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Clinical Article

Is Computerized Tomography Angiographic Surveillance Valuable for Prevention of Tracheoinnominate Artery Fistula, a Life-Threatening Complication after Tracheostomy?

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Objective : The aim of this study was to evaluate the utility of volume-rendered helical computerized tomography (CT) angiography focusing tracheostomy tube and innominate artery for prevention of tracheoinnominate artery fistula.

Methods : The authors retrospectively analyzed 22 patients with tracheostomy who had checked CT angiography. To evaluate the relationship between tracheostomy tube and innominate artery, we divided into three categories. First, proximal tube position based on cervical vertebra, named "tracheostomy tube departure level (TTDL)". Second, distal tube position and course of innominate artery, named "tracheostomy tube-innominate artery configuration (TTIC)". Third, the gap between the tube and innominate artery, named "tracheostomy tube to innominate artery gap (TTIG)". The TTDL/TTIC and TTIG are based on 3-dimensional (3D) reconstruction around tracheostomy and enhanced axial slices of upper chest, respectively.

Results : First, mean TTDL was 6.8±0.6. Five cases (23%) were lower than C7 vertebra. Second, TTIC were remote to innominate artery (2 cases; 9.1%), matched with it (14 cases; 63.6%) or crossed it (6 cases; 27.3%). Only 9% of cases were definitely free from innominate artery injury. Third, average TTIG was 4.3±4.6 mm. Surprisingly, in 6 cases (27.3%), innominate artery, trachea wall and tracheostomy tube were tightly attached all together, thus have much higher probability of erosion.

Conclusion : If low TTDL, match or crossing type TTIC with reverse-L shaped innominate artery, small trachea and thin TTIG are accompanied all together, we may seriously consider early plugging and tube removal.

Key Words : Tracheoinnominate artery fistula · Tracheostomy · Computerized tomography angiography · Imaging study · Complication.

INTRODUCTION

Tracheostomy is one of the oldest described surgical procedures, dating back to 2000BC. The success rate was extremely low, and prior to 1,800, only 50 life-saving tracheostomies were reported[9]. Presently, tracheostomy is the most effective procedure in the critically ill patients to assist in long-term ventilatory support[7,10]. To prevent procedure-related complications, one should be familiar with surface anatomy, approach through exact midline, control bleeders completely, and avoid violation of adjacent pleura. Most of complications can be speculated and managed effectively at the early period of procedure. Among various complications, the tracheoinnominate artery fistula (TIAF) is one of the most fulminating "disasters".

The frequency rate of TIAF around 0.3-0.7 per cent may appear insignificant; however, a mortality rate approaching 100 per cent in cases void of aggressive intervention[4]. This fistula probably start as simple contact-erosion and repeated stimuli weaken the trachea-vessel inter-space gradually. If we can visualize these key structures, i.e. tracheostomy tube, innominate artery from aorta, trachea itself and the inter-space between trachea and innominate artery, we can also predict the possibility of fistula formation and verify high risk group. However, despite the importance of this relationship, there have been no studies focusing this subject, probably because invasive procedures such as aortography are not routine screening procedure.

The aim of this study was to evaluate the efficacy of computerized tomography (CT) angiography for visualization of key structures described above, to propose objective measurement categories and to select high risk group of TIAF.

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MATERIALS AND METHODS

The following protocol was approved by Institutional Review Board (IRB) of our hospital.

Tracheostomy procedures

Twenty-two patients who underwent tracheostomy between January 2008 and May 2009 were included in this study and were reviewed retrospectively. The causes of neurologic disorders were as follows; 11 subarachnoid hemorrhages (SAHs), 9 infarctions and 2 contusions. The average age of patients were 65 years (range, 36-87 yr), and male : female ratio was 12 : 10. All of the tracheostomies were performed electively at the intensive care unit, by senior neurosurgical residents. To prevent inadvertent hypoxic damage or hurried neglect, intubations were preceded if possible. The patient's neck was extended and important surface landmarks, such as thyroid cartilage, cricoid cartilage and sternal notch, were marked. After infiltration of lidocaine, vertical incision was made between cricoid cartilage and sternal notch. Stepwise dissection and elevation of thyroid isthmus made the trachea visible. To maintain median route of dissection, manual palpations were performed frequently. At the exact midline of second and third tracheal ring, "T" or "I" shaped incision opening was made and through the everted rings, the tracheostomy tube was inserted cautiously. In some cases, round removal, rather than incision opening, of tracheal ring was done. The percutaneous procedure was not chosen in any cases.

CT angiography Imaging Technique

For visualization of vascular structures, the sixty-four channels spiral CT (Light speedTM VCT, GE Healthcare, USA) was used. A total of 60 mL of nonionic contrast material (Ultravist, Bayer Healthcare) was injected rapidly (4 mL/sec) by a pressure injector (Stellant CT injector system, Medrad, USA). The contrast bolus tracking was timed to permit imaging the proximal and distal branches of the Circle of Willis. The region of interest was targeted to common carotid arteries at mid-cervical area. At the point of 60 Housefield contrast intensity, rapid 0.625 mm thickness scanning was begun. Using 3-demensional (3D) image software (Advantage Workstation, GE Healthcare, USA), sagittal and coronal maximal intensity projections and surface volume rendering images were taken finally.

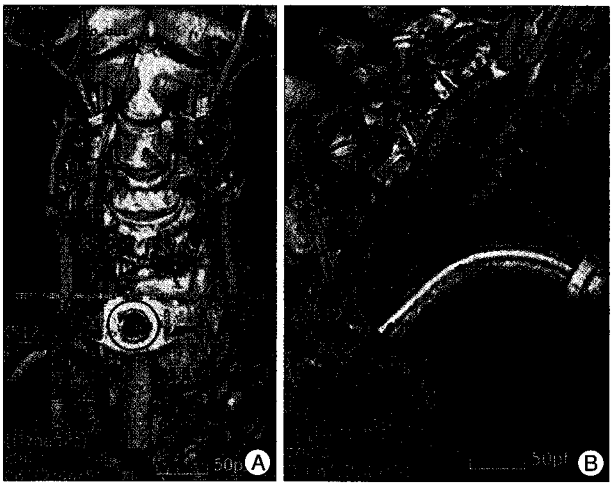

Fig. 1. The method of confirming tracheostomy tube departure level (TTDL). The three dimensional (3D) volume rendering computerized tomography (CT) angiography focusing tracheostomy tube and cervical arteries from aortic arch are chosen. On anteroposterior view (A), the departure level can be checked with reference to cervical vertebra (C6). On lateral view (B), the level can also be confirmed (dotted line). Note L-shaped configuration of innominate artery.

CT angiography based measurement categories

Category #1 : Tracheostomy tube departure level

To check the starting level, i.e. the level of horizontal tracheostomy tube, we introduced tracheostomy tube departure level (TTDL). The 3D reconstructed CT angiography clearly visualized cervical vertebras, carotid arteries, innominate artery and tracheostomy tube. The TTDL was defined as imaginary horizontal line connecting top of tracheostomy tube to cervical vertebra. If the level is at the disc space, point 5 (0.5) is added to upper cervical vertebra (Fig. 1).

Category #2 : Tracheostomy tube-innominate artery configuration

To check the TTIC, we moved our focus to lower level. The lower end of tracheostomy can be visualized well using various computerized techniques such as, rotation, partial cut, re-tracking of the image. The courses of innominate artery showed in wide ranges. To describe the courses and relationship between tracheostomy tube and innominate artery, we divided into three groups. If they were far apart from each other, it was named as "remote" type. If the distal end of tracheostomy tube matched the margin of innominate artery, it was named as "match" type. If the distal end of tracheostomy tube crossed downwardly from the margin of innominate artery, it was named as "cross" type (Fig. 2).

Category #3 : Tracheostomy tube to innominate artery gap

To check exact gap between tracheostomy tube and innominate artery, axial slice of enhanced CT was chosen rather than 3D reconstruction. At the axial cut of upper chest level, tracheal wall, esophagus, tracheostomy tube, innominate artery or major extracranial branches could be verified. The soft tissue between trachea and innominate artery could be also visible. The inter-space gap between tracheostomy tube and innominate artery were measured using Picture Archiving and Communication System (PACS, Maroview ver. 5.3, MAROTECH Inc., Seoul, Korea) (Fig. 3).

RESULTS

The measurement and evaluation results of following categories are summarized in Table 1.

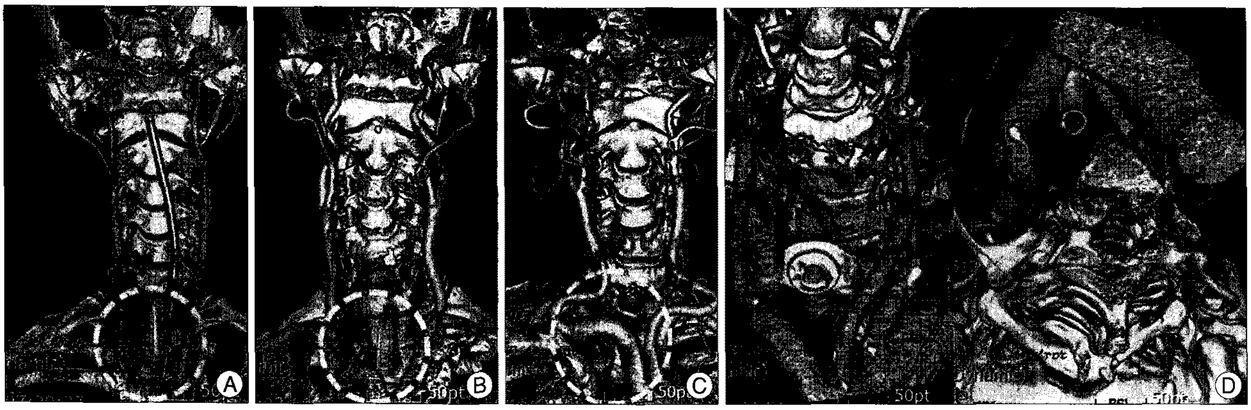

Fig. 2. Evaluation method of tracheostomy tube-innominate artery configuration (TTIC). A : The remote type; the tip of tracheostomy tube is far remote from innominate artery. This type is totally free from innominate artery injury. Note oblique configuration of innominate artery. B : The match type; the tip of tube is at the level of wall of innominate artery. In case of low TTDL, it can convert into cross type. C : The cross type; the tip of tube is far lower than innominate artery, looks like "X" crossing. The cross-sectional area is largest and it has the highest probability of contact erosion. Note reversed L-shape configuration of innominate artery. D : The top (left) or bottom (right) views clarify tracheostomy tube and surrounding arteries.

TTDL to check procedural suitability

Gross visualization of anatomical structures around tracheostomy can be evaluated by tracheostomy tube departure level (TTDL) study (Fig. 1). After 3D rotation, we can check the tube with anterior-posterior, lateral, head to feet and feet to head directions. The trachea is not visible, but with reference to cervical vertebras, the level of tracheostomy can be verified.

The mean TTDL was between C6 to C7 vertebra (C6.8±0.6). In 5 cases (23%), lower than C7 was noted and they might have higher probability to contact innominate artery. The low-lying tracheostomy, common procedural error, could be evaluated by these TTDL results.

TTIC to verify the configuration and relationship between tube and innominate artery

The contact probability could be determined by the course of innominate artery and ending level of tracheostomy. The remote type, separated each other, was only 2 cases (9.1%) (Fig. 2A). These patients had the lowest possibility to occur TIAF. The match type, contact each other, was seen in 14 cases (63.6%) (Fig. 2B). The cross type, X shaped intersection, was noted in 6 cases (23.7%) (Fig. 3). Most innominate arteries showed oblique running course from its aortic origin (Fig. 2A), but in 3 cases (13.6%), "reversed L-shape" configuration was noted (Fig. 2C). Its importance is much higher probability of contact tracheostomy tube despite of appropriate TTDL. The ages of patients with this configuration were 65, 87 and 72. Not all old patients showed this risky configuration. Conversely, some patients showed "L-shaped" configuration and these patients, despite of low lying tracheostomy, made the contact probability low (Fig. 1). The 3D rotation view was very useful to clarify the tube position from top or bottom view (Fig. 2D).

TTIG to evaluate contact status between trachea wall and innominate artery

Enhanced, thin sliced axial cut of upper chest can demonstrate upper dome of aortic arch, major cervical arteries including innominate artery, round tracheal wall and inside tracheostomy tube. With this study, the diameter of trachea, running course of innominate artery and soft tissues around trachea could be evaluated. At the cut slice of innominate artery and inside tracheostomy tube, the mean TTIG was measured as 4.3±4.6 mm. However, TTIG showed higher variability among the patients (0-11.3 mm). In 6 patients (27.3%), due to tight adhesion between innominate artery and tracheal wall, TTIG could not be measured with our PACS system and described as TTIG of 0 mm. In these patients, repeated mechanical stimulations, such as suction procedures, onto tracheostomy tube may directly propagate into innominate artery. Therefore, these patients could be categorized as highest risky group of TIAF (Fig. 4). The TTIG was less than 2 mm in 10 patients (45.5%).

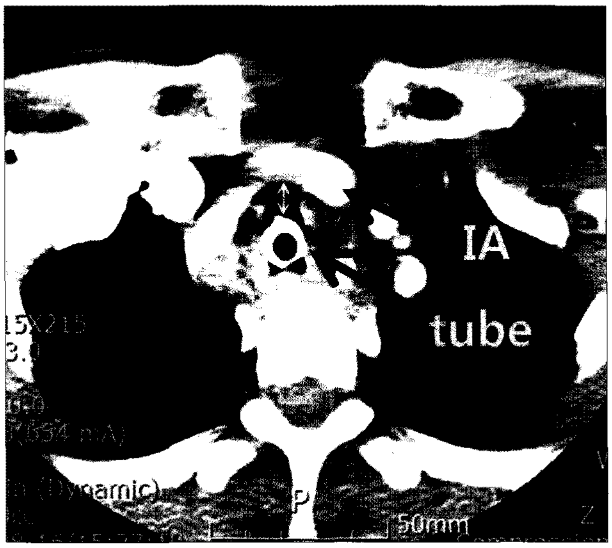

Fig. 3. Method of measuring tracheostomy tube to innominate artery gap (TTIG). The axial slice of enhanced CT of upper chest focusing tracheostomy tube and innominate artery (IA) is shown. The size of trachea and surrounding soft tissue are clearly visualized. In this patient, the TTIG is 9.9 mm (bidirectional arrow).

Table 1. Clinical and CT angiographic characteristics of patients with tracheostomy

No.	Age (yr)	Sex	Diagnosis	TTDL*	TTIC type	TTIG (mm)	Risk evaluation
1	65	F	Infarction	6.5	Cross	0	Very high
2	85	F	Infarction	7	Match	0	Very high
3	73	M	Infarction	7.5	Match	4.85	Low
4	38	F	SAH	6	Remote	7	Low
5	87	F	SAH	6	Cross	4.1	Low
6	61	F	Infarction	6	Cross	8.2	Very low
7	71	M	Contusion	7	Match	2.7	Low
8	64	F	SAH	7.5	Match	1.2	High
9	84	M	SAH	7	Match	0.9	Very high
10	65	M	Infarction	7	Cross	0	Very high
11	42	M	SAH	7.5	Match	5.17	Low
12	79	M	Infarction	6	Match	0	Very high
13	67	F	SAH	6.5	Match	5.38	Low
14	69	F	SAH	6.5	Match	11.25	Very low
15	49	M	SAH	7.5	Match	5.7	Low
16	36	M	SAH	7	Match	2	High
17	69	M	Infarction	7	Match	0	Very high
18	51	M	SAH	7	Cross	9.9	Very low
19	72	F	Infarction	6	Cross	0	Very high
20	71	M	Contusion	7.5	Match	5.3	Low
21	63	F	Infarction	6.5	Match	2	High
22	61	M	SAH	6	Remote	18	Very low

*The numeral of TTDL is level of cervical spine. If the level is at the disc space, point 5 (0.5) is added to numeral of upper cervical vertebra. CT : computerized tomography, SAH : subarachnoid hemorrhage, TTDL : tracheostomy tube departure level, TTIC : tracheostomy tube-innominate artery configuration, TTIG : tracheostomy tube to innominate artery gap

Fig. 4. Dangerous attachment of tracheostomy tube onto innominate artery (immeasurable TTIG). In this patient, the genu portion of tracheostomy tightly attaches onto innominate artery. Note small trachea and thin soft tissue surrounding trachea. The PACS system fails to measure TTIG (arrow).

DISCUSSION

The overall incidence of hemorrhage after tracheostomy is 3%. About 10% of this postoperative hemorrhage is known as TIAF. The reported incidence of TIAF in tracheostomy has ranged from 0% to 1%, and averages 0.3%[1]. But, the mortality rate is nearly 100%, even when surgical intervention is undertaken. TIAF has been reported as early as 30 hours after tracheostomy and up to several months after, with a peak incidence between the first and second week[5]. About 75% of TIAF present within 3-4 weeks after tracheostomy placement[6]. This means some period is needed to erode the tracheal wall, intervening tissue between innominate artery and tracheostomy tube. Some conditions such as long-term ventilation, excessive movement of tracheostomy, high airway pressure requiring high cuff pressure, sepsis, radiation therapy, steroid therapy or other immunosuppressive conditions can contribute to TIAF formation[3].

The mechanism of injury in TIAF after tracheostomy is pressure necrosis from the elbow, cuff, or tip of the tracheostomy tube. Anatomically, the innominate artery crosses the trachea at the ninth ring anteriorly, but there is a wide range (6-13th ring)[8]. The safest target for tracheostomy is between the first and third tracheal ring but in practical point of view, these may be difficult to indentify in patients with short wide necks. Nowadays, the more recent practice of using high-volume low-pressure cuffs, with routine monitoring of cuff pressures, has probably reduced the incidence[2]. The necrosis of trachea at "cuff" portion can be prevented by low pressure cuff with pressure monitoring. But, the "elbow" type necrosis can occur by either low-lying tracheostomy or high-riding, inverted-L shaped innominate artery. In summary, the biggest problem of TIAF is that its occurrence is dependent on procedural technique as well as patients' anatomic variations.

To the best of our knowledge, there are no reports visualizing the tracheostomy tube and innominate artery with 3D CT angiographic manners. To prevent TIAF, we can adopt CT angiographic findings stepwise. First, to confirm procedural appropriateness (right level of tracheal penetration), TTDL should be checked. With CT angiography, except for calcified tracheal wall, we can't visualize tracheal wall. However, with reference to cervical vertebra, we can effectively check the level of tracheostomy. Tracheostomy performed at relatively low level is exposed to much higher risk to be close to the artery[2]. The course of innominate artery can be checked by the second category, TTIC.

The value of TTIC is 3-D oriented, rapid categorization of patterns between tracheostomy tube and innominate artery; such as remote, match and cross. To prevent TIAF, the safest way is no contact between them. Our results clearly showed that 9% of patients had remote pattern. In other words, only about 10% of patients with tracheostomy tube are totally free from TIAF. Most of patients showed match type (63.6%) and these results indicate the importance of correct level of TTDL. If TTDL is lower than usual, match types can be converted to cross type. It is also surprising that substantial number of patients (23.7%) had cross type. This type has larger cross sectional area of contact than match type, with higher risk. The volume rendering, 3D oriented TTIC can't demonstrate tracheal wall itself, so exact risk evaluation can be checked by the third category, TTIG.

Unlike to TTDL or TTIC, TTIG is based on not 3D but on 2D oriented axial cut images. Most valuable significance of TTIG is excellent visualization of trachea and peritracheal soft tissues, the true barrier between tube and innominate artery. The diameter of trachea and thickness of peritracheal soft tissue show great individual variation. If one patient have cross type TTIC with large TTIG, and the other patients have match type TTIC with small TTIG, then we can categorize the latter patient as riskier group. We think TTIG has a higher value for risk evaluation, compared to TTIC. It is impressive that immeasurable (TTIG of 0 mm) TTIG was detected in surprisingly many patients (23.7%). In this group, we should pay our special attention to check any bleeding episode or infection evidence around tracheostoma.

Our study has several limitations. First, the CT study is static one and can't reflect possible changes of the neck structures including trachea. Also, neck motion, swallowing, suction procedure can migrate or compress some structures. To evaluate these variables, we should check CT angiography in every condition. However, it can be harmful to vital organs in the neck, especially the thyroid gland. Second, despite the high frequency of contact type TTIG, the incidence of TIAF was extremely low. So, the contact itself can be considered as only minor contributor to complicated TIAF. Other factors such as cuff pressure and infection are also thought to be important for TIAF formation.

CONCLUSION

Despite some limitations, our study based on CT angiography is considered to be useful to review procedure appropriateness (by TTDL), to verify diverse configuration of innominate artery (by TTIC) and to measure exact gap space (by TTIG). CT angiography is a noninvasive, simple, commonly using diagnostic tool with acceptable side effects. Based on our results, we recommend careful handling of tube and early planning of removal in cases with TTDL, match or crossing type TTIC, small trachea and thin TTIG.

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