Yonago Acta medica 1996;39:183–187

Dynamic Study of the Tracheal Cavity by Fast MRI with Coughing in Patients with Tracheomalacia

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Fast magnetic resonance imaging (MRI) with coughing was performed in 3 patients with tracheomalacia (TM) and 10 healthy volunteers, and its usefulness was evaluated. Twenty serial images were obtained using two-dimensional-turbo fast low angle shot (FLASH) sequences and the image data were transferred to a graphic workstation connected on-line. The maximum and minimum cross-sectional areas of the trachea were measured during deep breathing (forced expiration and inspiration) and during coughing, and the collapsibility index (CI) = [(maximum cross-sectional area – minimum cross-sectional area)/maximum cross-sectional area] × 100 (%) was calculated. In the healthy volunteers, CI was 36 ± 15% (mean ± SD) during forced expiration and inspiration and 48 ± 15% during coughing, and the difference was not significant. In the TM patients, it was 68 ± 6% and 85 ± 5%, respectively, with the value during coughing being significantly higher (*P* = 0.019). CI was significantly higher in the TM patients than in the normal volunteers both during forced expiration and inspiration (*P* = 0.006) and during coughing (*P* = 0.002). Fast MRI with coughing may facilitate the evaluation of the tracheal collapsibility in TM.

Key words: dynamic study; fast MR imaging; trachea; tracheomalacia

Tracheomalacia (TM) is defined as marked respiratory collapse of the trachea and main bronchi due to their increased collapsibility (Baxter and Dunbar, 1963). This condition is occasionally misdiagnosed as bronchial asthma because of stridor or neuropathy due to a suspicion that there is laryngeal obstruction and occasional syncope (Kwong et al., 1993). Occurrence of marked collapse of the trachea in TM patients during coughing has been known (Johnson et al., 1973). With the recent introduction of fast MRI with a scanning time of 0.2 s or less, dynamic imaging of mobile parts of the body has become possible (Jaeger et al., 1995). In this study, we examined the usefulness of fast MRI with coughing in the evaluation of TM.

Abbreviations: CI, collapsibility index; CT, computed tomography; FLASH, fast low angle shot; FOV, field of view; MRI, magnetic resonance imaging; TE, echo time; TI, inversion time; TM, tracheomalacia; TR, repetition time

Subjects and Methods

The subjects were 10 healthy volunteers and 3 patients who were suspected of having TM on the basis of clinical symptoms and chest X-ray findings, and were definitively diagnosed by bronchoscopy with coughing. They consisted of 8 males and 5 females and ranged in age from 17 to 68 years (mean 48 years). The clinical background and the data of spirograms of the 3 patients with TM are summarized in Table 1. All subjects gave written consent to participate in the studies after full explanation of its nature.

Fast MRI

Imaging procedure

MRI was performed using a 1.5 Tesla superconducting MR system (Magnetom Vision, Siemens, Erlangen, Germany) using a body coil.

The subjects were placed in the supine position, and transaxial images perpendicular to the posterior wall of the trachea were obtained by two-dimensional-turbo-FLASH sequences. The scanning level was fixed at 1 cm below the upper margin of the aortic arch, and serial images were obtained 10 min after the administration of Gd-DTPA. Scanning parameters were as follows: repetition time (TR), 3.5 ms; echo time (TE), 1.7 ms; inversion time (TI), 2 ms; flip angle (FA), 8˚; field of view (FOV), 250 × 250 mm; imaging matrix, 128 × 128; slice thickness, 6 mm; signal averaging, 1; and temporal resolution, 10 images per 2 s. Twenty serial images were obtained.

Analysis of MR images

The image data acquired were transferred to a graphic workstation (Titan II, KGT, Tokyo, Japan) connected on-line with the MRI system, and the software used for imaging processing was an application visualization system (AVS: AVS Inc., Waltham, MA).

Basic evaluation: A phantom experiment was performed to adjust the image display conditions incorporated in the graphic work station. The signal intensity of MRI was normalized to 1-byte data (0–255), and signal intensity levels were determined. The maximum intensity was defined as level 255, and the minimum intensity as level 0, and signals of level 0 to level 50 were displayed as images. The cross-sectional areas of the lumens of 5–55 cc injectors with known cross-sectional areas were measured under the above image display conditions, and the accuracy of this technique was tested. A regression line with a correlation coefficient of 0.987 was obtained.

The maximum and minimum cross-sectional areas of the tracheal lumen were measured in the subjects under the image display conditions tested by this phantom experiment.

Clinical evaluation: The maximum and minimum cross-sectional areas of the tracheal lumen were measured during forced expiration and inspiration and during coughing. The collapsibility index (CI) was calculated as [(maximum cross-sectional area – minimum cross-sectional area)/maximum cross-sectional area] × 100 (%). Differences in CI in the normal volunteers and TM patients between the period of forced expiration and inspiration and the period of coughing were examined by Student's *t*-test. A P value of less than 0.05 was regarded as significant.

Results

Among the 10 normal volunteers, CI (mean ± SD) was 36 ± 15 % (10–63%) during forced

Table 1. The clinical background and the data of spirograms in the patients with tracheomalacia

		Case number		
		1	2	3
Age	(year)	44	67	68
Sex		Male	Male	Female
Smoking history		1 pack/day × 20 years	1 pack/day × 45 years	Nonsmoker
VC	(L)	2.97	3.39	1.87
%VC	(%)	95.5	112.6	83.5
FVC	(L)	2.52	3.05	1.55
%FVC	(%)	86.0	101.3	69.2
FEV1.0	(L)	1.25	1.41	0.92
FEV1.0%	(%)	49.6	46.2	59.4
Cardiorespiratory disease		Asthma	Asthma, hypertension	Asthma, angina pectoris

$FEV_{1.0}$, forced expivatory volume in one second; $FEV_{1.0}$%, $FEV_{1.0}$/FVC × 100; FVC, forced vital capacity; %FVC, FVC percent of predicted; VC, vital capacity; %VC, VC percent of predicted.

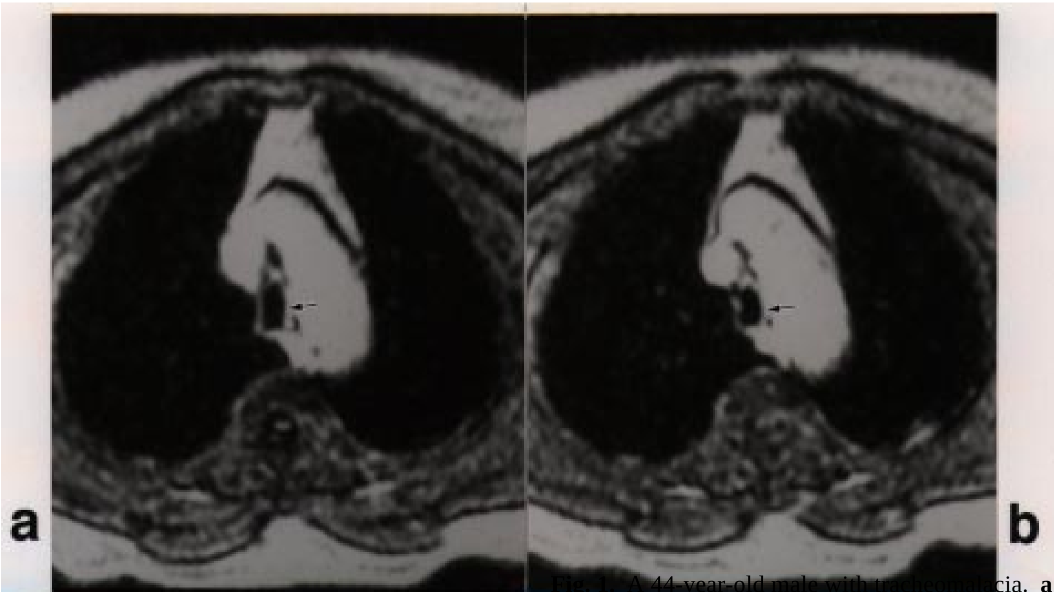


Fig. 1. A 44-year-old male with tracheomalacia. **a:** During forced inspiration. **b:** During forced expiration. **c:** During coughing. Narrowing of the trachea (arrow) is clearer during forced expiration than during forced inspiration but is even more notable during coughing.

expiration and inspiration and 48 ± 15% (25–83%) during coughing with no significant difference. Among the TM patients, it was 68 ± 6 (63–75%) during forced expiration and inspiration and 85 ± 5% (80–90%) during coughing, with the value during coughing being significantly higher (P = 0.019). CI was significantly higher for the TM patients than for the normal volunteers during both forced expiration and inspiration (P = 0.006) and coughing (P = 0.002).

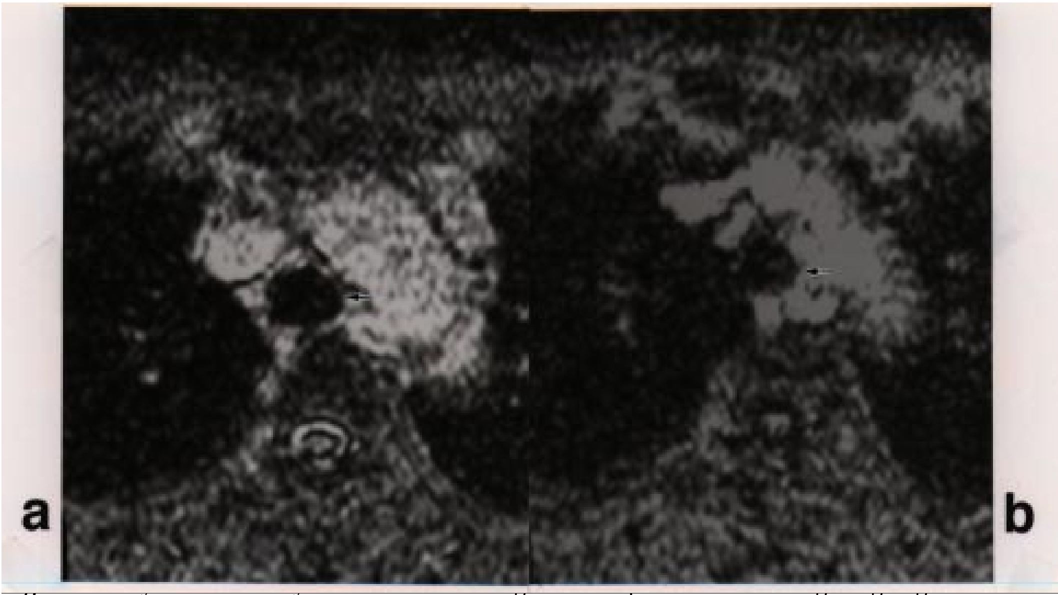
Discussion

A definitive diagnosis of TM has been made by dynamic radiography of the trachea (Johnson et al., 1973), bronchoscopy with coughing (Ikeda et al., 1992), or computed tomography (CT) (Gamsu and Webb, 1982, 1983; Vock et al., 1984; Stern et al., 1993; Kwong et al., 1993; Trigaux et al., 1994).

Dynamic radiography has a high temporal resolution but, unlike tomography, causes overlapping of images. There is also the problem of radiation exposure.

Bronchoscopy with coughing is an invasive examination and requires tedious preparation including local anesthesia. Also, as the bronchoscope is a single-eye device, measurement of the depth is impossible, and quantitative evaluation based on objective measurement of the images is difficult (Ikeda et al., 1992).

In many reports using dynamic CT, the tomographic plane and level were fixed, and serial images of the trachea were obtained from forced expiration to forced inspiration (Kimura



difference is observed in the cross-sectional area of the trachea (arrow) during forced expiration as compared with during coughing.

et al., 1990; Stern et al., 1993; Trigaux et al., 1994). CT of the trachea during coughing has not been reported. As demonstrated in this study, tracheal narrowing during forced expiration and inspiration is less notable than that during coughing. Therefore, collapsed lesions may be masked in scanning only during forced expiration and inspiration (Ikeda et al., 1992). Also, CT is appropriate for measurement of the tracheal diameter (Vock et al., 1984; Stern et al., 1993), but it has the problems of X-ray exposure and limitation of the tomographic plane to the transverse view (Suto et al., 1993).

Fast MRI has excellent temporal resolution in addition to advantages such as the freedom of selection of the imaging plane, high contrast resolution, and minimum invasiveness (Suto et al., 1993). In this study, the scanning time was 0.2 s per scan, and images could be obtained without blurring even during coughing.

In this study using fast MRI, the difference between the collapsibility during forced expiration and inspiration and that during coughing was not significant in the normal volunteers but was significant in the TM patients (Figs. 1 and 2). CI was significantly higher in the TM patients than in the normal volunteers both during forced expiration and inspiration and during coughing.

These findings indicate that marked expiratory collapse may be induced by coughing in TM patients due to weakness of the trachea unlike normal individuals. Also, fast MRI with coughing may reveal slight differences between TM patients and normal individuals that escape detection by MRI during forced expiration and inspiration.

In this paper, a dynamic study was performed in the same transverse plane as CT because, in the coronal plane, which allows evaluation of the entire length of the trachea, the trachea may be displaced out of the scanning area due to anteroposterior movement of the thorax if thin slices are used, and because saber sheath type lesions such as in Case 1 are difficult to evaluate in the sagittal plane. Therefore, by our present method of dynamic MRI studies using the transverse plane, similar to the CT studies, we don't make the best use of the freedom of selection of the scanning plane permitted in MRI, and further evaluation may be needed considering technical aspects such as the scanning procedure and selection of the scanning plane. Furthermore, how quantitative data such as those of the CI used in this study are related to various clinical data of TM remains unknown because of the insufficiency of the number of cases. Further accumulation of cases may be needed to solve these problems.

In conclusion, fast MRI with coughing is expected to facilitate evaluation of the collapsibility of the trachea in TM.

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(Received August 19, Accepted September 14, 1996)