marked puncture point's nearest margin was more than 1 mm laterally in the coronal plane (measurements were performed with a ruler) and/or when the puncture point was not placed at the intended intercartilage gap in the craniocaudal plane.

The final decision of whether to perform PDT or refer the patient for surgical tracheostomy was based on the US findings; if a decision in favor of PDT was made, the procedure was performed with US guidance. In group B (n = 175; mean age, 57.52 years ± 11.39; age range, 19–91 years; 76 women, 99 men), the procedure was completed "blindly"—that is, without peri- or preoperative US assistance. Physical landmarks were used to locate the puncture site.

The patients in groups A and B were assessed at physical examination in terms of whether they had short necks (distance between the cricoid cartilage and the sternal notch, ≤3 cm) that might complicate PDT. The patients with extremely short necks (in whom the distance between the cricoid cartilage and the sternal notch was ≤ 1 cm and the PDT puncture sites were located below the level of the sternal notch) were also determined.

The numbers of puncture attempts and acute (within 24 hours) perioperative complications were recorded, along with follow-up results (mean follow-up, 137 days ± 44; range, 3–8 months).

The PDT procedure times were measured for all patients. The measurements were initiated at the time of the preoperative US evaluation in group A and at the time of the preoperative physical examination in group B. The measurements of the procedure times for the procedures that were uncompleted (despite multiple attempts) were stopped at the time of the decision to refer the patient for surgical tracheostomy.

The perioperative complications of minor bleeding (bleeding that was controlled by compressing the wound), major bleeding (where pressure-compressed wound dressing or electrocauterization was used to control bleeding or there was a need for blood transfusion), transient oxygen desaturation (hypoxia improved by short disruption of the procedure for ventilatory support), cuff perforation, and cranial guidewire migration were recorded. The investigation of the possible causes of bleeding was performed by reviewing the pre- and postprocedure radiologic and laboratory test results.

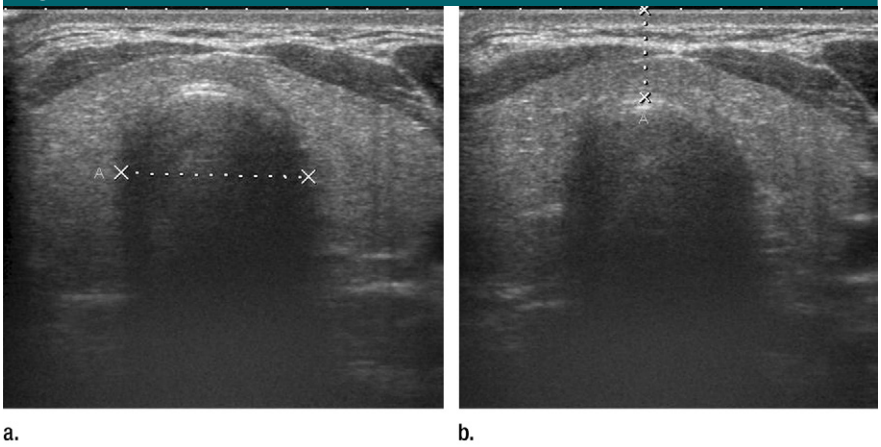
Preoperative US Evaluation

In group A, standard 7.5–12.5-MHz linear probes were used in most cases, whereas 5.0–10.0-MHz microconvex probes (PVF-745 V Micro Convex Ultrasound Probe; Toshiba Medical Systems, Tokyo, Japan) were preferred for the US examinations in patients with short necks. Doppler US imaging was used in patients with aberrant vascularity to reveal the arterial or venous origin (Fig E1 [online]). Increased thyroidal isthmic vascularity was considered, particularly when it was accompanied by a thickened (≥10 mm) thyroidal isthmus (Fig E2 [online]). In these conditions, altered puncture levels (either more cranial or more caudal) were preferred to prevent possible complications due to bleeding. Tracheal diameters (the side-to-side distance of the acoustic shadow of the tracheal air), tracheal depths (the distance between the skin and the anterior tracheal air interface), and the gaps between the first and second tracheal rings (the preferred puncture site for standard PDT) were measured at US (Fig 1); patients with irregular tracheal cartilage ring formations were noted (Fig 2).

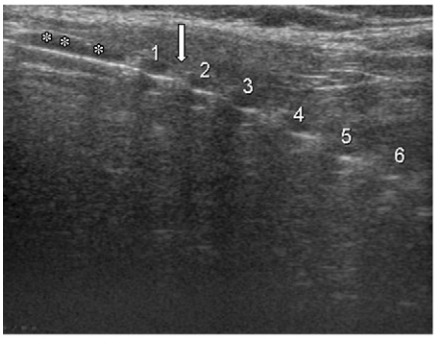
US-guided PDT

The patients who were appropriate candidates for the PDT procedure in groups A and B were monitored in terms of blood pressure, pulse oximetry data, and precordial electrocardiographic data during the entire procedure. Deep sedation followed by neuromuscular blockade was maintained by means of intravenous infusion of propofol (Diprivan; AstraZeneca Pharmaceuticals, London, England) and administration of fentanyl-vecuronium (fentanyl citrate, Abbot Laboratories, North Chicago, Ill; and Norcuron, Organon Pharmaceuticals, Fresnes, France), respectively. After sterilization of the skin, the endotracheal tube was withdrawn to the laryngeal inlet under the vocal cords to prevent the perforation of the cuff by the seeking needle. Placement of the tube shaft and its cuff levels were ensured by detecting the shaft's echogenic US "double-line" appearance at the anterior margins of the tracheas (Fig 3). Consecutive inflations and deflations of the balloon with real-time US visualization were used to ensure a definite cuff-balloon level (Movie 1 [online]). The insertion of the seeking needle was performed with US guidance to achieve the tracheal puncture through the planned midline level. The insertion routes were determined by identifying the slight echogenicity of the needle; and, in most cases, tilting the needle was used to aid in its recognition when necessary (Movie 2 [online]). The advancement of the needle tip was limited on the basis of the previously measured tracheal depth to avoid posterior tracheal wall injuries. The caudal advancement of the guidewire through the tracheal lumen was ensured by demonstration of

Figure 1



a. b.



c.

Figure 1: Preoperative US evaluation of the neck in 37-year-old male patient in the ICU. **(a)** Tracheal diameter was established by measuring the side-to-side width of the tracheal air shadow in the axial plane. **(b)** The tracheal depth was established by measuring the distance between the skin and the anterior margin of the trachea in the axial plane. **(c)** Numbers starting from the top = tracheal cartilage rings; * = cricoid cartilage. Arrow = optimal puncture level for standard PDT (gap between the first and second tracheal rings) in the sagittal plane.

Figure 2

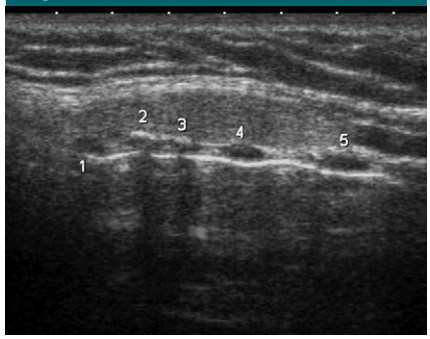


Figure 2: Sagittal US image shows irregular formation of tracheal rings in 64-year-old female patient in the ICU (the tracheal rings are numbered). A thyroidal isthmic parenchyma covering the anterior margin of the trachea was also detected.

the guidewire's penetration angle in the sagittal US plane; in this way, cranial guidewire migrations were prevented (Fig 4).

Technical Features of the PDT Procedure

PDTs were performed by using the Griggs guidewire dilating forceps method (Portex; Smiths Medical, Keene, NH). In patients in group A, tubes with individual inner diameters of 6, 7, 8, 9, and 10 mm (with corresponding outer diameters of 8.2, 9.6, 10.9, 12.3, and 13.7 mm) were used for the patients with premeasured tracheal diameters of 14.9 mm or smaller, 15–18.9 mm, 19–22.9 mm, 23–26.9 mm, and 27 mm or larger, respectively, to prevent the over- or underestimation of tube sizes. Tubes with extra length in the proximal portion were chosen to accommodate patients with deep-set tracheas (tracheal depth, ≥19 mm). In group B, tubes with 7–8-mm inner diameters were used for men, and tubes with 7-mm inner diameters were used for women.

For each patient, the US-guided PDT procedures were accomplished in two consecutive stages. In the first stage, the interventional radiologist (A.Y.) performed the seeking needle puncture of the trachea and introduced the guidewire through the tracheal lumen. Real-time US guidance was used during these steps; thus, accuracy of the placement of the tracheal puncture and the caudal advancement of the guidewire through the distal portion of the tracheal lumen were definitively confirmed. In the second stage, a clinician (M.Y.) completed the remaining steps of the procedure, which included dilation of the tracheostomy ostium and placement and stabilization of the tracheostomy tube.

Statistical Analyses

Groups A and B were compared, with subanalyses of the patients with short necks. Student t tests were used to compare the continuous variables. The Fisher exact test was performed to compare proportions (none of the patients were counted more than once with respect to complications). Statistical software (SPSS, version 13; SPSS, Chicago, Ill) was used for the statistical computations. $P < .05$ was considered to indicate a significant difference.

Results

Results of Descriptive Statistical Analysis between the Groups

Age and sex were similar between groups A and B ($P = .21$ and $P = .90$, respectively). Forty patients (24.4%) were classified as having a short neck among 164 patients in group A, and 45 patients (25.7%) were classified as having a short neck among 175 patients in group B ($P = .80$). A total of three patients (1.8%) in group A and three patients (1.7%) in group B were classified as having extremely short necks ($P > .99$)

Tracheal Quantification and Consideration of Challenging Aspects

In group A, tracheal quantifications could not be performed in two of 166 patients because of subcutaneous emphysema and in three patients because of their extremely short necks. Measurements of the tracheal diameter and

Figure 3



Figure 3: Sagittal US confirmation of a withdrawn endotracheal tube in 63-year-old male patient in the ICU. The "echogenic double line" indicates the tube shaft (arrows), and a distal irregular area of echogenicity represents the cuff (×).

Figure 4



Figure 4: US-guided PDT procedure in 36-year-old male patient in the ICU. Left: Advancement of the guidewire through the caudal tracheal segment was confirmed with US. Right: Sagittal US image shows well-arranged angulation and caudal advancement of the guidewire through the tracheal cartilage (arrow).

ring calibrations were obtained in 161 patients. The mean tracheal diameters, skin-to-trachea distances, and lengths between the first and second tracheal rings were 19.29 mm ± 3.27 (range, 11.3–27.1 mm), 12.60 mm ± 3.77 (range, 6.5–29.6 mm), and 2.69 mm ± 0.62 (range, 1.0–4.2 mm), respectively (Table 1). In six patients with deep-set tracheas, tubes with extra length in the proximal portion were used. Irregular formations of the tracheal cartilage rings were detected in 17 (13.7%) of 161 patients on US images in the mid-sagittal plane (Fig 2).

In 50 (32.5%) of 154 patients (31 [34.8%] of 89 women and 19 [29.2%] of 65 men), tube sizes different from those specified by the standard of care on the basis of the preoperative US findings were used. Statistical analyses of the use of alternative tube sizes were performed with respect to patient age and sex. No significant effect of age was found (P = .920), but the incidence of the use of alternative tube sizes was higher in the female patients (P = .001). The mean age of the patients for whom alternative tube sizes were used was 58.76 years ± 16.08; that of the patients for whom alternative tube sizes were not used was 59.02 years ± 14.37.

Preoperative US examinations revealed conditions necessitating precaution in 38 (23.2%) of 164 patients in group A (Table 2); US-guided PDT was considered to be feasible for 28 of 38 patients with less severe conditions that could substantially complicate the standard "blind" PDT procedure. The incidence of precautions was higher in the patients with short necks (21 of 40) than in the patients with normal-length necks (17 of 124) (P = .001).

Surgical tracheostomies were performed in 12 of the 166 patients in group A: Ten patients exhibited factors that discouraged the use of PDT, even if performed with US guidance, because of the possibility of serious complications (nine of these 10 patients had short necks), and in two patients with subcutaneous emphysema, physical examination and US could not provide adequate anatomic information to allow a PDT procedure. US-guided PDTs were performed in 154 (92.8%) of the 166 patients, and the surgical approach was adopted for the remaining 12 patients (7.2%).

Disparities between US and Physical Examinations

US revealed that reconsideration of the puncture sites previously determined by the clinician was needed in 39 (23.8%) of 164 patients (Table 2). The locations were inaccurate in 25 of 39 of these patients and were corrected at US. In 14 cases, puncture sites at levels other than the standard level were selected to prevent possible complications. Eleven of these 14 cases, in which the altered, more cranially or caudally located puncture levels were preferred to prevent possible bleeding, involved patients with a thick (>10 mm) and hypervascular thyroidal isthmus, as demonstrated at preoperative US. The proximal interstice between the cricoid cartilage and the first tracheal ring was selected in 10 patients, and more caudal gaps were selected in four patients.

Midline tracheal punctures through the intended levels were achieved by using US in 12 patients with deviated tracheas. In four patients, the clinician's decision regarding the entry level was correct, and no revision was necessary. In eight patients, the physical landmarks were suboptimal for determining the appropriate puncture site; the clinician's decision regarding the entry level was corrected in three patients, and the clinician's decision for surgical tracheostomy was converted to US-guided PDT in five patients.

The initial decisions of the clinician for surgical tracheostomy were revised to US-guided PDT after US examination in six patients (five patients had tracheal deviation, as mentioned above, and one patient had a thick tracheal isthmus and massive tracheal edema), and US-guided PDT

Table 1

Descriptive Statistics and Results of Comparisons of Tracheal US Measurements for All Group A and Group B Patients and according to Sex

Group, Parameter, and Sex	No. of Patients	Datum	*P* Value
Group A			
Tracheal diameter (mm)			.001
Male patients	93	20.22 ± 3.13 (11.3–27.1)	
Female patients	68	18.02 ± 3.06 (12.2–24.5)	
All patients	161	19.29 ± 3.28 (11.3–27.1)	
Tracheal depth (mm)			.015
Male patients	93	13.22 ± 3.93 (7.0–29.6)	
Female patients	68	11.76 ± 3.39 (6.5–17.0)	
All patients	161	12.61 ± 3.77 (6.5–29.6)	
Distance of gap between first and second tracheal rings			.003
Male patients	93	2.82 ± 0.59 (1.0–4.2)	
Female patients	68	2.52 ± 0.64 (1.3–4.0)	
All patients	161	2.70 ± 0.63 (1.0–4.2)	
Age (y)			.350
Male patients	96	60.49 ± 14.82 (18–89)	
Female patients	70	58.30 ± 14.92 (19–86)	
All patients	166	59.57 ± 14.85 (18–89)	
Group B			
Age (y)			.355
Male patients	99	58.17 ± 11.73 (19–91)	
Female patients	76	56.52 ± 11.52 (19–81)	
All patients	175	57.52 ± 11.39 (19–91)	

Note.—Data are means ± standard deviations, with ranges in parentheses. *P* = .084 for comparison of the age distributions between groups A and B.

was performed without major complications. The initial decision of the clinician for PDT on the basis of physical examination findings was revised to surgical tracheostomy after US in nine patients. Conditions presenting a possibility of major complications in six patients, and extremely short necks in three patients, led to the preference for surgical tracheostomy. The radiologist agreed with the clinicians' initial decisions for surgical tracheostomy after US examination in three patients. At physical examination, a palpated pulsatile vessel along the puncture site (confirmed as a high-located brachiocephalic trunk at US) was a consideration in one patient. Massive subcutaneous emphysema inhibited the ability to assess the neck with a physical examination or US in two patients.

In group B (n = 175), surgical tracheostomies were preferred by the clinician in six patients. A subcutaneous dilated vessel over the trachea was palpated in one patient; this vessel was subsequently identified as the anterior jugular vein at US (this patient was still counted in group B). Massive goiters in two patients and extremely short necks in three patients were the prominent causes of suboptimal physical examination and surgical tracheostomy decisions by the clinician. In two patients, PDT was initially preferred; however, PDT could not be successfully completed in these patients (after multiple unsuccessful puncture attempts), and they were referred for surgical tracheostomy.

Procedure Times and Complication Rates

The mean procedure times required to complete the PDT procedure (with US guidance in group A) were 24.09 minutes ± 8.05 (range, 14–68 minutes) and 18.62 minutes ± 6.34 (range, 12–81 minutes) in groups A and B, respectively (P = .001). The number of patients who required multiple puncture attempts was six (3.9%) of 154 in group A and 23 (13.6%) of 169 in group B (P = .003).

Perioperative complications occurred in 12 (7.8%) of 154 patients in group A, compared with 25 (15.0%) of 167 patients in group B (P = .054) (Table 3). In group A, one case of major bleeding was hypothesized to be related to mild coagulopathy from chronic renal failure, while four cases of minor bleeding were attributed to a thick thyroidal isthmus in one patient (the puncture was made through the isthmus parenchyma because of the lack of hypervascularity), a thick and hypervascular thyroidal isthmus in one patient (minor bleeding occurred even after the puncture level was revised caudally according to US findings), and relatively difficult deployments of the PDT tubes because of evident tracheal deviations in two patients (Fig E3 [online]). No complications due to cuff perforation were detected in the patients in group A.

Perioperative complications were more common in patients with short necks (19.4% [six of 31]) than in patients without short necks (4.8% [six of 123]) (Table 4).

In the follow-up period of 3–8 months (mean, 137 days ± 44), two patients in group B experienced excessive bleeding at the PDT site on the 15th and 22nd days after the PDT procedure. Immediate surgical repair stopped the bleeding in the first patient, but percutaneous and subsequent surgical intervention did not prevent fatality in the second patient. Trachea–brachiocephalic trunk fistula formation was hypothesized to be the cause of these two catastrophic complications. No PDT-related delayed complications were observed in group A during the midterm follow-up period.

Discussion

The perioperative complications of PDT include bleeding (2.5%–4.4% of all cases) and, less frequently, pneumothorax, subcutaneous emphysema, posterior tracheal wall laceration,

Table 2

Preoperative US Findings and Related Intervention Decisions Applied among 166 Group A Patients

Procedure and No. of Patients	Decision at Preoperative US	Procedure Ultimately Applied to Maintain Airway Access	Findings at Preoperative US
US-guided PDT ($n = 154$)			
22, 9*	Revision of clinician's initial puncture site made after US	Inappropriate initial puncture site corrected at US to midline on the level of the gap between the first and second tracheal rings	No additional condition for precaution
3, 2*	Revision of clinician's initial puncture site made after US	Inappropriate initial puncture site corrected at US to midline on the level of the gap between the first and second tracheal rings	Tracheal deviation (unilateral lung collapse in one patient, prior neck surgery in one patient, and massive goiter in one patient)
2, 1*	Revision of clinician's initial puncture site made after US	Altered to more caudally located puncture sites	Aberrant vessels (anterior jugular vein in one patient and inferior thyroidal vein in one patient)
11, 4*	Revision of clinician's initial puncture site made after US	Altered to more caudally located puncture sites	Thick and hypervascular thyroidal isthmus
1	Revision of clinician's initial puncture site made after US	Altered to more caudally located puncture sites	Aberrant inferior thyroidal vein with thick thyroidal isthmus
104, 10*	No revision of clinician's initial puncture site was necessary	US-guided PDT was performed by considering additional conditions, with precautions if necessary	No additional precaution
1	No revision of clinician's initial puncture site was necessary	US-guided PDT was performed by considering additional conditions, with precautions if necessary	Thick thyroidal isthmus
4, 2*	No revision of clinician's initial puncture site was necessary	US-guided PDT was performed by considering additional conditions, with precautions if necessary	Tracheal deviation (due to prior radiation therapy in two patients and massive goiter in two patients)
5, 2*	Clinician's initial decision for surgical tracheostomy was revised to US-guided PDT after US	US-guided PDT was performed by considering additional conditions, with precautions if necessary	Tracheal deviation (due to massive goiter in three patients, prior neck surgery in one patient, and prior pneumonectomy in one patient)
1, 1*	Clinician's initial decision for surgical tracheostomy was revised to US-guided PDT after US	US-guided PDT was performed by considering additional conditions, with precautions if necessary	Thick thyroidal isthmus and massive neck edema
Surgical tracheostomy ($n = 12$)			
1, 1*	Clinician's initial decision for PDT was revised to surgical tracheostomy on the basis of US findings	Additional conditions with the possibility of major complications led to surgical tracheostomy	High brachiocephalic trunk
1, 1*	Clinician's initial decision for PDT was revised to surgical tracheostomy on the basis of US findings	Additional conditions with the possibility of major complications led to surgical tracheostomy	Massively deviated and deep-set trachea (due to massive goiter)
2, 2*	Clinician's initial decision for PDT was revised to surgical tracheostomy on the basis of US findings	Additional conditions with the possibility of major complications led to surgical tracheostomy	Thick and hypervascular thyroidal isthmus that precluded finding a safe level for PDT
2, 1*	Clinician's initial decision for PDT was revised to surgical tracheostomy on the basis of US findings	Additional conditions with the possibility of major complications led to surgical tracheostomy	Aberrant vascularity (medially coursed right common carotid artery)
3, 3*	Clinician's initial decision for PDT was revised to surgical tracheostomy on the basis of US findings	Surgical tracheostomy was performed owing to the lack of appropriate puncture site for PDT	The level of the gap between the first and second tracheal rings was below the level of the sternal notch
1, 1*	Clinician's initial decision for surgical tracheostomy was agreed to by radiologist	Additional contraindications	High brachiocephalic trunk
2	Clinician's initial decision for surgical tracheostomy was agreed to by radiologist	Insufficient findings were revealed at both physical and US examinations	Massive subcutaneous neck emphysema

* Patients with short necks.

Table 3

Perioperative Complications and Results of Statistical Comparisons among Groups

Perioperative Complication	US-guided PDT (n = 154)	Standard "Blind" PDT (n = 167)	P Value
Minor bleeding	6 (3.9)*	11 (6.6)	.277
Major bleeding	2 (1.3)†	5 (3.0)‡	.290
Transient oxygen desaturation	4 (2.6)	4 (2.4)	.908
Cranial migration of guidewire	0	2 (1.2)	.155
Cuff perforation	0	3 (1.8)	.080
Total	12 (7.8)	25 (15.0)	.054

Note.—Data are numbers of patients, with percentages in parentheses.

* In four cases of minor bleeding in group A, one was attributable to a thick thyroidal isthmus, one was attributable to a thick and hypervascular thyroidal isthmus, and two were attributable to relatively difficult deployments of the PDT tubes due to evident tracheal deviations. In two cases, minor bleeding could not be attributed to a specific aspect.

† One case of major bleeding in group A was hypothesized to be related to mild coagulopathy due to chronic renal failure.

‡ Blood transfusions after electrocauterization were required in two of five patients in group B.

Table 4

Results of Statistical Analysis of Short Neck Situation among Groups

Parameter	Group A	Group B	P Value
Total no. of patients with short necks	40/164 (24.4)	45/175 (25.7)	.803
No. of patients with short necks who underwent PDT	31/154 (20.1)	42/167 (25.2)	.290
Precautions in patients with short necks noted at US	21/40 (52.5)	...	.001
Precautions in patients with normal-length necks noted at US	17/124 (10.4)	...	
Perioperative complications in patients with short necks (n = 22)	6/31 (19.4)	16/42 (38.1)	.122
Perioperative complications in patients with normal-length necks (n = 15)	6/123 (4.9)	9/125 (7.2)	.596

Note.—Data are numbers of patients, with percentages in parentheses. P = .016 for comparison of perioperative complications between patients with short necks and those with normal-length necks in group A. P = .001 for comparison of perioperative complications between patients with short necks and those with normal-length necks in group B. P = .001 for comparison of preoperative complications between patients with short necks and those with normal-length necks in the total cohort. P = .054 for comparison of preoperative complications between group A and group B.

endotracheal tube damage, hypoxia, hypotension and arrhythmias, cuff leaks, endotracheal tube obstruction, loss of airway, premature extubation, and wound infection (9–13). The presence of anatomic vascular variations, tracheal aberrations, or accompanying cervical disease or disorder can lead to increased complication rates (14).

Results of previous studies (5,6,15) have prompted the use of US before PDT as an efficacious method for the prevention of potential complications. In addition to using US to identify anomalous vasculature and appropriate insertion levels and to triage patients to either a surgical or a percutaneous approach, we utilized US to precisely quantify the tracheal dimensions to enable the selection of tubes of the appropriate size. We hypothesized that the use of US would have a preventative effect against the rare complications of PDT, such as the formation of a trachea–brachiocephalic trunk fistula, particularly given the two main mechanisms of the entity, as follows: first, the pressure effects of the cuff of the tube or the distal tip on the anterior tracheal wall; and second, anterior tracheal wall ischemia from the pressure generated by angulated tube necks (16). In our study, two cases of extensive bleeding related to trachea–brachiocephalic trunk fistulas were observed in group B, and no cases were observed in group A.

Bertram et al (17) found that the distances of tracheal rings from the cricoid cartilage could vary across patients; preoperative US might be beneficial for the prevention of inadvertent injury to the first tracheal ring. In our study, irregularly formed tracheal rings were detected in 17 (10.6%) of 161 patients. Previous investigators (5,6) found that the initial puncture levels for PDT had to be reconsidered in 20%–24% of patients after US scanning, which is similar to our rate of 23.8% (39 of 164 patients). A substantial number of patients in this group (12 of 39) had deviated tracheas, which were demonstrated at US.

The penetration of the thyroidal isthmus during PDT has been reported to occur relatively frequently without serious complications (7); however, Bonde et al (2) preferred to locate the thyroidal isthmus by using preincisional US to prevent isthmus puncture, which is accompanied by the risk of bleeding. In our study, we also checked for the the presence of the thyroidal isthmus along the puncture site and revised the puncture level only in patients with thick and hypervascular thyroidal isthmi. A surgical tracheostomy was preferred for two patients with thick and hypervascular thyroidal isthmi that extended to the retrosternal space.

In our study, conditions that could complicate PDT were detected at higher rates in patients with short necks than in patients with normal-length necks in each of our study groups. In a study by Muhammad et al (14), 33 patients with approximately 1 cm or less of tracheal segment between the cricoid ring and the superior margin of the sternum were classified as having short necks at US examination. Surgical tracheostomy was performed in nine of these 33 patients because the cricoid ring was found to be below the sternal notch. In our study, three of the 40 patients with short necks were referred for surgical tracheostomy; this difference is likely related to our 3-cm and 1-cm definitions of a short neck and an extremely short neck, respectively.

Mullins et al (18) reported that even a minor increase in the tracheostomy tube diameter allows a large increase in airflow. Prior studies (19–21) have revealed the feasibility of the selection of more accurately sized endotracheal tubes for pediatric patients on the basis of US measurements of the tracheal dimensions. In our report, we suggest that measurement of the tracheal dimensions with US in adults could be an effective method to select PDT tubes of the most appropriate diameter and length. We used tubes with extra length in the proximal portion for patients with deep-set tracheas to prevent the complications caused by tubes of improper lengths that have been reported by Mallick et al (22).

Sustić and colleagues (23) used Doppler US and Rezende-Neto et al (24) used US to ensure that the withdraw level of the endotracheal tube would prevent cuff perforation by the seeking needle. In our study, US examination in the midline-sagittal plane during the pullback of the cuff showed the tube shafts as echogenic "double-line" structures near the tracheal anterior air interface that ended with the irregular round opacities of the cuff balloon. Consecutive inflation and deflation of the cuff accurately showed the cuff level in instances in which it was imprecise. The penetration length of the seeking needle was limited to a calculated tracheal depth to prevent posterior tracheal wall damage. Chacko et al (8) reported the advantages of US guidance by an introduced cannula and guidewire insertions during PDT; our findings were similar to those of their study. We used US to ensure the proper direction of the guidewire; the identification of the penetration angle through the intercartilage gap could indicate the direction of the extension.

In previous studies, the complication rates of standard PDT have been reported to be between 5.1% and 19% (10–12,25), and the procedure times have ranged from 8 to 26 minutes (2,25–27). In our study, despite its negative effect on the procedure time, the use of US guidance for PDT reduced the perioperative complication rates compared with standard PDT; the difference between the groups was not statistically significant (P = .054). Future studies with extended series are suggested to verify our findings. Significantly fewer multiple puncture attempts were required to access the tracheal lumen in the patients who underwent US-guided PDT (P = .003).

The limitations of this study were as follows: First, we excluded pediatric patients and patients with evident cervical spine precautions that prevented proper patient positioning; the outcomes of our study support the hypothesis that US guidance is beneficial for PDT in such patients. Second, comparisons of the results of long-term follow-up and the effects of obesity were neglected (accurate body mass index calculation could not be achieved for patients in the ICU because of their clinical status). The inability to blind the observer to the treatment group was a necessary limitation of our study. Because the procedures of the different groups were performed by different physicians, some of the differences in complication rates may have resulted from differences in the surgeon rather than from differences in image evaluation and guidance. A small sample size limited our ability to demonstrate significant differences in some group comparisons.

In conclusion, PDT could be a safer procedure when performed by using peri- and preoperative US assistance; despite an acceptable increase in procedure times, the use of US guidance for PDT could reduce the complication rates of the procedure.

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