Association between surgical tracheostomy and chronic tracheal stenosis: a retrospective, single-center study

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Research Article

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Abstract

Background: Tracheal stenosis is a major complication of tracheostomy. Hence, a smaller endotracheal tube (ETT) tends to be selected for patients with a prior tracheostomy history. However, it likely comes from our trial and error, not scientific evidence, because tracheal stenosis after conventional surgical tracheostomy remains relatively uncharacterized. In this study, we retrospectively examined the association between conventional surgical tracheostomy and tracheal shape as assessed by transverse computed tomography (CT).

Methods: Patients who underwent surgery for head and neck cancer during the period January 2010 to December 2013, with a temporary tracheostomy closed within 3 months, were included. Exclusion criteria were tracheostoma before surgery, permanent tracheostomy, or insufficient CT follow-up. Transverse CT slices were measured 2 cm above and below the tracheostomy site (0.5 cm/slice for a total of 9 slices). The minimum cross-sectional tracheal area and horizontal and vertical diameters in transverse CT slices were compared before (baseline [BL]) and 6 months (6M) and 12 months (12M) after tracheostomy. Tracheal stenosis was defined as a decrease in the minimum cross-sectional tracheal area compared to BL.

Results: Of 112 patients, 77 were included. The minimum tracheal area was significantly decreased at 6M and 12M compared to BL (BL: mean 285 [SD 68] mm^2, 6M: 267 [70] mm^2, $P<0.01$ vs. BL, 12M: 269 [68] mm^2, $P<0.01$ vs. BL), and the localization was predominantly at or above the tracheostomy site at 6M and 12M. Tracheal stenosis was identified in 55 patients at 6M and in 49 patients at 12M without any respiratory symptoms. With regard to horizontal and vertical diameter, only horizontal diameter was significantly decreased at 6M and 12M compared to BL (BL: 16.8 [2.4] mm, 6M: 15.4 [2.7] mm, $P<0.01$ vs. BL, 12M: 15.6 [2.8] mm, $P<0.01$ vs. BL).

Conclusions: Conventional surgical tracheostomy was associated with decreased horizontal diameter of the trachea (triangulation) and which resulted in decreased cross-sectional tracheal area in more than one-half of the patients without any respiratory symptoms. In patients with prior tracheostomy, regardless of the presence or absence of respiratory symptoms, use of a smaller ETT should be considered.

Background

Tracheostomy is commonly performed in cases of upper airway obstruction and for patients who require prolonged mechanical ventilation [1]. The benefits of tracheostomy include upper airway management as well as decreased risk of ventilator-associated pneumonia in patients intubated long-term [2, 3]. However, tracheostomy can alter tracheal shape at the surgical site to result in an A-frame or triangular-shaped deformity [4–6], which can lead to tracheal stenosis [7]. Tracheal stenosis of > 30–50% of the original size can cause respiratory symptoms, and the incidence of symptomatic tracheal stenosis after tracheostomy is reported to be 1–6% [7–9]. Asymptomatic tracheal stenosis after tracheostomy has not been well examined [10, 11], given that asymptomatic or mild tracheal stenosis is often not subject to active treatment. Regardless of this fact, a smaller tube tends to be selected for patients who have a prior history of tracheostomy. However, it likely comes from our trial and error, not from scientific evidence.

At our institute, otolaryngologists perform surgical tracheostomy during surgery for head and neck cancer to prevent postoperative upper airway obstruction. And their cancer follow-up were performed with imaging over time which included trachea around tracheostomy.

Therefore, the purpose of the present study was to retrospectively examine the association of conventional surgical tracheostomy with asymptomatic tracheal stenosis over time as assessed by transverse computed tomography (CT) in head and neck cancer patients.

Methods

This retrospective study was approved by the Jikei University Certified Review Board, which provided a waiver of written informed consent (number 29–127[8743]). This study was conducted in accordance with the principles of the Helsinki Declarations.

Patients who underwent surgery for head and neck cancer during the period January 2010 to December 2013, with a temporary tracheostomy closed within 3 months, were included in the study. Exclusion criteria were tracheostoma before surgery, permanent tracheostomy, or insufficient CT follow-up. Patients were intubated after anesthesia induction, and tracheostomy with a U-shaped tracheal incision was performed during the surgery, with ventilation continued through the tube in the tracheostoma. The tube was removed within a few months, once respiratory safety was confirmed, to close the site.

Data collection and tracheal measurement

Demographic information, including age, sex, height, body weight, body mass index, and medical history, was reviewed and collected from medical records. All patients underwent CT before (baseline [BL]) and after surgery at 6 months (6M) and 12 months (12M) for cancer evaluation. The presence and extent of tracheal stenosis were analyzed retrospectively using the CT images, which were set to 0.5 cm per slice. In the transverse plane, cross-sectional tracheal area and vertical and horizontal diameters were measured for each of 9 slices over a distance of 4 cm (2 cm above and below the tracheostomy site). The cross-sectional tracheal area was calculated by tracing around the trachea, and diameters were measured by determining 2 sites of the tracheal wall in each of the horizontal and vertical directions (Fig. 1) with picture archiving and communication system image display (Synapse; Fujifilm Corp, Tokyo, Japan). The minimum cross-sectional area for each patient at each time point (BL, 6M, and 12M) was used for analysis. Tracheal stenosis was defined as a decrease of the minimum cross-sectional area at 6M or 12M compared to BL.

Statistical analysis

Statistical analysis and figure creation were performed with GraphPad Prism software (version 8, GraphPad Software Inc, San Diego, CA). Statistical normality was confirmed with the Shapiro-Wilk test. Quantitative data are presented either as mean (SD) or median (first, third quartile), per statistical normality, and qualitative data are presented as n (%). A one-way repeated-measures analysis of variance with a Tukey post hoc test or Friedman test with a Dunn post hoc test was performed to test tracheal measurements per statistical normality. A P value < 0.05 was considered statistically significant.

Results

A total of 112 patients who underwent surgery and tracheostomy were identified, and 77 were deemed eligible for analysis (Fig. 2). Patient demographic characteristics are summarized in Table 1. The average age was 61.8 (11.1) years, and 57 (74%) patients were male. A total of 55 (71%) patients were smokers. The average time to tracheostomy closure was 34 (14) days.

No patients had any respiratory symptoms.

Table 1
Patient demographic characteristics (n = 77)

Age, y, mean (SD)	**61.8 (11.1)**
Sex (male/female), n (%)	57 (74)/20 (26)
Height, cm, mean (SD)	163.4 (7.9)
Bodyweight, kg, mean (SD)	58.8 (11.3)
Body mass index, kg/m^2, mean (SD)	21.9 (3.3)
Hypertension, n (%)	34 (44.2)
Diabetes, n (%)	12 (15.6)
COPD, n (%)	8 (10.4)
Smoker, n (%)	55 (71.4)
COPD: chronic obstructive pulmonary disease	

Included patient characteristics in this study are shown (n = 77).

The minimum cross-sectional tracheal area was significantly decreased at 6M and 12M after tracheostomy compared to BL (BL: 285 [68] mm^2; 6M: 267 [70] mm^2, $P < 0.01$ vs. BL; 12M: 269 [68] mm^2, $P < 0.01$ vs. BL) (Fig. 3A). Of the 77 analyzed patients, tracheal stenosis was observed in 55 (71.4%) patients by 11.9% (9.4%) at 6M, and in 49 (63.6%) patients by 12.2% (8.8%) at 12M.

With respect to horizontal and vertical tracheal diameters, the horizontal diameter was significantly decreased compared to BL (BL: 16.8 [2.4] mm, 6M: 15.4 [2.7] mm, $P < 0.01$ vs. BL, 12M: 15.6 [2.8] mm, $P < 0.01$ vs. BL) (Fig. 3B). The percent decrease of the horizontal diameter compared to BL was − 8.1% [12%] at 6M and − 7.1% [12%] at 12M. As shown in Table 2, many patients with a horizontal diameter of 15.0 to 19.9 mm at BL decreased to < 14.9 mm at 6M.

Table 2
Horizontal tracheal diameter demographics through the protocol

	Horizontal diameter (mm)				
	≤ 9.9	10.0 ~ 14.9	15.0 ~ 19.9	≥ 20.0	total
BL	0	15	56	6	77
6M	1	34	37	5	77
12M	3	32	37	5	77
BL: baseline					

Changes in horizontal diameter during the observation period for all included patients (n = 77).

No significant difference was observed for vertical diameter (BL: 19.5 [17.2, 22.8] mm, 6M: 20.7 [17.6, 22.3] mm, $P = 0.23$ vs. BL, 12M: 19.7 [17.5, 22.5] mm, $P = 0.32$ vs. BL) (Fig. 3C).

The minimum cross-sectional area for the 9 CT slices for each patient was localized to the most caudal or cranial level at BL (Fig. 4A) and was predominantly at or above the tracheostomy site at 6M and 12M (Fig. 4B). The localization of the maximal tracheal area was predominantly below the tracheostomy site (caudally) at 6M and 12M (Fig. 5B, C), whereas no predominant localization was observed at BL (Fig. 5A).

Discussion

We used CT to assess tracheal stenosis, one of the late complications of tracheostomy, and detailed decreased tracheal area and decreased horizontal diameter. Our results showed that conventional surgical tracheostomy was associated with (1) a decrease of the minimum cross-sectional tracheal area in more than one-half of patients at 6M, which was maintained at 12M without any respiratory symptom, (2) localization of the minimum cross-sectional area in the cranial direction and of the maximum tracheal area in the caudal direction from the tracheostomy site, and (3) a significantly decreased horizontal tracheal diameter at 6M and 12M compared to BL, suggesting triangular-shaped tracheal stenosis after tracheostomy (Fig. 6). In most reports regarding tracheostomy, bronchoscopy has been used to assess for tracheal stenosis [12]. However, bronchoscopy cannot measure detailed changes in tracheal diameter and is relatively invasive compared to computed tomography (CT) [13–16]. Thus, this is the first study to show detailed CT findings of asymptomatic tracheal stenosis over time after conventional surgical tracheostomy.

Tracheal stenosis - decreased area after tracheostomy

The incidence and degree of chronic tracheal stenosis after surgical tracheostomy of the intact trachea, which closes in a few months, especially how the tracheal lumen changes during follow-up, has not been fully elucidated. James et al. studied asymptomatic tracheal stenosis after surgical tracheostomy in patients with head and neck cancers [11]. In that study, the incidence of tracheal stenosis was 8.8% (8 of 91 patients) by measuring the shortest anteroposterior or transverse tracheal diameter with CT or magnetic resonance imaging [11]. In the present study, we defined tracheal stenosis as a decrease of minimum cross-sectional tracheal area compared to BL; accordingly, more than one-half of patients developed tracheal stenosis. The horizontal diameter also decreased in more than one-half of patients. The reason for this difference is not clear, but the longer intubation period in the present study might have increased the number of patients with tracheal stenosis [7, 17]. We selected the cross-sectional tracheal area for evaluation of tracheal stenosis because our focus was on overall tracheal deformity, including the examination of horizontal and vertical diameters. With respect to localization, the minimum tracheal area was seen at the very proximal and distal locations at BL, where there might be difficulty with intubation even in patients without stenosis. After tracheostomy, the minimum tracheal area was predominantly observed above the tracheostomy site, consistent with prior reports examining symptomatic tracheal stenosis or deformity by endoscopy [5, 12]. However, the maximum area was broadly distributed across the trachea at BL. Interestingly, we found that the maximum tracheal area was localized in the caudal direction when the tracheostomy tube was placed for approximately 1 month until respiratory safety was confirmed; this might prevent the development of granulation tissue and resulting stenosis.

Tracheal stenosis - decreased horizontal diameter after tracheostomy

With respect to horizontal and vertical diameters, there have been no prior studies as to how much each diameter changes. An intriguing finding of the present CT study was that the horizontal diameter decreased 7–8% from BL over time, but the vertical diameter did not change compared to BL. This heterogeneous change was associated with a triangular shape of the trachea (Fig. 6) [4, 18] and, therefore, might have contributed to the decreased cross-sectional tracheal area, consistent with previous research [14].

Tracheal stenosis and ETT selection

Patients with a triangular-shaped trachea can be difficult to intubate [6]. For many of the patients in the present study, the horizontal diameter was 15.0 ~ 19.9 mm at BL, decreasing to 10.0 ~ 14.9 mm after tracheostomy. The average decrease of the horizontal diameter after tracheostomy was by 1.4 mm at 6M and 1.2 mm at 12M. This should be one of the reasons for selecting appropriate ETTs for patients with prior tracheostomy. Comparing various types of available ETTs (Table 3), all with an inner diameter of ≥

7.5 mm have an outer diameter > 10.0 mm. In addition, it is important to consider the cuff when selecting the tube because it could get stuck if the outer diameter is close to the shortest tracheal horizontal diameter.

Table 3
Endotracheal tube diameter

Manufacturer	Inner Diameter (mm)	Outer Diameter (mm)
Covidien, Hi-Lo	8.0	10.8
	7.5	10.2
	7.0	9.5
	6.5	8.9
	6.0	8.2
Teleflex, Hi-Lo	8.0	11.4
	7.5	10.9
	7.0	10.4
	6.5	9.9
	6.0	9.4
Smiths Medical, Hi-Lo	8.0	10.9
	7.5	10.3
	7.0	9.6
	6.5	8.9
	6.0	8.2

Detail endotracheal tube information about inner/outer diameter for three different manufactures.

Combining the above information and our present data, a 10.0 ~ 14.9 mm horizontal diameter might be used as a cutoff for reconsideration of ETT size selection. A decreased horizontal diameter might support downsizing the ETT to prevent airway trouble. We suggest that anesthesiologists evaluate neck CT images if available to make sure that an appropriate ETT size is considered and, if necessary, select a smaller ETT with appropriate cuff volume for patients with a history of surgical tracheostomy. The results of the present study might provide anesthesiologists with practical information regarding asymptomatic tracheal stenosis after tracheostomy and the usefulness of CT for pre-anesthesia preparation.

Limitations

This study has several limitations. First, this was a retrospective study, and causality was not assessed. Second, several reports indicate that cuff pressure is a risk factor for tracheal stenosis [8, 19]; however, all of the patients in this study underwent tracheostomy during surgery, and cuff pressure was monitored right after intubation. Third, we analyzed a total distance of 4 cm (2 cm above and below the tracheostomy site) by transverse-plane CT, not the entire trachea [20]. We focused on the relation between tracheostomy, especially the tracheostomy site, and tracheal stenosis. We believe that assessment 2 cm above and below the tracheostomy site is enough to evaluate for tracheal stenosis before surgery.

Conclusions

The present CT study detailed the development of asymptomatic tracheal stenosis after tracheostomy. The decreased cross-sectional tracheal area at 6M and 12M after tracheostomy appeared to be due to a decrease in horizontal tracheal diameter, resulting in a triangular-shaped trachea. The use of CT can help to evaluate tracheal stenosis before anesthesia in patients with prior tracheostomy.

Abbreviations

6M: 6 months, 12M: 12 months, BL: baseline, CT: computed tomography, ETT: endotracheal tube

Declarations

Ethics approval and consent to participate

This retrospective study was approved by the Ethics Board of the Jikei University School of Medicine, which provided a waiver of written informed consent (number 29-127[8743]).

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to patients' privacy but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests or disclosures.

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Not applicable.

Authors’ contributions

Yuki Kuwabara and Kentaro Yamakawa contributed to the study’s conception and design. Data collection and analysis were performed by Seiko Okui, Erica Miyazaki, Yuki Kuwabara, and Kentaro Yamakawa. This study was supervised by Shoichi Uezono. The manuscript was written by Yuki Kuwabara and Kentaro Yamakawa, and all authors reviewed and approved the final manuscript.

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Not applicable.

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Figures

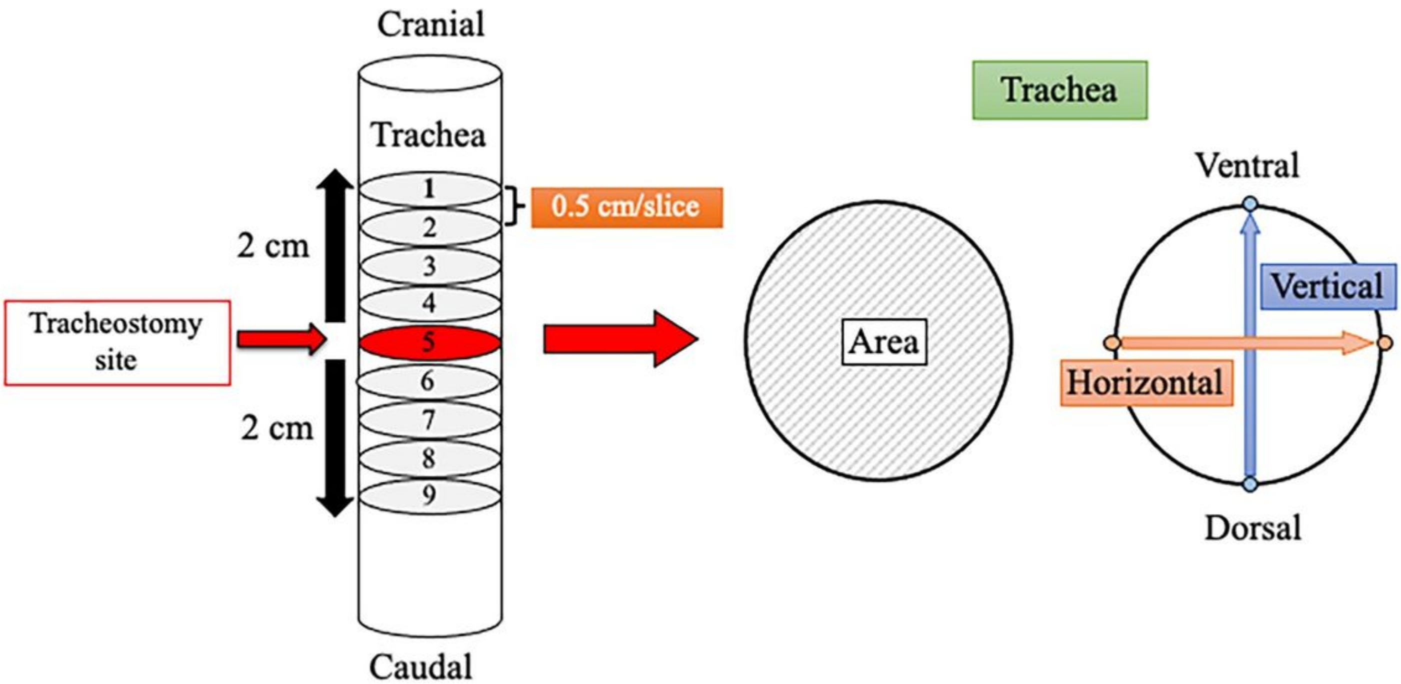

Figure 1

Schematic of method for measuring the tracheal lumen using computed tomography. Measurement was performed over a distance of 4 cm above and below the tracheostomy site. Each image slice was set to 0.5 cm, and 9 slices were analyzed. The minimum tracheal area among the 9 slices was selected for each time point (baseline, 6 months, and 12 months). Horizontal and vertical tracheal diameters were also measured

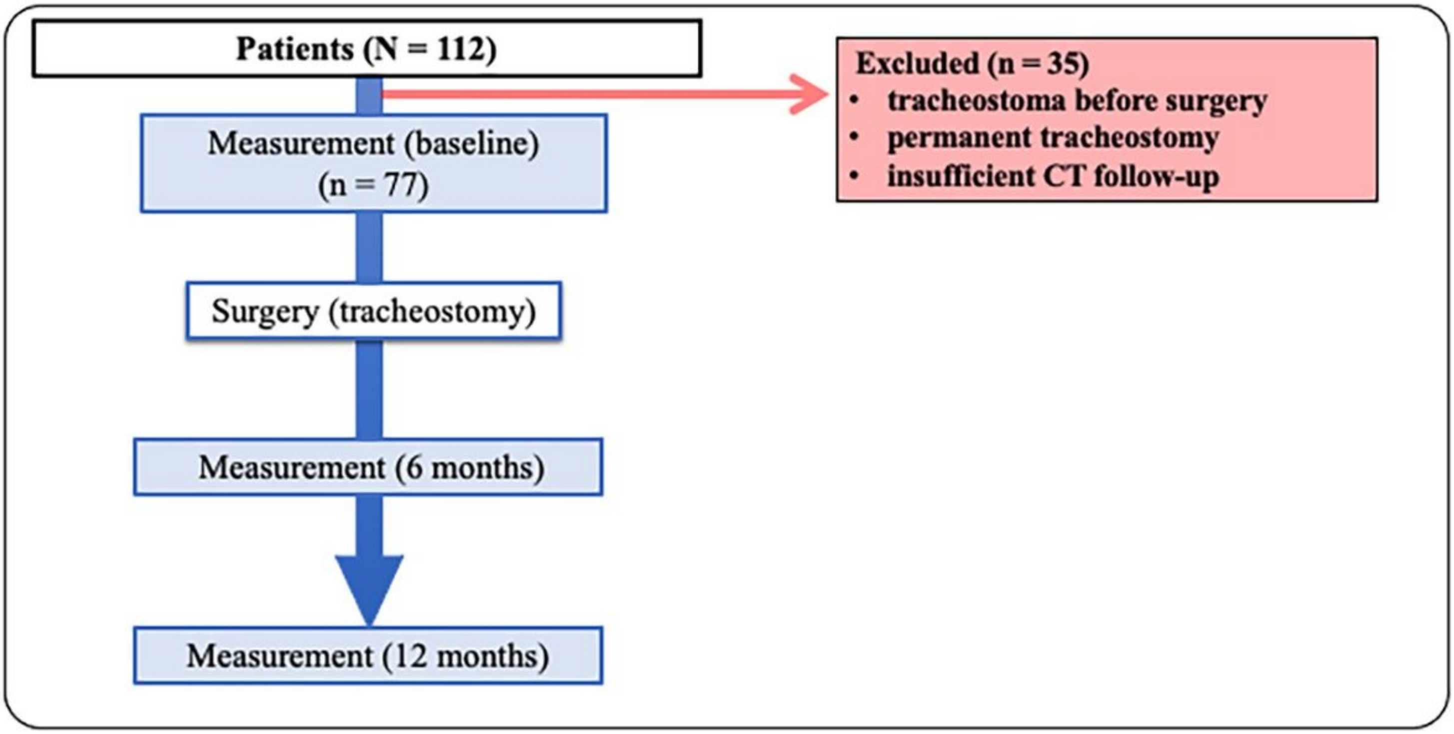

Figure 2

Flow of study protocol. Of 112 patients who underwent surgery for neck and head cancer, 77 were included in the study. Computed tomography was performed before surgery (baseline) and at 6 and 12 months after surgery

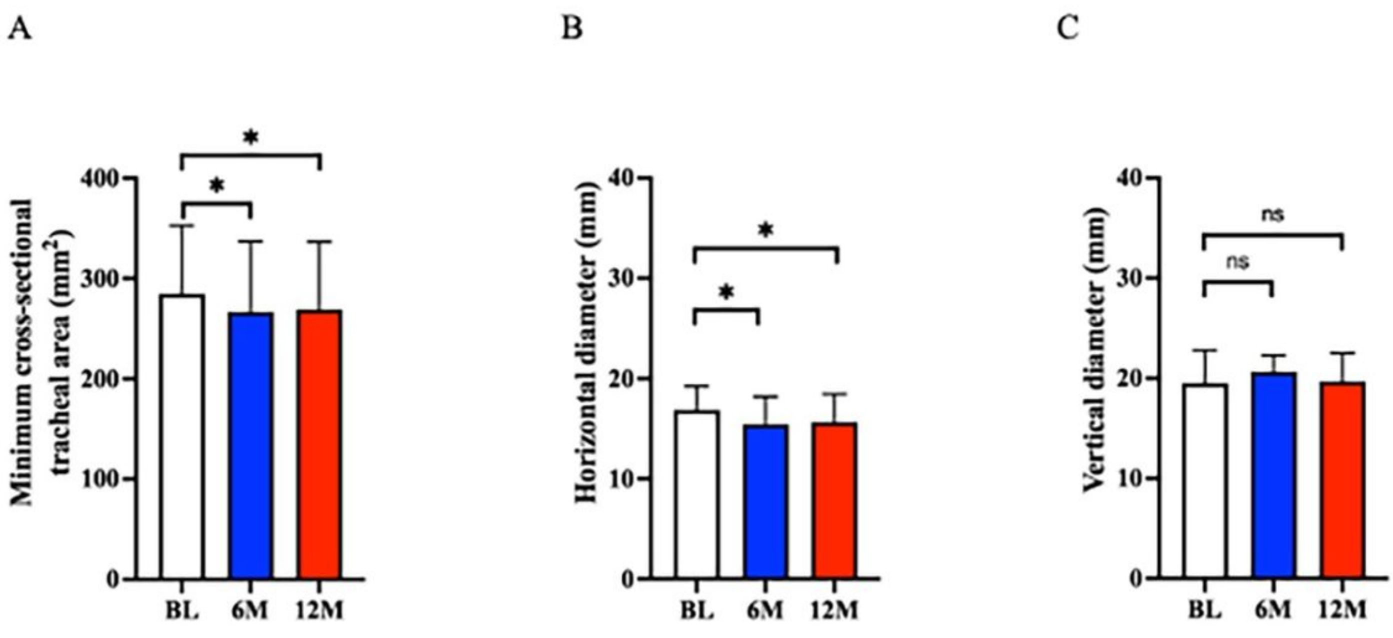

Figure 3

Tracheal stenosis after tracheostomy. **A** The minimum tracheal area decreased significantly at 6M and 12M (both $P<0.01$ vs. BL). There was no difference between 6M and 12M ($P = 0.66$). *$P<0.01$. **B** The horizontal tracheal diameter decreased significantly at 6M and 12M compared to BL (both $P<0.01$ vs. BL). There was no difference between 6M and 12M ($P = 0.43$). *$P<0.01$ **C** The vertical diameter did not change over time (6M: $P = 0.23$ vs. BL; 12M: $P = 0.32$ vs. BL). No change was observed between 6M and 12M ($P>0.99$). Bar graphs are shown as mean ± SD (A, B) and median, first, and third quartile (C). 6M: 6 months after surgery, 12M: 12 months after surgery, BL: baseline, ns, not significant

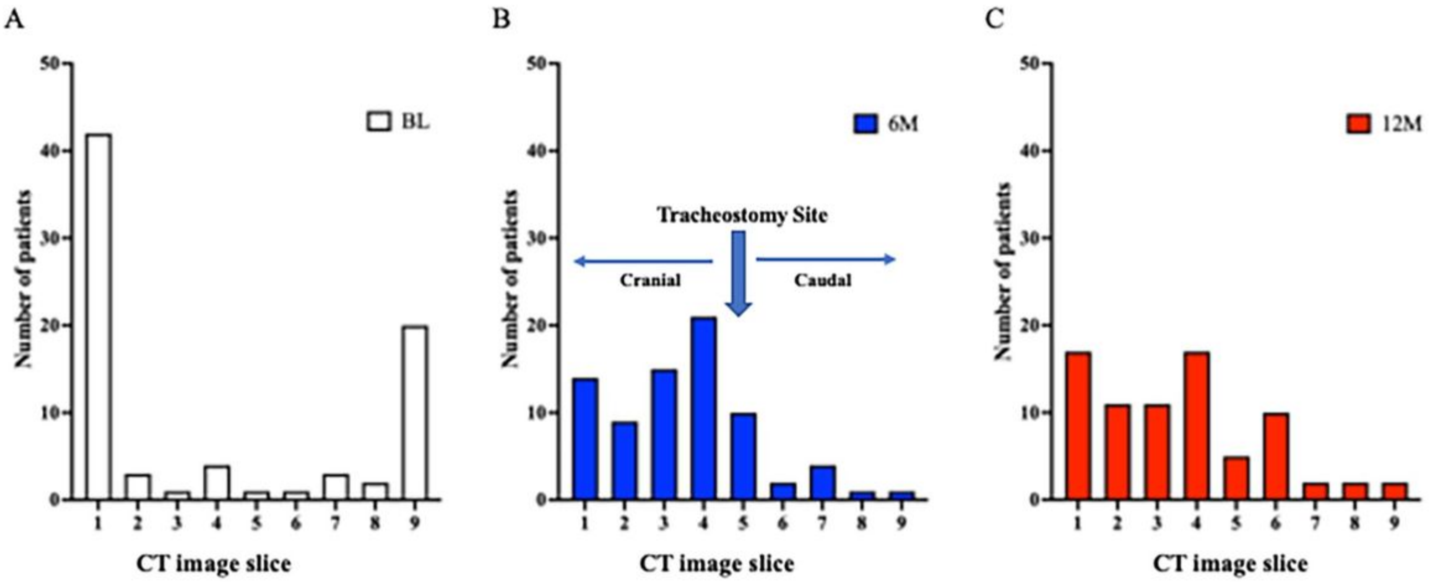

Figure 4

Localization of site of minimum tracheal area before and after tracheostomy. A total of 9 CT slices were obtained for each patient (cranial to caudal, with tracheostomy site in the middle [slice 5]). **A** At BL, the site of minimum tracheal area was at the most cranial (slice 1) or most caudal (slice 9) slice. **B, C** At 6M and 12M, the site of minimum tracheal area was predominantly at or above the tracheostomy site. 6M: 6 months after surgery, 12M: 12 months after surgery, BL: baseline, CT: computed tomography

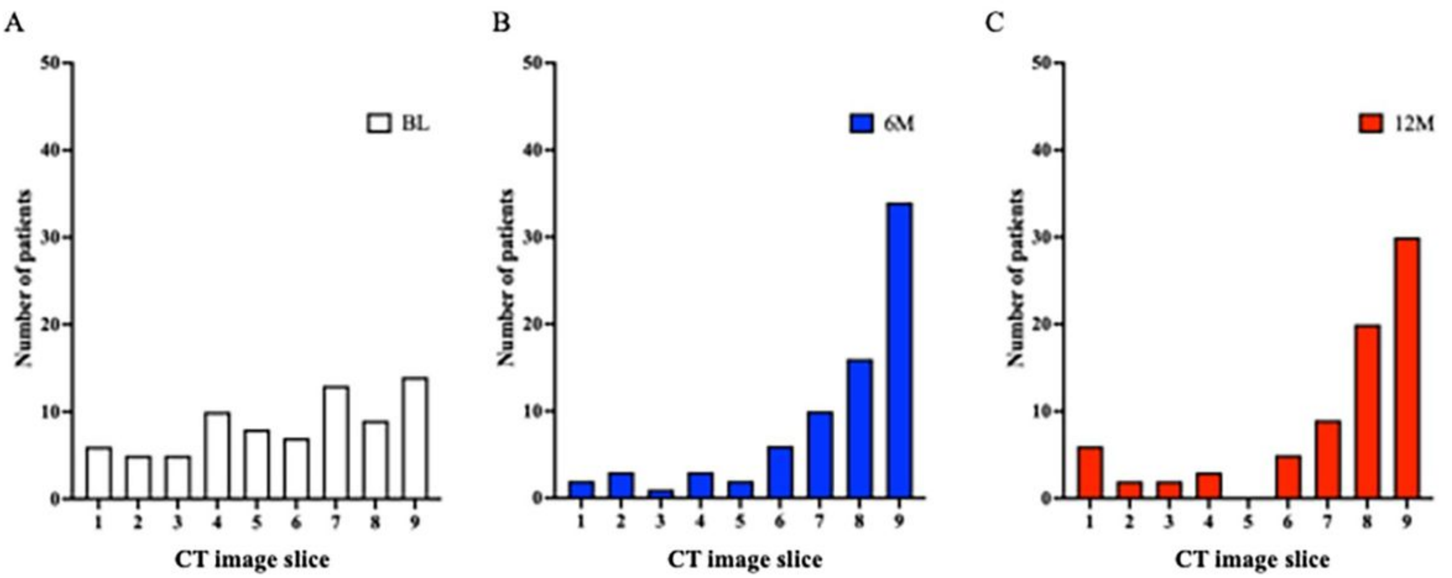

Figure 5

Localization of site of maximum tracheal area before and after tracheostomy. A total of 9 CT slices were obtained for each patient (cranial to caudal, with tracheostomy site in the middle [slice 5]). **A** At BL, there was no predominant localization of the site of maximum tracheal area. **B, C** At 6M and 12M, the site of maximum tracheal area was localized below the tracheostomy site (caudally). 6M: 6 months after surgery, 12M: 12 months after surgery, BL: baseline, CT: computed tomography

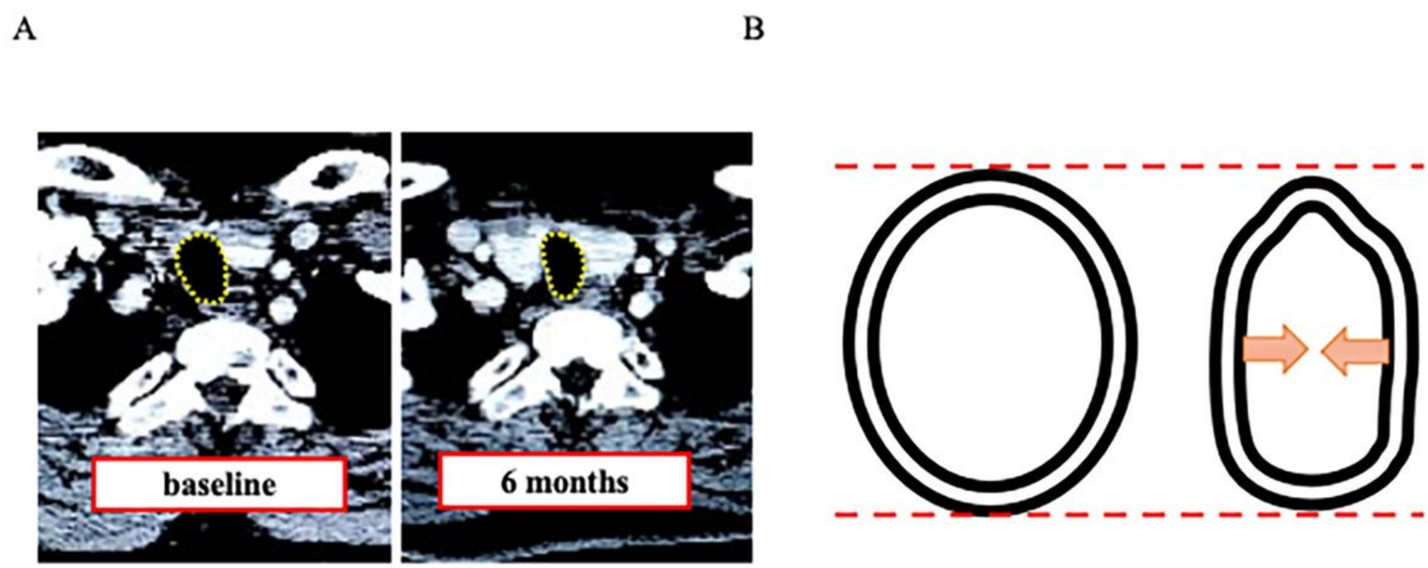

Figure 6

Tracheal stenosis after tracheostomy. **A** Representative computed tomography images of tracheal stenosis. **B** Schematic showing triangulation after tracheostomy