4-Dimensional CT assessment of tracheal diverticulum

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Purpose

Air cystic lesions are not uncommonly found on CT of the chest and neck.

Tracheal diverticula are tracheobronchial anomalies characterized by single or multiple outpouchings of the tracheal wall \(^1,2,3\). By strict definition, diverticula must have communications with the trachea, whereas a cyst may not \(^1\).

Tracheal diverticula are present in 1 to 2% of individuals at autopsy \(^2,4\). 98.5% of them are located at the right posterolateral side of the trachea at the thoracic inlet \(^2,5\).

Tracheal diverticula may be congenital or acquired \(^6,7\). The more common acquired form is thought to be secondary to increased intraluminal pressure causing out-bulging through weakened tracheal musculature which is often associated with chronic cough and chronic obstructive pulmonary disease (COPD) \(^6,8\). The walls of acquired diverticula consist only of respiratory epithelium, lacking any cartilaginous rings \(^9,10\).

Tracheal diverticula may be symptomatic due to compression on the trachea or infection in the cyst \(^1\). Diverticulum can act as a reservoir for mucous secretions \(^7\) and this may present as recurrent respiratory infections or aspiration \(^11\). Tracheal diverticula have also been reported to cause difficulty in intubation, airway compromise, or ineffectual ventilation \(^12,13,14\).

The differential diagnosis of tracheal diverticulum includes pharyngocele, laryngocele, Zenker diverticulum, apical lung hernia, blebs and bulla, and pneumomediastinum \(^2,15,16,17\).

Fibreoptic bronchoscopy is considered the gold standard for the diagnosis of the tracheal diverticulum, but often fails as the point of communication with the trachea is commonly narrow and is difficult to visualise. Conventional multi-detector CT only shows the communication of diverticulum with tracheal lumen in 7.8-34.6% of cases \(^12,18,19\).

The recent advent of 320-Multidetector CT (320-MDCT) scanners allows dynamic volume CT of respiratory tract over an anatomical range of 16 cm that allows 4-dimensional
(4D) assessment of airway conditions including laryngeal dyskinesia, tracheomalacia, excessive dynamic airway collapse, and tracheal varices \textsuperscript{19, 20, 21, 22}.

The aim of this retrospective study was to assess the efficacy of 4-D CT in the diagnosis of the tracheal diverticula.
Methods and Materials

4-D CT’s of the larynx and trachea have been performed to investigate for symptoms of laryngeal dysfunction and dynamic airway collapse in our institution since April 2009. These studies were approved by the research ethics committee at our institution.

4-Dimensional CT (4D-CT)

CT studies of the larynx and trachea were performed over 1 breathing cycle using the Toshiba Aquilion One CT (Toshiba Medical Systems, Tokyo, Japan) with a 320-slice detector ray to scan a 16-cm Z-axis 'volume'. Parameters were 80 kVp, 150-350 mA and 350 ms gantry rotation speed. The radiation doses were in a range of approximately 1.5 - 4 milli-Sieverts (mSv). Integrated CT software was used to reconstruct continuous dynamic multiplanar images, and dynamic 3-D laryngeal airway images using volume rendering technique that could be viewed in 4-dimensional cine mode.

Image review and measurements

All these CTs were independently reviewed a radiologist and a respiratory fellow. Patients with paratracheal air cysts were identified. The locations, maximal and minimal dimensions of the air-cysts and their communications with trachea measured with electronic calipers, and corresponding respiratory phase were recorded.

Statistical analysis

A Bland-Altman plot with a priori limits of agreement at ± two standard deviations was used to assess agreement between the two readers (XLSTAT 2013.3, Addinsoft SARL, Andernach, Germany). The Wilcoxon signed-rank test was used to test for differences between inspiratory and expiratory data (IBM SPSS 20.0.0, Armonk, New York, USA).
Results

Reader agreement

The agreement of the two readers' measurements was compared with Bland-Altman plots. No systemic bias was found. Both readers detected the same number of paratracheal cysts and number of tracheal communications.

Patients

During the study period, 617 patients had 4-D CT’s of neck for the investigation of suspected laryngeal dysfunction. 14/617 patients (2.3%) (4 male and 10 female, age range 53 - 79, mean age of 54) had CT evidence of paratracheal air-cystic lesions.

Characteristics

Communications with the trachea were seen in all these air-cyst lesions, confirming the diagnosis of tracheal diverticula. 15 paratracheal air-cystic lesions were found in these 14 patients, with two discrete lesions found in one patient. 13/15 were located at the levels of T1 and T2 vertebrae posterolaterally on the right, with the other two just superior to the first tracheal ring and at T4 vertebral level on the right.

Narrow-based diverticula

The majority of patients (11/15) had narrow-based diverticula (Figure 1). These communications measured between 0.2-1.0 mm (mean: 0.3 mm) in diameter.

There is expansion of tracheal diverticula on expiration, particularly in AP and vertical dimensions (Figure 2).

Table 1: Narrow-based diverticula (n=11)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Inspiration (mean ±SD)</th>
<th>Expiration (mean ±SD)</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior-posterior (mm)</td>
<td>8.0±5.3</td>
<td>8.3±5.4</td>
<td>0.012</td>
</tr>
<tr>
<td>Transverse (mm)</td>
<td>5.7±3.7</td>
<td>5.7±3.2</td>
<td>0.445</td>
</tr>
<tr>
<td>Vertical (mm)</td>
<td>7.7±4.8</td>
<td>8.5±5.2</td>
<td>0.015</td>
</tr>
</tbody>
</table>
Estimated volume $324.3\pm575.7$ $378.4\pm688.2$ 0.062 (mm$^3$)$^+$

*Expiration and inspiration (2-tailed Wilcoxon signed rank test); $^+0.5 \times$ anterior-posterior $\times$ transverse $\times$ vertical

Broad-based diverticula

There were 4 broad-based tracheal diverticula (Figure 3). The communications measured between 2.5-4.5 mm (mean: 3.5 mm) in diameter. The diverticula are larger on expiration. Statistical testing was not reliable as the numbers were too low to achieve significance.

Table 2: Broad-based diverticula (n=4)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Inspiration (mean $\pm$SD)</th>
<th>Expiration (mean $\pm$SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior-posterior (mm)</td>
<td>4.0$\pm$1.2</td>
<td>5.0$\pm$1.3</td>
</tr>
<tr>
<td>Transverse (mm)</td>
<td>3.3$\pm$1.5</td>
<td>3.4$\pm$1.0</td>
</tr>
<tr>
<td>Vertical (mm)</td>
<td>5.4$\pm$0.6</td>
<td>6.3$\pm$1.2</td>
</tr>
<tr>
<td>Estimated volume* (mm$^3$)$^+$</td>
<td>34.9$\pm$14.1</td>
<td>50.8$\pm$10.2</td>
</tr>
</tbody>
</table>

*Expiration and inspiration (2-tailed Wilcoxon signed rank test); $^+0.5 \times$ anterior-posterior $\times$ transverse $\times$ vertical

Tracheal communication

All four wide diverticular communications with trachea could be seen throughout the breathing cycle. Only 3/11 narrow communications with trachea could be visualized throughout the entire breathing cycle. The remaining eight narrow communications could only be detected at some time point during the expiratory phase when the diverticula and neck were generally larger (Figure 4).

Out of the 11 narrow communications, six were straight while five were very tortuous (Figure 5).

History review
Review of the medical files showed six patients had symptoms potentially attributable to diverticula. These included cough, choking sensation, episodic stridor, hoarse voice, and recurrent pneumonia (Figure 6 and Figure 7).
Fig. 1: Axial image from the non-contrast dynamic CT of larynx in a 41 year old demonstrated an irregular tracheal diverticulum (black arrow) lying posterolateral to the trachea on the right at T2 level which has a straight narrow communication with the trachea (black arrow head) (Figure 1a). Virtual bronchoscopy reviewed the orifice of the communication at the internal surface of the trachea (blue arrow) (Figure 1b).

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**Fig. 3:** Axial images from the non-contrast dynamic CT of larynx in a 72 year old female demonstrated a large wide-necked irregular tracheal diverticulum (arrows) posterolaterally on the right at T1 level.

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Fig. 2: Coronal reconstructed images using volume rendering technique with air being displayed in blue color from non-contrast dynamic CT of larynx in a 55 year old female revealed the change in size of the tracheal diverticulum (arrows) during the breathing cycle. This diverticulum markedly increased in size during expiration (Figure 2b) when compared to that during inspiration (Figure 2a). The images could be viewed in cine mode, and therefore, it was technically easy to detect the largest and smallest size and the exact stages of the breathing cycle when these happened.

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Fig. 4: Coronal reconstructed cine images of trachea only using volume rendering technique with air being displayed in blue color from non-contrast dynamic CT of
larynx in a 35 year old female demonstrated 2 diverticula (arrow head for the superior diverticulum and arrow head for the inferior diverticulum). Both diverticula had straight communications with the trachea. The neck of the superior diverticulum could only be seen at the expiratory phase. The communication with trachea for the inferior diverticulum could be seen in both inspiratory and expiratory phases, but was larger in size during expiration. Similarly, the sizes of both diverticula were larger during expiration.

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**Fig. 5:** Coronal reconstructed images using volume rendering technique with air being displayed in blue color and esophagus in orange color from non-contrast dynamic CT of larynx in a 55 year old female showed a very narrow tortuous 'thread-like' communication (arrow head) between the tracheal diverticulum and the adjacent trachea.

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Fig. 6: CXR (Figure 6a) of a 60 year old male demonstrated repeated right lower zone pneumonia secondary to infected mucous aspiration from a tracheal diverticulum (arrow). The diverticulum was confirmed on volume rendering CT image (Figure 6b) which also had a very narrow tortuous communication with trachea.

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Fig. 7: Coronal reconstructed images of trachea using volume rendering technique in a 45 year old female demonstrated a large tracheal diverticulum which caused pressure / choking symptom. The diverticulum and its communication with trachea were larger on expiration (Figure 7b) as compared to inspiration (Figure 7a).
Conclusion

To our knowledge, this is the first study to utilize the 4-D capability of a 320-slice CT to assess tracheal diverticula. 87% of tracheal diverticula in our series show some degree of expansion during expiration and shrinkage during inspiration, with an average increase of 45.9% in volume from inspiration to expiration. The change in size during respiration would be related to the patent communication between the diverticulum and airway.

In previous studies of tracheal diverticula found on conventional CT, communications with tracheal lumen were visualized in 7.8-34.6% of cases.\textsuperscript{2,15,23} The communications were detected in all 15 diverticula in our series although eight of the communications were only detectable at some points during expiratory phase. We believe that the much greater rate of detection of communications in our series is due to the fact that the dynamic changes in size of tracheal diverticula and their necks during the respiratory cycle can be readily appreciated on the 4-D viewing of images.

Five tracheal communications had very tortuous appearances and this has not been previously described in the literature. 4/5 of these tortuous communications can only be seen during expiration which probably explains why this phenomenon has not been described previously in series with conventional CT.\textsuperscript{12,18,19}

Limitations of our study include a relatively small sample size and that the patient population was limited to those experiencing respiratory symptoms requiring CT investigation. The small total numbers of tracheal diverticula found limits the statistical significance of some of our findings, making it difficult to compare between groups of diverticula e.g. wide and narrow-necked or symptomatic and asymptomatic.

CONCLUSION

The diagnosis of tracheal diverticula can be difficult on conventional static CT as most communications are not readily detected. The 4D-CT can be a valuable tool in diagnosing tracheal diverticula by improving the detection of their communications with the trachea and their change in size during respiration. It is the first time in literature that dynamic changes of tracheal diverticula, the visualization of some of these communications only in certain time points during the breathing cycle and some of these communications being very narrow and tortuous been reported.
References


