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Pharynx volume derived from three-dimensional computed tomography is associated with difficult intubation in spinal deformity surgery

A retrospective cohort study

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Abstract

Spinal abnormality surgery, including surgery for ankylosing spondylitis and idiopathic scoliosis, can present significant challenges to anesthesiologists because of the potential difficult airway. The bedside screening tests routinely used to detect difficult airways are highly variable. Pharynx volume calculated using three-dimensional (3D) computed tomography (CT) may play a role in predicting difficult airways.

We conducted a retrospective cohort study on patients (aged ≥14 years) who received orthopedic surgery for ankylosing spondylitis/idiopathic scoliosis under general anesthesia. Volume of the pharynx air space was calculated through volume rendering technique by 3D reconstruction of patients' cervical spine CT. Patients were divided into 2 groups according to their pharynx volume, pharyngeal volume lower than 16 mL (n = 11) and equal or higher than 16 mL (n = 13).

Pharynx volume in low volume group was 10.4 ± 3.6 mL (n = 11), and the counterpart in high volume group was 20.8 ± 5.5 mL (n = 13). The incidence of difficult intubation was significantly higher in low pharynx volume group than in high pharynx volume group (54.5% (6/11) vs 7.6% (1/13), $P = .023$). Bedside screening tests including modified Mallampati test, inter-incisor gap and thyromental distance, or radiological variables such as anterior neck soft tissue thickness to vocal cords were not different between the 2 groups.

Smaller pharynx volume played an important role in difficult airways for patients undergoing orthopedic surgery for ankylosing spondylitis/idiopathic scoliosis.

Abbreviations: 3D = three-dimensional, CT = computed tomography.

Keywords: difficult airway, pharynx volume, spinal abnormality surgery, three-dimensional computed tomography

1. Introduction

Spinal abnormality surgery, including surgery on ankylosing spondylitis or idiopathic scoliosis, can present significant challenges to the anesthesiologists as a consequence of the potential difficult airway.[1] Although bedside screening tests are routinely used to recognize patients at high risk of having a difficult airway, their accuracy is not satisfactory. Commonly used bedside screening tests included Mallampati test, modified Mallampati test, Wilson risk score, thyromental distance, sternomental distance, mouth opening test and the upper lip bite test. A systematic review involving 844,206 participants from 133 studies revealed that all bedside screening tests are with relatively low sensitivities and high variability.[2]

There are many efforts to understand the underlying mechanism to cause difficult airways from the perspective of the airway anatomy. Ultrasonic assessment is used to measure arm-chin distance, mandible length, and thickness of soft tissue from skin to thyroid.[3] There are also radiological variables to identify the distance between C1 and C2 spinous processes and up to 21 parameters were compared between easy and difficult intubation patients.[4] But these findings are inconclusive partly due to limitations of techniques. All these measurements were derived from 2-dimensional images but patients' airway

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The study protocol (2021-452) was approved by the Ethics Committee of Peking University People's Hospital, Beijing, China (Chairperson Prof S. Mu), which waived the requirement for informed consent because of the retrospective design.

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are three-dimensional (3D). The improvement and widespread diffusion of 3D segmentation software allowed a more detailed visualization of pharyngeal air space and enabled the calculation of volume.[5] Computed tomography (CT) results can be used for ameliorating intubation procedures.

Pharynx volume is important in anesthesiology for correctly assessing intubation procedures. Size of pharynx represents a sensitive issue in clinical and surgical anatomy: pharyngeal geometry is important for managing intubation.[6] The pharyngeal size and shape are linked to the success rate in ventilation procedures. Several studies published 3D segmentation of pharyngeal volume with patients in supine position.

Given the average reference value of the volume of oropharynx and laryngopharynx was 16 mL,[7] we hypothesize that patients with pharynx volume less that 16 mL would have a higher incidence of difficult intubation. Hence, we performed this retrospective cohort study about the incidence of difficult intubation in patients undergoing ankylosing spondylitis/idiopathic scoliosis orthopedic surgeries.

2. Materials and Methods

We conducted a retrospective cohort study on patients (aged ≥14 years) who received orthopedic surgery for ankylosing spondylitis/idiopathic scoliosis under general anesthesia. Patients were divided into 2 groups according to their pharynx volume, pharyngeal volume lower than 16 mL and equal or higher than 16 mL, which was calculated through cervical 3D CT. The incidence of difficult airway was compared between 2 groups. The study was approved by Peking University People's Hospital Institutional Review Board (2021-452), and informed consent was waived because of the retrospective design. This article complied with the STROBE guidelines for a cohort study.

2.1. Study protocol

We searched the anesthesia information management system of Peking University People's Hospital for patients (aged ≥14 years) undergoing orthopedic surgery for ankylosing spondylitis/idiopathic scoliosis between June 2018 and May 2020. Cervical, thoracic and lumber spine CT scans were performed to identify spinal segments involved in ankylosing spondylitis/idiopathic scoliosis.

Difficult intubation was defined by the American Society of Anesthesiologists as existing when "a conventionally trained anesthesiologist experiences difficulty with facemask ventilation of the upper airway, difficulty with tracheal intubation, or both." In our study difficult airway was identified according to the anesthesia records, which was reported as an adverse event as part of the institutional quality control program. A difficult airway was marked in the Anesthesia Information Management System when more than 3 attempts of intubation or 3 intubation tools were applied. Types of laryngoscopes used and whether the patients were intubated awake were recorded by reviewing the anesthesia records.

Bedside screening tests results were also recorded in in the Anesthesia Information Management System, including modified Mallampati test, inter-incisor gap, thyromental distance, and neck mobility. Radiological variables on cervical CT images were quantified by a radiologist (author Bei An). Anesthesia records and medical charts were reviewed to collect bedside airway assessment results and anesthetic features.

2.2. 3D CT reconstruction of structures and morphologic analyses

All CT scans were acquired from 256-row spiral CT scan (GE Medical Systems, Milwaukee, WI, USA) at 120 kV and 200 to 500 mA, with 0.625-mm slice thickness and 512 × 512 matrix. While taking the CT scan, the patients were awake in supine position, with the head in neutral position and the mandible in intercuspal position. The projection line was parallel to the canthomeatal line.[7]

Pharynx could be divided into nasopharynx, oropharynx, and laryngopharynx. Anatomical limits were defined as follows: oropharynx was bounded superiorly by a plane passing through posterior nasal spine, and anteriorly by a plane passing through posterior nasal spine and perpendicular to the hard palate. The lateral and posterior boundaries were the lateral and posterior pharyngeal walls, respectively. Laryngopharynx was delimited inferiorly by a transverse plane passing through the inferior edge of the fourth cervical vertebra and perpendicular to the median sagittal plane.[7]

The 3D reconstruction of pharynx was accomplished through GE AW VolumeShare™ 7. Three-dimensional reconstruction of the pharyngeal air space is described in the supplementary material (Supplemental Digital Content 1, http://links.lww.com/MD/H625). The pharynx air space delineated by above definition was extracted by the discrepancy of CT value between soft tissues and the air space. And then the volume of the air space of pharynx was calculated through volume rendering technique, which is described in the supplementary material (Supplemental Digital Content 2, http://links.lww.com/MD/H626).

2.3. Statistical analysis

The incidence of difficult intubation was compared between groups. Normality distribution of different variables was tested by Kolmogorov–Smirnov test. Continuous variables are expressed as mean ± standard deviation or median with the first (Q1) and third quartile (Q3). Categorical variables are expressed as percentages. Between-group differences were evaluated using the independent t test or Mann–Whitney *U* test for continuous variables and the chi-square test or Fisher exact test for categorical variables, as appropriate. All *P* values were 2 tailed, and $P < .05$ was considered statistically significant. Statistical analysis was performed using the SPSS 22.0 statistical software package (SPSS Inc., Chicago, IL).

2.4. Sample size calculation

The study was initially powered as a retrospective cohort study. Given the existing evidence that the average pharyngeal volume being 16 mL, patients were divided into 2 groups, that is, pharyngeal volume lower than 16 mL and equal or higher than 16 mL.[7] The overall incidence of difficult intubation (defined as laryngoscopic view Cormack and Lehane grading 3 and 4) was 5%.[8] The incidence of difficult intubation in ankylosing spondylitis/idiopathic scoliosis patients is 50% according to previous clinical experiences. When $\alpha = 0.05$, $\beta = 0.2$, 12 patients were needed in each group. A patient was assigned Cormack and Lehane score 3 if only the epiglottis is seen (and no part of the glottis), while a score of 4 was assigned when the epiglottis cannot be viewed.[9] For patients who underwent awake fiberscope-guided intubation, a direct laryngoscopic examination was performed to identify the Cormack and Lahane score before using flexible fiberscopes.

3. Results

There were 66 patients who met the inclusion criteria during the study period. Sixteen patients were excluded due to age less than 14 years of old. Another 25 patients were excluded due to no documentation of cervical spine CT. Finally there were 24 patients included in this study (Fig. 1).

Pharynx volume was calculated through 3D reconstruction technique of the air space volume of pharynx (Fig. 2). The mean pharynx volume was 16 mL, which was in accordance

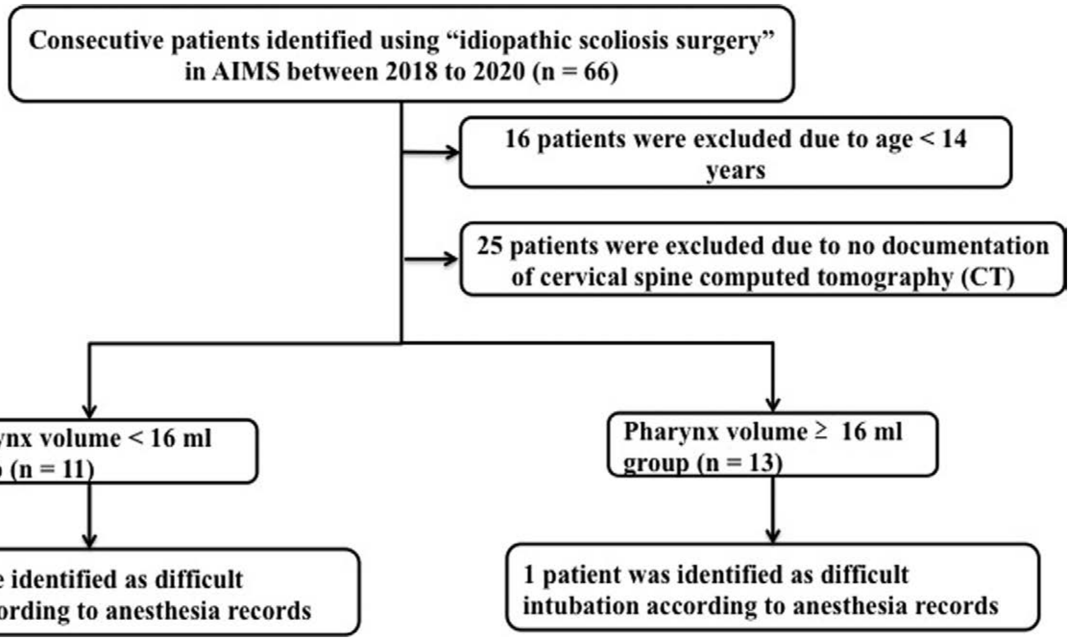

Figure 1. Trial flow. Patients (aged ≥14 years) who received orthopedic surgery for ankylosing spondylitis/idiopathic scoliosis under general anesthesia were included in this retrospective study.

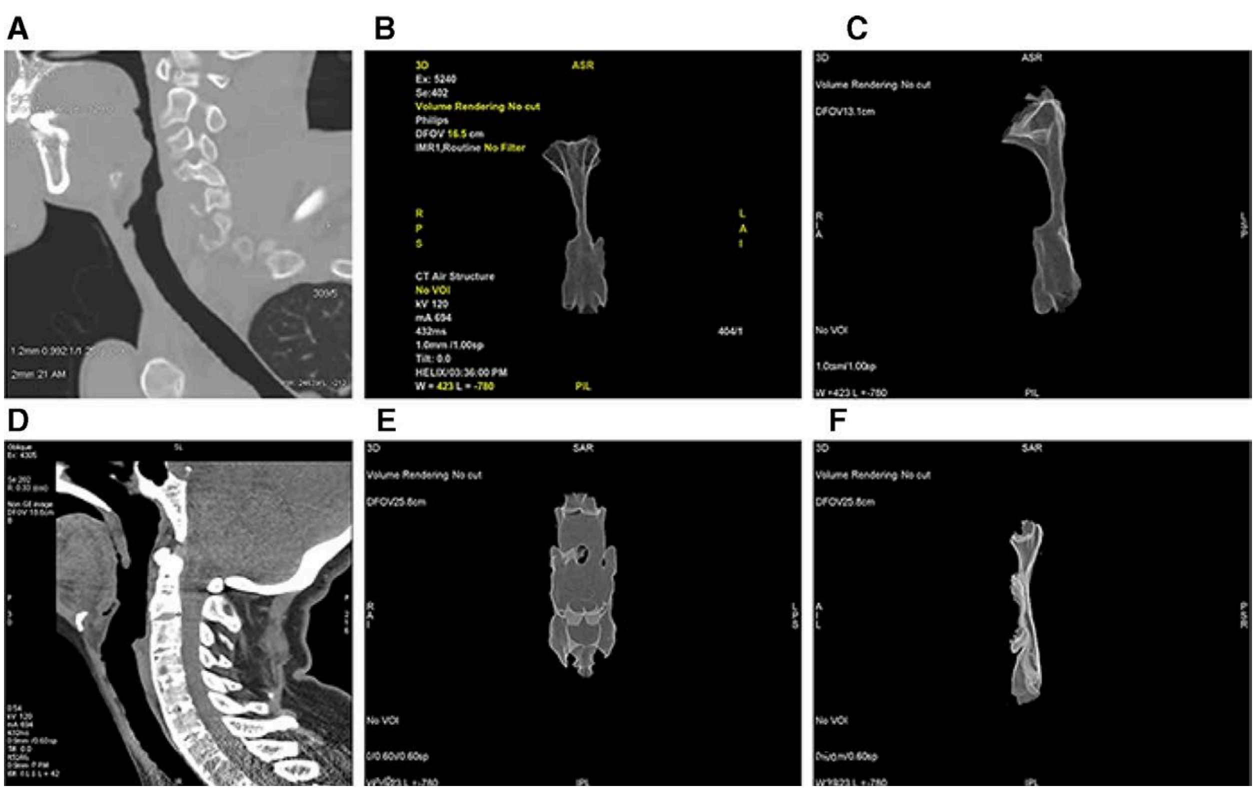

Figure 2. 3D reconstruction and calculation of pharynx volume. Panel A, B and C belongs to a patient with pharynx volume of 4.4 mL, who encountered difficult intubation. Panel D, E and F belongs to a patient with pharynx volume of 30 mL, who had no difficulty when intubated. A and D = Sagittal view of the upper airway. B and E = Coronal plane of the 3D pharynx. C and F = Sagittal plane of the 3D pharynx.3D = three-dimensional.

with Gibelli.[7] Therefore patients were divided into 2 groups, lower than 16 mL and equal to or higher than 16 mL. The incidence of difficult intubation was significantly higher in low pharynx volume group than in high pharynx volume group (54.5% (6/11) vs 7.6% (1/13), $P = .023$). Pharynx volume in patients who encountered a difficult airway was 10.3 ± 5.3 mL (n = 7), and the counterpart in patients who did not have difficult airways was 18.3 ± 6.3 mL (n = 17). There was statistically significant difference in pharynx volume for patients with and without difficult airway ($P < .001$). In our study, the cutoff value 16 mL detected the possibility of difficult airway with specificity of 70.6% and sensitivity of 85.7%. Among the 7 difficult airway cases, 5 patients underwent awake intubation using flexible fiberscopes. The other 2 patients were intubated using Airtraq® or Macintosh laryngoscope with more than 3 attempts, the duration between injection of induction agents to intubation was 33 minutes and 31 minutes respectively.

Bedside screening tests including modified Mallampati score, inter-incisor gap, thyromental distance or percentage of patients with severely limited neck mobility were not different between 2 groups according to the anesthesia records. Radiologic variables obtained through cervical CT including thickness of anterior soft tissue to vocal cords, hyomental distance, altanto-occipital gap or distance between C1 and C2 spinous processes etc were not different between 2 groups (Table 1).

4. Discussion

In our study patients in pharyngeal volume <16 mL had a significantly higher incidence of difficult intubation, which present clues to understand the underlying mechanism of a difficult airway.

A systematic review involving 844,206 patients from 133 studies investigated the sensitivity and specificity of bedside airway screen tests.[2] The index tests which predicted difficult airways included the modified mallampati test >3 points (original or modified; asking a sitting patient to open his mouth and to protrude the tongue as much as possible so that visibility can be determined); Wilson risk score >2 points (including patient's weight, head and neck movement, jaw movement, receding chin, buck teeth); thyromental distance <6.5 cm (length between the chin and the upper edge of Adam's apple); sternomental distance <12.5 cm (length between the chin and the notch between the collar bones); inter-incisor gap ≤3.5 cm; upper lip bite test Class III (lower incisors cannot bite the upper lip)[8]; or any combination of these tests. The average sensitivity ranged from 24% (thyromental distance) to 51% (modified Mallampati test) and average specificity ranged from 87% (modified Mallampati test) to 93% (mouth opening test). These bedside screening tests examined in this review are not well suited for the purpose of detecting unanticipated difficult airways because they missed a large number of people who had a difficult airway.[2]

Defects of anatomy accounts for the difficult intubation. Structurally, the pharyngeal airway is surrounded by soft tissues such as the tongue and lateral pharyngeal wall, which are enclosed by bony structures such as the mandible and the vertebrae. It is self-evident that pharyngeal air space should be big enough to allow visualization of vocal cords and insertion of laryngoscopes and endotracheal tubes. Many imaging techniques have been used for the evaluation and learning the image of pharyngeal airway. Ultrasonography of the airway provided some diagnostic criteria to predict a Cormack and Lehane score 3 or at laryngoscopy, for example, distance from skin to epiglottis >27.5 mm (average value in our study being 35 mm),[10] or anterior neck soft tissue thickness at the level of the vocal cords >23 mm (average value in our study being 10 mm in both groups).[11] Some radiological evaluation also yielded valuable information, such that the hyomental distance <55 mm was associated with difficult laryngoscopy (average value in our study being 33 mm),[12] Atlanto-occipital gap <6.0 mm (average value in our study being 4.4 mm),[13] or ossification of the anterior longitudinal ligament resulting in a narrow pharyngeal space.[14] However the key airway anatomy feature in difficult airway remains inconclusive.

In the last years, literature has increasingly focused on the volumetric assessment of pharynx in its different portions. The improvement and widespread diffusion of 3D segmentation software allowed a more detailed visualization of pharyngeal air space and enabled the calculation of volume.[5] CT has the advantage of allowing quantification of pharyngeal airway and surrounding soft tissues in 3 dimensions, and the measurement of pharyngeal airway is increasingly accurate and sophisticated. 3D segmentation on CT scans represents the ideal condition for a detailed analysis of pharyngeal air space. CT results can be used for ameliorating intubation procedures. Size of pharynx represents a sensitive issue in clinical and surgical anatomy, pharyngeal geometry is important for managing intubation. Low pharynx volume was also related with positional obstructive sleep apnea patients.[15] The pharyngeal size and shape and strictly linked to the success rate in ventilation procedures.[16] In Samra's study, 21 radiological parameters were compared between easy intubation and difficult intubation groups.[4] Only 1 measurement, that is, the distance between the uppermost visible part of the airway and

Table 1

Airway radiological variables and the incidence of difficult airway.

	Pharynx volume <16 mL group (n = 11)	Pharynx volume ≥16 mL group(n = 13)	Statistic	*P* value
Age	25 ± 12	28 ± 16	–0.501	.621
Male (n (%))				
BMI	22.9 ± 5.7	20.4 ± 4.3	1.259	.221
Pharynx volume (mL)	10.4 ± 3.6	20.8 ± 5.5	–5.365	<.001*
Difficult intubation (n (%))	6 (54.5%)	1 (7.6%)	6.331	.023*
Duration of anesthesia (min)	461 ± 169	398 ± 138	0.999	.329
Anterior neck soft tissue thickness at the level of hyoid bone (mm)	16.2 ± 4.9	12.8 ± 4.2	1.850	.078
Anterior neck soft tissue thickness at the level of epiglottis (mm)	37.9 ± 4.2	31.9 ± 11.5	1.631	.117
Anterior neck soft tissue thickness at the level of the vocal cords (mm)	10.3 ± 3.6	9.8 ± 3.9	0.403	.690
Hyomental distance (cm)	33.0 ± 12.7	32.6 ± 8.8	0.101	.921
Atlanto-occipital gap (mm)	4.2 ± 3.4	4.4 ± 1.9	–0.096	.924
Distance between the spinous processes of first cervical vertebra and the second cervical vertebra (mm)	5.6 ± 2.4	7.0 ± 4.3	–0.976	.340
Distance from the antero-inferior border of the fourth cervical vertebra to the antero-superior border of the first cervical vertebra (mm)	63.2 ± 6.4	68.6 ± 10.5	–1.475	.154
Mallampati classification (3–4)	3 (27.3%)	3 (23.1%)	3.752	.290
Inter-incisor gap (<= 3.5 cm)	6 (54.5%)	3 (23.1%)	4.953	.292
Thyromental distance (<6.5 cm)	6 (54.5%)	3 (23.1%)	3.021	.221
Severely limited neck mobility	4 (36.4%)	4 (30.8%)	1.314	.725

BMI = body mass index.
*$P < .05$.

the posterior pharyngeal wall achieved statistical significance, indicating the association between a small pharynx volume and difficult intubation.

In our study, patients in 2 groups had similar bedside screening test results and similar airway radiological variables. The main difference is the pharynx volume and the incidence of a difficult airway. According to the American Society of Anesthesiologists, difficult airways occur due to a number of factors, airway anatomical and physiological variation, endocrine diseases, post-traumatic anatomic structural malformations, foreign body obstruction, jaw fracture and even displacement.[17] Patients in our study did not have these risk factors except pharynx volume variation. Thus a small pharynx volume is associated with difficult airway in our study because bedside tests, other airway parameters or risk factors were not different between patients in two groups.

This study has some limits. Firstly, there is possible variability due to breathing, swallowing, and tongue movements during CT scan. Certain variability must be expected. Secondly, screening with cervical CT and calculating pharynx volume using 3D reconstruction software is not cost-effective in regular patients. It is suitable for patients undergoing spinal abnormality surgery who routinely require spinal CT scan.

In conclusion, pharynx volume played an important role in difficult airway for patients undergoing spinal abnormality surgery including surgery about ankylosing spondylitis/idiopathic scoliosis.

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