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【 ORIGINAL ARTICLE 】

A Computed Tomographic Assessment of Tracheostomy Tube Placement in Patients with Chronic Neurological Disorders: The Prevention of Tracheoarterial Fistula

Maki Tateyama[1], Masatoshi Konno[1], Rina Takano[1], Koichi Chida[1], Hiroya Rikimaru[2] and Keiji Chida[1]

Abstract:

Objective Tracheoarterial fistula (TAF) is a rare but devastating complication of tracheostomy caused by pressure necrosis from the elbow, tip, or over-inflated cuff of the tracheostomy tube. The incidence of TAF is reportedly higher in patients with neurological disorders than in those without such disorders. To evaluate the incidence of and factors contributing to the misalignment of tracheostomy tubes in bedridden patients with chronic neurological disorders.

Methods We retrospectively assessed three-dimensionally reconstructed serial computed tomography (CT) images to see if the tip of the tube made contact with the tracheal wall and if the main arteries were running adjacent to the tube's elbow, tip or cuff.

Results The tip of the tube was in contact with the tracheal wall in 14 of the 30 patients assessed. Among them, the tip was adjacent to the innominate artery in eight, the aortic arch in three and an aberrant right subclavian artery in one. In one patient with the tube tip adjacent to the aortic arch and the other four patients, the cuff of the tube was adjacent to the innominate artery across the tracheal wall. Patients with the tube tip in contact with the anterior tracheal wall had a significantly greater cervical lordosis angle than those without contact ($p<0.05$).

Conclusion More than half of tracheostomized patients with chronic neurological disorders had a latent risk of TAF. The variability in the location of the innominate artery, anomalies of the aortic arch, and skeletal deformities may therefore be contributing factors.

Key words: chronic neurological disorders, tracheostomy, tracheoarterial fistula, multiplanar reconstruction CT, lordosis

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Introduction

Patients with advanced neurodegenerative and neuromuscular disorders frequently need tracheostomy because of progressive hypoventilation and/or bulbar dysfunction, which can causes recurrent aspiration pneumonia. Tracheoarterial fistula (TAF) is generally rare (0.3-0.7%) but is the most serious complication of tracheostomy, and it carries an extremely high mortality in the absence of aggressive surgical intervention (1-4). While TAF reportedly occurs most commonly within the first three weeks after tracheostomy (4), a comparable incidence of TAF has also been reported in patients with long-term tracheostomies (1). In addition, the incidence of TAF is reportedly higher in patients with neuromuscular disorders and central nervous system disorders than in those without such disorders (5, 6). Thus, preventing TAF is an important issue in managing patients with advanced neurological disorders who require a chronic tracheostomy.

[1]Department of Neurology, National Hospital Organization Iwate Hospital, Japan and [2]Department of Radiology, National Hospital Organization Sendai Medical Center, Japan
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Correspondence to Dr. Maki Tateyama, tateyama.maki.jm@mail.hosp.go.jp

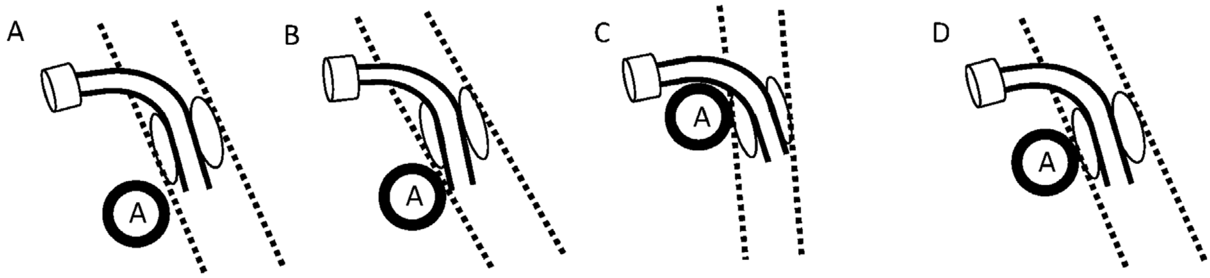

Figure 1. Various alignment patterns of tracheostomy tubes. A: No apparent risk of tracheoarterial fistula. B: The tip of the tracheostomy tube is in contact with the tracheal wall with a major artery adjacent to the tip. C: The elbow of the tracheostomy tube is in direct contact with a major artery in the extratracheal space. D: A major artery runs adjacent to the tracheostomy tube cuff across the tracheal wall.

Numerous case reports have ascribed TAF to pressure necrosis of the main arteries, especially the innominate artery, caused by the tracheostomy tube's elbow, tip, or over-inflated cuff (1-3). Thus, TAF may be able to be prevented if the elbow and tip of the tracheostomy tube are not adjacent to the main arteries and if the cuff pressure is kept low enough when the cuff is adjacent to the main arteries. However, few studies have explored the prevention of TAF (7, 8). In the past decade, we and others have showed that assessing the spatial relationship between the tracheostomy tube, trachea and major arteries using computed tomography (CT) is useful for not only diagnosing TAF but also preventing it (9-13).

In the present study, we retrospectively evaluated the alignment of tracheostomy tubes and adjacent arteries in bedridden patients with chronic neurological disorders using three-dimensionally reconstructed serial CT images. We studied the incidence and type of misalignment of the tubes as well as factors contributing to such misalignment.

Materials and Methods

Patients

We reviewed the available medical records and chest or neck CT scans acquired between January 2012 and March 2016 at the National Hospital Organization Iwate Hospital. We found records for 30 hospitalized patients with chronic neurological disorders who had a tracheostomy and had undergone chest or neck CT.

Multidetector CT

A 16-slice multidetector CT (MDCT) scanner (Activion 16; Toshiba Medical Systems, Tokyo, Japan) was used. The technical parameters were as follows: a detector row configuration of 1 mm, pitch 11 for neck and 15 for chest, reconstruction increment 1 mm and section thickness 1 mm. An X-ray tube (120 kV) was used in all examinations. Scans were performed with the patient in the supine position and breathing spontaneously or using an artificial ventilator.

Image analyses

For the thin-section multiplanar reconstruction (MPR) images, thin-section transverse images and MPR images in the coronal and sagittal planes (1- to 2- mm slice intervals) were reviewed at a width of 300 HU and level 25 HU window settings with paging on a viewer (XTRECK view; J-MAC Systems, Sapporo, Japan). The window, level and opacity of the volumes were subjectively selected to optimize the visualization of the tracheostomy tube.

Neck CT was performed on 18 patients to evaluate the alignment of the tubes. In these patients, axial, sagittal and coronal images were obtained using MPRCT. The other 12 patients underwent chest CT imaging that included the tracheostomy tubes in order to evaluate pulmonary disorders, such as pneumonia. In these patients, sagittal and coronal images were simply reconstructed on a FAINWORKS server (J-MAC Systems) using transverse images with 2-mm-thick slices at a slice interval of 2 mm.

The alignment of the tracheostomy tubes was assessed using serial images of sagittal, coronal and transverse sections in each patient. We evaluated whether or not the tip of the tube was in contact with the tracheal wall and whether or not major arteries ran adjacent to the tip of the tube in these patients (Fig. 1A and B). In addition, we evaluated whether or not a major artery was in direct contact with the elbow of the tube in the extratracheal space or ran adjacent to the cuff across the tracheal wall (Fig. 1C and D). Two neurologists assessed the images independently. If the evaluation of the two examiners did not coincide, a third neurologist assessed the images, and the final judgment was determined by the majority.

We also analyzed the cervical lordosis angle in the patients who underwent neck CT. The cervical and thoracic sagittal alignment was assessed by angles made by lines drawn tangential to the posterior border of the C3 and T3 vertebral bodies using reconstructed sagittal images. Medical records were reviewed, and data were collected for the patient age, weight and gender; the diagnosis and duration of the illness; the manufacturers and size of the tracheostomy tubes; and any measures taken to correct misalignment of the tubes.

Statistical analyses

Statistical analyses were performed using the GraphPad Prism 7 software program (MDF, Tokyo, Japan). Statistical significance was analyzed by the Mann-Whitney U test and Fisher's exact test. Comparisons were considered to be statistically significant if $p<0.05$. The study was approved by the Institutional Review Board of the National Hospital Organization Iwate Hospital.

Results

Patients

The diagnoses of the 30 patients studied included amyotrophic lateral sclerosis (ALS) (in 8), multiple system atrophy (MSA) (in 9), Parkinson's disease (PD) (in 2), myotonic dystrophy (DM) (in 2), spinal muscular atrophy (in 1), Huntington disease (in 1), mitochondrial myopathy (in 1), spinocerebellar atrophy (in 1), multiple sclerosis (in 2), myasthenia gravis (in 1), and anoxic encephalopathy (in 2). All the patients were bedridden and received tube feeding, requiring total assistance. There were 20 men and 10 women, and the mean age was 63.9±11.6 years. The duration of illness was 12.9±11.1 years, and the duration between tracheostomy and the CT evaluation was 53.4±43.0 months. Thirteen patients used artificial positive pressure ventilators. The tracheostomy tubes were provided by four manufacturers (Medtronic Japan, Tokyo, Japan; Koken, Tokyo, Japan; Smith Medical, Minneapolis, USA; Senko Medical Instrument Mfg., Tokyo, Japan). The length of the tubes ranged from 61 to 81 mm.

Alignment of the tracheostomy tubes

In 14 patients, the tip of the tube was in contact with the tracheal wall: anteriorly in 11 patients (A group), posteriorly in 2 patients (P group) and laterally in 1 patient. In the A group, the tip was in close proximity to a vessel in nine patients: the innominate artery in seven (Fig. 2A, B and G) and the aortic arch in two. In the P group, the tip was adjacent to the right aortic arch in one and an aberrant right subclavian artery in one (Fig. 2D-F, H and I). In the patient with lateral wall contact, the tip was adjacent to the innominate artery. In the patient with the tube tip in contact the tracheal wall anteriorly adjacent to the aortic arch, the cuff of the tube was also adjacent to the innominate artery. This patient had prominent scoliosis. Among the 16 patients without contact between the tip of the tube and the tracheal wall, the cuff of the tube was adjacent to the innominate artery across the wall of the trachea in 4 patients. No patients had direct contact between the tube elbow and arteries in the extratracheal space, and we noted no patients with a high-riding innominate artery.

There was no significant relationship between the frequency of the tube tip contacting the tracheal wall and the tube length, patient illness, duration of illness, length of time the tracheostomy had been in place and the patient's gender, age or weight. Positive pressure artificial ventilators were more frequently used in the patients with contact between the tube tip and the anterior tracheal wall than in those without anterior contact ($p<0.05$). Twenty two patients underwent two or more chest or neck CT scans. Among these patients, we noted no sequential changes in the spatial relationship between the tracheostomy tube and the tracheal wall with disease progression unless severe lung disorders, such as empyema, atelectasis and pneumothorax, altered the location of the trachea.

The Cervical lordosis angle was assessed in the 18 patients who underwent neck CT. Patients with contact between the tube tip and anterior tracheal wall had a greater cervical lordosis angle than those without anterior contact ($p<0.05$) (Fig. 3). Furthermore, there appeared to be a greater degree of lordosis among the patients with any contact of the tip with the wall, whether anteriorly, posteriorly, or laterally, than among those without such contact. However, this difference was not statistically significant ($p=0.051$). There were 5 patients (2 with MSA and 1 each with ALS, PD and mitochondrial myopathy) with advanced cervical lordosis in whom the angles exceeded 40°. The tip of the tube was in contact with the tracheal wall in all five (anteriorly in four, posteriorly in one). These findings suggest that advanced cervical lordosis might be one of the factors involved in misalignment of tracheostomy tubes.

Measures to reduce the risk of TAF

Given the CT findings, several measures were taken to prevent the tip of the tracheostomy tube from making contact with the tracheal wall adjacent to the arteries, including placing the tubes more shallowly using gauze cushions at the tracheostomy orifice or replacing the tube with a shorter one, one with a more appropriate angle or a custom-made tube (Fig. 2C). The cuff pressure was maintained under 25 mmHg with a measuring instrument in all patients.

Discussion

In 1924, Schlaepfer reviewed 115 cases of TAF in the literature. The most common injury site was the innominate artery (in 83 cases), followed by the common carotid artery (in 5 cases) (14). In the 1960s, direct injury to the innominate artery by the elbow of the tracheostomy tube was recognized as a cause of TAF, leading investigators to advocate avoiding the low placement of the tracheostomy (15, 16). Subsequently, compression necrosis of the tracheal wall and the adjacent innominate artery by an over-inflated cuff or the tube tip was reported as another mechanism causing TAF (4). This notion was supported by a cadaver study revealing that the tube tip, cuff or both were adjacent to the innominate artery when the tube was placed normally between the second and third tracheal rings (8). Although numerous case reports of TAF have been published for over

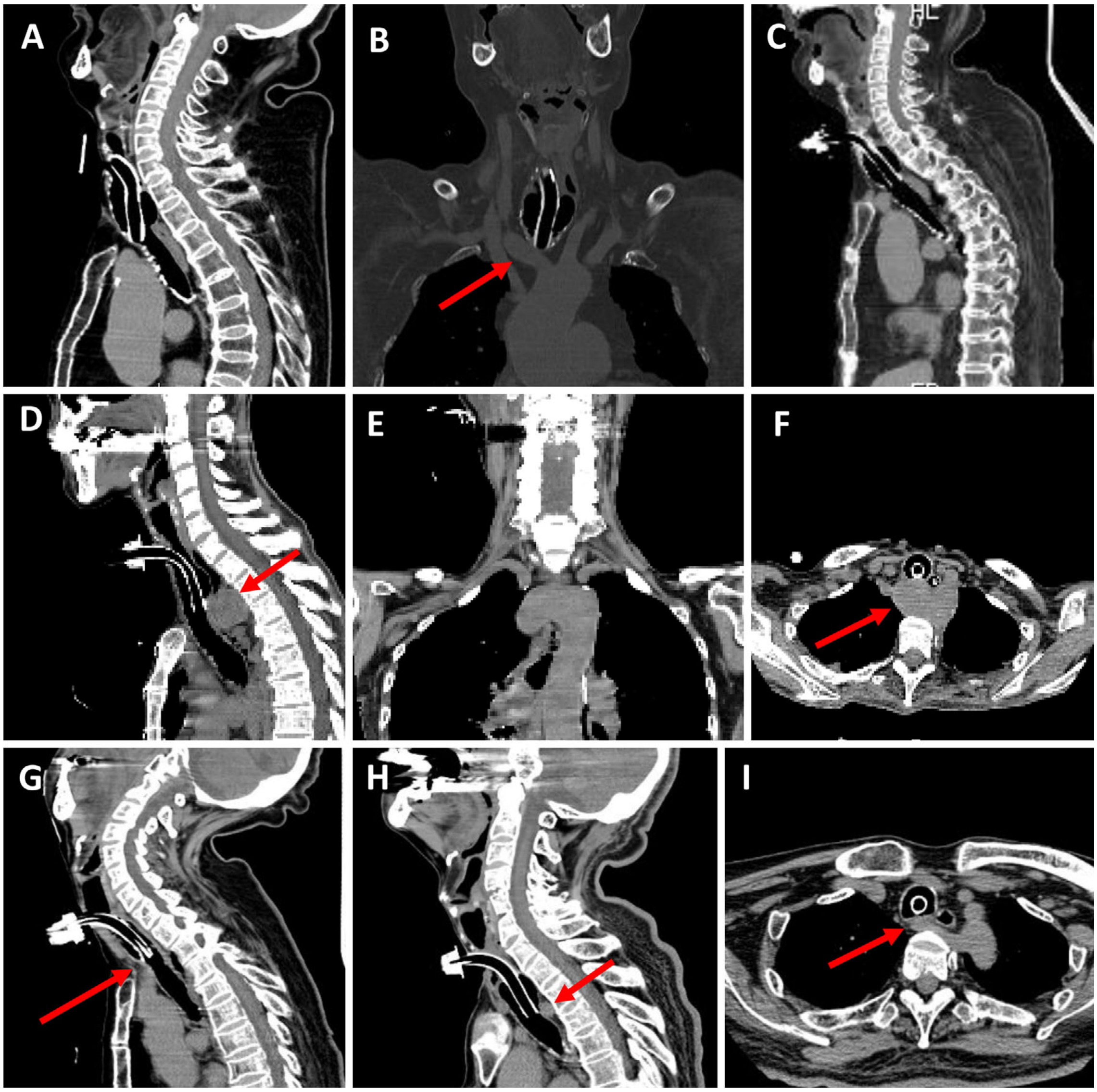

Figure 2. CT findings. A-C: Patient 1. A, B: The tip of the tracheostomy tube is in contact with the anterior wall of the trachea adjacent to the innominate artery (arrow); C: A replacement tracheostomy tube customized for the patient has resolved the misalignment; D-F: Patient 2. The tip of the tracheostomy tube is contact with the posterior tracheal wall adjacent to a right aortic arch (arrows); G: Patient 3. The tip of the tracheostomy tube is in contact with the anterior tracheal wall adjacent to the innominate artery (arrow) in a patient with prominent cervical lordosis; H, I: Patient 4. The tip of the tracheostomy tube is in contact with the posterior tracheal wall adjacent to an aberrant right subclavian artery (arrows).

the past century, TAF has not been eradicated, despite technological improvements in tracheostomy tubes. One reason for this might be the paucity of preventive strategies.

In the present study, the tip of the tracheostomy tube was in contact with the tracheal wall in approximately half of our patients with chronic neurological disorders. In 8 of this series of 30 patients (27%), the tip was adjacent to the innominate artery. In a study of 22 patients with cerebrovascular disorders or brain injury who had tracheostomies, Sung et al. measured the gap between the tracheostomy tube and the innominate artery (TTIG) using an axial-enhanced CT slices (7). They found no measurable TTIG in 6 patients (27%) and categorized these patients as belonging to the high risk group for developing tracheoinnominate artery fistula (7). Although the methods used and the patients studied were different, the findings from the present study and that of Sung et al. indicate that around a quarter of patients with chronic tracheostomy may be at risk of erosion of the innominate artery by the tube tip. In addition, the tube cuff was adjacent to the innominate artery in five of our patients. In these patients, maintaining the appropriate cuff pressure is particularly important. The blood flow of the human trachea is impaired at 22 mmHg and totally obstructed at 37 mmHg (17). Therefore, keeping the cuff pressure below 25 mmHg will help prevent significant tracheal damage (17). Of note, however: no patients had the elbow of the tube in

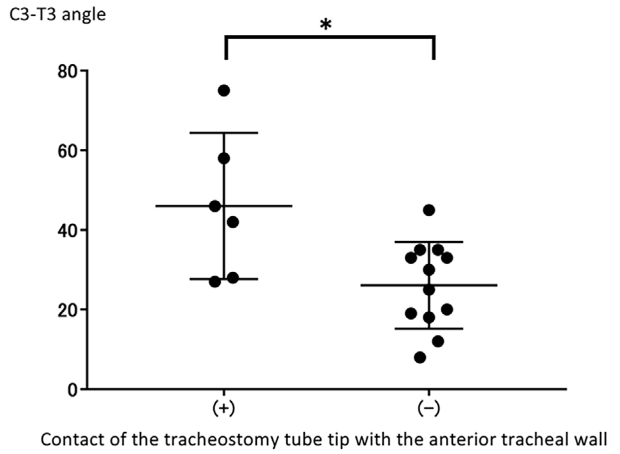

Figure 3. Neck lordosis and tracheostomy tube placement. Based on the C3-T3 angle, a greater degree of cervical lordosis is significantly associated with contact of the tracheostomy tube tip with the anterior tracheal wall ($p<0.05$).

direct contact with the innominate artery. The reason for this may be that the tracheostomy was done at the appropriate tracheal ring in each patient. The available evidence therefore shows that, although the reported incidence of tracheo-innominate artery fistula is low, a significant number of bedridden patients with chronic neurological disorders who require tracheostomy carry some risk of erosion of the tube into the innominate artery, given the considerable natural variation in the location of the artery (8). It is noteworthy that there were unexpected anatomic variations in the major arteries of the 2 patients in our study with tube tips making contact with the posterior wall near the arteries; 1 had an aberrant right subclavian artery and 1 a right aortic arch, of which the general incidence is estimated to be 0.04-0.1% (18). This finding suggests that, despite their rarity, the possibility of vascular anomalies should also be considered when assessing the risk of TAF (2, 10).

We found that patients with contact between the tip and anterior tracheal wall generally had more advanced cervical lordosis than those without anterior contact. Saito et al. reported that skeletal deformity, including scoliosis and lordosis, is involved in the misalignment of tracheostomy tubes in patients with Duchenne muscular dystrophy (5). These findings suggested that, in patients with neurodegenerative and neuromuscular disorders, the alignment of tracheostomy tubes should be monitored based on the progression of skeletal and postural abnormalities.

In the present study, artificial positive pressure ventilators were more frequently used in patients in whom the tube tip was in contact with the tracheal wall anteriorly than in those without anterior contact. We have no adequate explanation for this finding and further investigations in a larger patient group may be necessary. Until such points are clarified, careful manipulation of the tracheostomy tube is needed in patients with chronic neurological disorders using artificial positive pressure ventilators.

Several limitations associated with the present study warrant mention. First, we evaluated patients who were lying supine only at rest, a position in which many spend most of their time. However, these patients required suctioning several times or more a day and their positions had to also be laterally changed in order to prevent the occurrence of bedsores. No information is yet available on the spatial relationship between the tracheostomy tube, trachea and arteries during these movements (7). Because the exact mechanisms causing TAF, particularly in patients with chronic tracheostomy, are not fully elucidated, further investigation is required to determine whether or not such procedures and changes in the position contribute to tracheal wall injury by the tracheostomy tube. Second, we did not evaluate the appearance of the tracheal wall by bronchoscopy, as this modality was not available at our hospital.

The present study suggests that patients with chronic neurological disorders are fairly commonly at risk of TAF in terms of close proximity between the tracheostomy tube and arteries around the trachea. The considerable natural variation in the location of the innominate artery, anomalies of the aortic arch and its branches and skeletal deformities common in such neurological disorders may all contribute to the latent risk of TAF. Comorbid conditions, such as inflammation and malnutrition, might also be involved in the risk of TAF (1, 2). Correcting these factors as well as adjusting the tracheostomy tube to a presumably safer position and maintaining the appropriate cuff pressure may be the best way at present of reducing the risk of TAF. Serial three-dimensional CT allows for the evaluation of the spatial relationship between the tracheostomy tube, trachea and arteries without the use of contrast medium, which facilitates the proper placement of the tube. The image acquisition time of CT is short enough to be tolerable for bedridden patients with chronic neurological disorders with or without mechanical ventilators. Further investigations combining the CT evaluation of the anatomic spatial relationships with a visual inspection of the trachea by bronchoscopy may provide useful information for ensuring the safe management of chronically-placed tracheostomy tubes.

The authors state that they have no Conflict of Interest (COI).

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