DETECTION OF BENIGN CERVICAL TRACHEAL STENOSIS WITH IN VITRO HIGH-FREQUENCY ULTRASOUND: A PRELIMINARY STUDY

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ABSTRACT

***Background**: High-frequency ultrasound (HFU) is non-invasive and non-radiative technique, which has high resolution and can be easily used in follow up. The aim of this paper is to investigate the imaging characteristics and application of high-frequency ultrasound in the detection of benign cervical tracheal stenosis.*

***Methods**: A total of 23 patients who underwent bronchoscopy which proved benign cervical tracheal stenosis were recruited and underwent to in vitro high frequency ultrasonography. The imaging characteristics were compared with those of healthy subjects. Variables related to tracheal stenosis were compared with those in bronchoscopy.*

***Results**: 1) In patients with tracheal stenosis, high-frequency ultrasonography showed irregular shape at the stenotic segment which presented intermittent, discontinued or disappeared continuity, uneven thickness of tracheal wall and abnormal echoes. These findings were significantly different from those in control group (P<0.05); 2) The diameter of trachea at the most stenotic segment or the diameter of endotracheal stent was 8.52±2.68 mm (range: 4~14 mm) in the high-frequency ultrasonography and 8.39±2.79 mm (range: 2~14 mm) in bronchoscopy showing no significant difference (t=0.514, P=0.613), but the diameter in high-frequency ultrasonography was relevant with that in bronchoscopy (r=0.89, 95%CI: 0.87, 0.91).*

***Conclusion**: For patients with cervical tracheal stenosis mainly at the anterior tracheal wall and those receiving tracheal stenting, high frequency ultrasound can identify the abnormal structure at the stenotic segment and be used to evaluate the diameter of stenotic trachea. The in vitro high frequency ultrasound can provide imaging characteristics to determine the therapeutic efficacy and the follow up of tracheal stenosis.*

***Key words**: Benign tracheal stenosis, bronchoscopy, high frequency ultrasound, imaging findings, tracheal measurement.*

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Introduction

The incidence of tracheal stenosis, whose characteristic symptom is dyspnea, is increasing over year and tracheal stenosis has the potential to develop into a refractory disease[(1)]. The clinical diagnosis of tracheal stenosis is mainly based on the clinical manifestations and findings in bronchoscopy and imaging examinations. To date, intervention based comprehensive therapy has become the major strategy in the treatment of tracheal stenosis. Following interventional therapy, patients are usually required to be followed up aiming to monitor the re-stenosis[(2)]. As an imaging examination, high-frequency ultrasound (HFU) is non-invasive and non-radiative technique, which has high resolution and can be used in follow up. Thus, HFU may serve as an important method for the follow up of patients with cervical tracheal stenosis[(3-5)]. In the present study, 23 patients with benign cervical tracheal stenosis were recruited and the findings in HFU were reviewed aiming to evaluate the value of HFU in the detection of cervical tracheal stenosis.

Material and methods

Subjects

Tracheal stenosis (TS) group: A total of 23 inpatients with tracheal stenosis were recruited from Nov 2010 to May 2011. There were 17 males and 6 females with a median age of 42 years (range: 13~71 years). The median course of disease was 6 months

(range: 1 month ~ 3 years). The cervical tracheal stenosis was pathologically proven. Biopsy followed by pathological examination showed granulation tissue formation. The cause of tracheal stenosis included tracheotomy (n=9) following traffic accident or tetanus and orotracheal intubation due to pneumonia (n=14). Among these patients, 9 received intratracheal stenting (39.13%) and 14 had no intratracheal stent (60.87%). These patients underwent bronchoscopy more than twice during the follow up period. The interval between last treatment and ultrasonography ranged 1 week to 4 months.

Control group: A total of 120 patients were randomly selected from subjects undergoing physical examination from October 2010 to February 2011. There were 60 males and 60 females and the age ranged from 18 years to 70 years. Inclusion criteria: Subjects were classified as American Society of Anesthesiologists grade I, and respiratory diseases, cervical diseases, cardiovascular diseases, systemic diseases and tumors were excluded. CT demonstrated there was no abnormality in respiratory tract and subjects with tracheobronchial variation were also excluded.

High-frequency ultrasonography

Ultrasound Diagnostic Equipment (DC-N6Pro; Mairui Bio-Medical Electronics Co., Ltd, China) and Phlips-IU22 (Philips, Netherlands) were used and the frequency of linear array probe was 5-12 MHz. Patients lied in a supine position and the pillow was removed. The hypsokinesis of the head was employed aiming to expose the anterior and lateral neck and relax the muscles in the neck. In the ultrasonography, the probe was adherent to the skin and detection was performed perpendicular to the skin. Compression was avoided or the trachea was compressed or subjects presented discomfort. Scan was done at the trachea from the annular cartilage to the sternal notch at different directions (cross, longitudinal, sagittal and circular sections).

The observations included:

• regularity, continuity, thickness and echoes of the trachea;

• location and shape of intratracheal stent;

• the maximal diameter of air-mucosa interface of each tracheal ring was measured from the annular cartilage to the sternal notch (Figure 1).

The smallest diameter was used as the diameter of tracheal stenosis. For patients with intratracheal stent, the diameter of the stent served as the diameter of tracheal stenosis. The above mentioned findings in tracheal stenosis patients were compared with those in bronchoscopy.

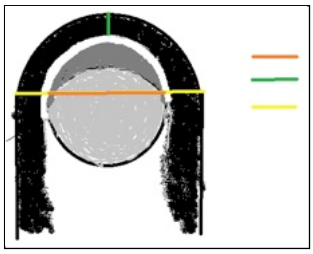

Figure 1: Cross section of cervical trachea (at thyroid isthmus) under ultrasonography.

Bronchoscopy

Bronchoscope (Olympus-260; Japan) was used. The most stenotic trachea was identified under the bronchoscopy and the tracheal diameter was measured and recorded.

Ultrasonography and image analysis were done by two sonographers with experience in ultrasonography of superficial organs of the neck. Bronchoscopy was performed by a physician with experience in interventional therapy of respiratory diseases. Interval between ultrasonography and bronchoscopy was 2~24 h and double-blind design was employed in the study.

Statistical analysis

Statistical analysis was performed with SPSS version 16.0. The Fisher exact test was employed to compare the characteristic findings under ultrasonography between tracheal stenosis patients and controls. A value of $P<0.05$ was considered statistically significant.

The tracheal diameter was expressed as mean ± standard deviation and t test was employed for comparing the diameters in ultrasonography and bronchoscopy followed by analysis of variance. A value of $P<0.05$ was considered statistically significant. Linear regression analysis and correlation analysis were also done.

Results

The imaging characteristics of cervical trachea under high frequency ultrasonography in healthy controls included: tracheal cartilage presented symmetrical even crescent-shaped, hypoechoic at cross-sections and pea-like beaded echoes with regular intervals at longitudinal sections; hyperechoic areas were found at the interface between tracheal wall and surrounding soft tissues and the interface was continuous, clear and smooth; the air-mucosa interface was

clear at the inner trachea; the posterior tracheal wall was unclear due to the intratracheal air (Figure 2A).

Figure 2: Findings of cervical trachea under ultrasonography in tracheal stenosis patients and healthy controls (cross section)

A: healthy controls: the tracheal cartilage presented symmetrical, crescent-shaped, even hypoechoes, had continuous, clear and smooth borderline. White arrow: smooth arc-shaped hyperechoes showed the A-M interface.

B: Tracheal stenosis patients with intratracheal stenting: white arrow showed the stent. There were clear, continuous spotty hyperechoes in the trachea which were arc-shaped and adherent to the inner trachea.

C: Tracheal stenosis patients without intratracheal stenting: The stenotic trachea had irregular shape, the thickness was uneven, and the echoes of tracheal ring were uneven. Arrow showed arc-shaped hyperechoes indicating A-M interface.

*D: Tracheal stenosis patients following tracheotomy: * indicated intermittent continuity and irregular hypoechoes extended to the epidermis.*

The imaging characteristics of cervical trachea under high frequency ultrasonography in patients with tracheal stenosis included: the stenotic trachea was irregular or angled, the echoes of tracheal wall were discontinued or disappeared, the tracheal wall was uneven in thickness, the echoes of tracheal ring increased unevenly or irregular spots with hyperechoic interfaces were found at the tracheal ring. Intermittent continuity was found at the echoes of anterior tracheal wall in 9 patients. In these patients, ultrasonography showed the intermittent continuity at the echoes of anterior tracheal wall which was angled. The trachea with intermittent continuity at the echoes presented focal, irregular, uneven hypoechoes extending to the epidermis. These 9 patients had a history of tracheotomy. In all 9 patients receiving intratracheal stenting, the stent was detected under the ultrasonography. In addition, high frequency ultrasonography showed the continuous spotty hyperechoes at the trachea which were arranged intensely in a line-like way. At the cross sections, the echoes were round and adherent to the inner trachea (Figure 2B-D, Figure 3).

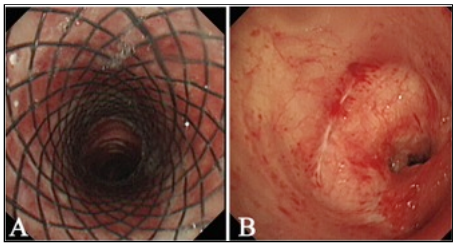

Figure 3: Detection of cervical tracheal stenosis by Bronchoscopy.

A: patients with intratracheal stent;

B: cervical tracheal stenosis patients: thickening of tracheal wall which had uneven thickness and was not smooth, and the trachea was narrowed.

To determine the difference in the morphology of the trachea between tracheal stenosis patients and controls, the following characteristics under ultrasonography were compared: regularity and continuity of the trachea, thickness and echoes of tracheal wall (Table 1). Fisher exact test was employed for statistical analysis and results showed significant difference in the morphology of the trachea between tracheal stenosis patients and controls ($P<0.05$). This suggests the trachea of patients with tracheal stenosis is morphologically different from that in healthy controls demonstrated by ultrasonography.

	Regular shape	Continuity	Uneven thickness	Abnormal echoes	Total
control	60	60	0	0	120
TS	0	14	23	23	60
Total	60	74	23	23	180

Tab. 1: Imaging characteristics of the trachea under ultrasonography in benign tracheal stenosis patients and healthy controls.

Tracheal or stent diameter in 23 patients: The mean tracheal or stent diameter in 23 patients was 8.52±2.68 mm (range: 4~14 mm) under ultrasonography and 8.39±2.79 mm (range: 2~14 mm) showing significant difference ($t=0.514$, $P=0.613>0.05$). Correlation analysis showed there was positive correlation between the minimal diameter under ultrasonography and bronchoscopy ($r=0.89$, 95%CI: 0.87, 0.91).

Discussion

Benign tracheal stenosis often develops after tracheal tuberculosis, tracheal intubation, tracheotomy, tracheal trauma, lung transplantation, etc[1, 6, 7]. Tracheotomy and tracheal intubation are the main

causes of benign tracheal stenosis in adults followed by tracheal tuberculosis, and the former two are also the major causes of iatrogenic tracheal stenosis. Stenosis is the most frequently found at the site of tracheotomy followed by the site of balloon during the tracheal intubation. In addition, stenosis may also be found at the site of catheter head during the tracheal intubation because the friction between the catheter and the anterior and posterior wall of the trachea may cause hyperplasia of granulation tissues[2, 8, 9]. In the present study, 9 out of 23 (39.1%) patients had a history of tracheotomy, and orotracheal intubation was found in 14 patients (60.9%). Bronchoscopy confirmed the stenosis at the upper and middle segment of central airway. Biopsy and pathological examination showed rough collagens with staggered arrangement and a few fibroblasts forming scars.

For patients with cervical tracheal stenosis, the reduction in cross-sectional area of the trachea by 25~75% may cause clinical symptoms. In recent years, intervention based comprehensive therapy has been an effective and minimally invasive strategy for the treatment of tracheal stenosis. In this strategy, removal of focal scars, balloon dilation or intratracheal stenting can be performed. These methods may achieve short-term effectiveness. With the continuous proliferation and repair of local tissues and scar formation, tracheal restenosis may develop. Thus, interventional therapy is required repeatedly. Bronchoscopy has been used as a gold standard in the evaluation of tracheal stenosis. However, bronchoscopy is invasive and may cause damage or discomfort to patients. High frequency ultrasound is non-invasive and may be applied repeatedly. Thus, high frequency ultrasound has the promise to become an ideal method in the post-operative follow up of patients with tracheal stenosis[4,10,11].

The imaging characteristics of benign tracheal stenosis under ultrasonography included:

• Abnormal echoes at the stenotic segment: diffused uneven enhancement, reduction or stratification of echoes, or increase in spotty hyperechoic areas;

• Abnormal tracheal wall: the cross-sectional trachea was not smooth and arc-shaped as in healthy controls, but angled or transformed;

• The thickness of tracheal wall was uneven;

• For patients with tracheotomy, the anterior tracheal wall had intermittent continuity, and focal irregular, uneven, heterogenous hypoechoes presented at the discontinued trachea and extended to the epidermis.

The above findings may be explained as follows: during the tracheotomy or tracheal intubation, the mucosa, submucosa and perichondrium are susceptible to damage due to their thinness, leading to ischemia, mucosal ulcer, chondritis, and granulation tissue formation, cartilage necrosis, scar formation or fibrosis and remodeling of airway. The scar contraction or the thinning / softening of the tracheal cartilage following compression finally result in tracheal stenosis[2]. These pathological alterations lead to the above findings under ultrasonography. The hyperechoes and calcified plaque are also found at the trachea of healthy old subjects. Thus, spotty hyperechoes alone can not be employed to determine the tracheal stenosis.

After comparing the findings in ultrasonography with those in bronchoscopy, results showed there was no marked difference in the minimal diameter of the trachea under the two techniques. Moreover, the tracheal diameters determined by ultrasonography and bronchoscopy had positive correlation. Our experience demonstrates that detection of the minimal tracheal diameter: air-mucosa interface of the inner trachea in patients without intratracheal stenting is crucial for the detection of tracheal diameter and should be carefully identified. For patients undergoing tracheal stenting, the metal presented intermittent spotty hyperechoes which were significantly different from the echoes of surrounding tissues. This is helpful for the detection of stent diameter and to determine the complications of stenting such as stent migration. Although the posterior tracheal wall was unclear under ultrasonography due the presence of air in the trachea, for patients undergoing tracheotomy or tracheal intubation, injury is mainly present at the anterior tracheal wall, which is the main cause of tracheal stenosis and can be identified by the ultrasonography.

Conclusion

For patients with cervical tracheal stenosis at the anterior and lateral wall and those receiving intratracheal stenting, high frequency ultrasonography can identify the structural abnormalities at the stenotic segment which are characterized by irregular shape, intermittent, discontinued or disappeared continuity, uneven thickness and abnormal echoes. Moreover, high frequency ultrasonography can be employed to accurately determine the tracheal diameter at the stenotic segment. Thus, we speculate that high frequency ultrasonography can provide evi-

dence for the determination of therapeutic efficacy of cervical tracheal stenosis and the post-operative follow up of patients with cervical tracheal stenosis.

References

1) Cosano PA, Munoz CL, Cosano P, et al. *Endoscopic Treatment of Central Airway Stenosis: Five years' Experience*. Arch Bronconeumol 2005; 41: *322-7*.
2) Rahman NA, FrutherO, Shitrit D, et al. *Flexible bronchoscopic management of benign tracheal stenosis: long term follow-up of 115 patients*. J Cardiothorac Surg 2010; 5: *2*.
3) Shih JY, Lee LN, Wu HD, et al. *Sonographic imaging of the trachea*. J Ultrasound Med 1997; 16: *783-90*.
4) Giguère CM, Manoukian JJ, Patenaude Y, et al. *Ultrasound and a new videobronchoscopic technique to measure the subglottic diameter.* Otolaryngol 2000; 29: *290-8*.
5) Ding LW, Wang HC, Wu HD, et al. *Laryngeal ultrasound a useful method in predicting post-extubation stridor.* A pilot study. EurRespir J 2006; 26: *384-9*.
6) Chan AL, Yoneda KY, Allen RP, et al. *Advances in the management of endobronchial lung malignancies*. Curr Opin Pulm Med 2003; 9: *301-8*.
7) Kidong E, Sehokkenbroek AA, Franssen CF, et al. *Dilatation tracheoscopy for laryngeal and tracheal stenosis in patients with Wegener's granulomatosis*. Eur Arch Otolaryngol 2008; 265: *549-55*.
8) Kidong E, Kumjung M, Yunsang S, et al. *Ultrasonographic evaluation of tracheal collapse in dogs*. J Veter Sci 2008; 9: *401-5*.
9) Thornton RH, Gordon RL, Kerlan RK, et al. *Outcomes of tracheobronchial stent placement for benign disease*. Radiology 2006; 204: *273-82*.
10) Murad H, Jobn J, Manoukian, et al. *Ultrasonography and videobronchoscopy to assess the subglottic diameter in the paediatric population a first look*. J Otolaryngol 2002; 31: *220-6*.
11) Lakhal K, Delplace X, Cottier JP, et al. *The feasibility of ultrasound to assess subglottic diameter*. Anesth Analg 2007; 104: *611-4*.

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