Original Article

The utility of the low motion area ratio for the preoperative detection of pleural adhesions: dynamic chest radiography analysis

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Background: Dynamic chest radiography (DCR) is useful for detecting preoperative pleural adhesions, predicting operation time and blood loss, and determining the surgical approach. However, since DCR evaluations are subjective, an objective index was needed. Therefore, we focused on the low motion area (LMA) ratio derived from the objective data obtained through DCR. The purpose of this study was to examine the relationship between the LMA ratio and pleural adhesions, as well as to evaluate its cutoff values, detectability, and overall utility.

Methods: The study encompassed patients who received DCR prior to thoracic surgery from January 2020 to December 2023. The LMA ratio was calculated using an analysis workstation for DCR. Pleural adhesions were defined as adhesions extending to >20% of the thoracic cavity and/or taking >5 min to dissect. The relationship between the presence of pleural adhesions and the LMA ratio was analyzed retrospectively.

Results: A total of 338 patients were analyzed, of whom 65 had pleural adhesions. The median LMA ratio for patients with adhesions was 56.0%, while that of patients without adhesions was 41.5%, which amounted to a significant difference (P<0.001). This was also true in the group of patients with pulmonary comorbidities (56.0% *vs.* 41.0%, P<0.001). When the analysis was limited to the group of patients with a large lung field change rate (>28.2%; n=169), the power of detection using the LMA ratio improved [52.0% *vs.* 36.9%, area under the curve (AUC) =0.748]. When the two groups were further divided according to the extent of adhesion, the LMA ratio was significantly higher for extensive adhesions (49.8% in grade 1, the narrow adhesion, and 66.1% in grades 2–4, the extensive adhesion).

Conclusions: The LMA ratio is a useful objective index for detecting pleural adhesions. Adding the cutoff value of the LMA ratio (approximately 50%) to the conventional criteria may allow for a more reproducible preoperative assessment.

Keywords: Dynamic chest radiography (DCR); low motion area (LMA); pleural adhesion; surgery; lung cancer

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Introduction

Dynamic chest radiography (DCR) is an advanced X-ray imaging method using a flat-panel detector to visualize lung ventilation, diaphragm motion, and blood flow. This procedure can be conducted using a standard X-ray generator, without the need for contrast medium, and at a dose below 1.9 mGy, meeting the International Atomic Energy Agency dose limit for two-view chest radiography (front and lateral) (1,2). DCR can be performed without significant stress to the patient and with low radiation exposure (3-5), and has already been applied to the evaluation and diagnosis of several respiratory and cardiovascular diseases (6-10). We focused on applying DCR in surgery and reported its utility for the preoperative detection of pleural adhesions to predict operation time and bleeding volume, as well as to determine the surgical approach (11). DCR has high specificity (91.0%) and negative predictive value (88.0%) for preoperative detection. Its diagnostic performance was comparable or superior to that of previous reports on the assessment of adhesions using dynamic computed tomography, magnetic resonance imaging, and ultrasound (12-20). However, assessment of DCR using reference frame ratio calculation processing (PL)-mode and lung motion tracking processing (LM)-mode is based on subjective judgment and is strongly influenced by the experience of individual physicians (21,22).

Among the various dynamic image modes provided by DCR, we focused on the low motion area (LMA) ratio in the LM mode, which is an objective index as the ratio of the LMA to the lung field area. We investigated the correlation between the preoperative LMA ratio on DCR and pleural adhesions, in addition to the conventional methods we have reported, and now report the cutoff value, detection performance, and utility. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1247/rc).

Methods

Patients

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Seirei Mikatahara General Hospital (No. 23-02, 2023) and individual consent for this retrospective analysis was waived. Informed consent for the surgery was obtained from each patient before the examinations, and the contents of this study were disclosed to our hospital. This study included patients who underwent DCR prior to surgery between January 2020 and December 2023, with the exclusion of those diagnosed with pneumothorax or mesothelioma due to the presence of cavities or adhesions in the thoracic cavity. All DCR examinations were conducted within three days prior to surgery.

Imaging protocol of DCR

DCR was conducted during respiration using a conventional radiography system (RADSpeed Pro; SHIMADZU, Kyoto, Japan) paired with a flat-panel detector (AeroDR fine; Konica Minolta, Tokyo, Japan). Patients were instructed to inhale and exhale in accordance with normal tidal breathing.X-ray exposure parameters included a tube voltage of 100 kV, tube current of 80 mA, pulsed X-ray duration of 6.3 ms, and a source-to-image distance of 2 m. A filter composed of 2.8 mm Al and 0.1 mm Cu was used to eliminate soft X-rays. The exposure time was approximately 14 seconds, with a pixel size of 200 µm × 200 µm, matrix size of 4,248×4,248, and a total imaging area of 43.2 cm × 43.2 cm. Images were captured in 16-bit grayscale with signal intensity corresponding to the incident exposure on the X-ray detector. Dynamic images were obtained at 15 frames per second, synchronized with pulsed X-rays to minimize radiation exposure, resulting in an entrance surface dose of about 1.7 mGy.

Image analysis

DCR generates multiple dynamic images, which were analyzed with specialized software (Konica Minolta Inc., Tokyo, Japan) on a standalone workstation (Windows 10 Enterprise, Microsoft, Redmond, WA, USA; Intel® Core™ i5-7500 CPU, 3.40 GHz; 8 GB RAM). Representative DCR images and their corresponding analysis are shown in *Figure 1*. DCR (*Figure 1A*) was originally a simple dynamic imaging modality that could be used to calculate the lung field change rate using dedicated software. In the bone suppression processing (BS) mode (*Figure 1B*), the clavicle and ribs are erased, while PL (*Figure 1C*) and LM (*Figure 1D*) modes are associated with ventilation. The LM mode is a still image, not a dynamic one. This mode visualizes the upward movement of the lungs during expiration. The colorless area shows little movement, with <1.5 mm of upward movement during expiration. We

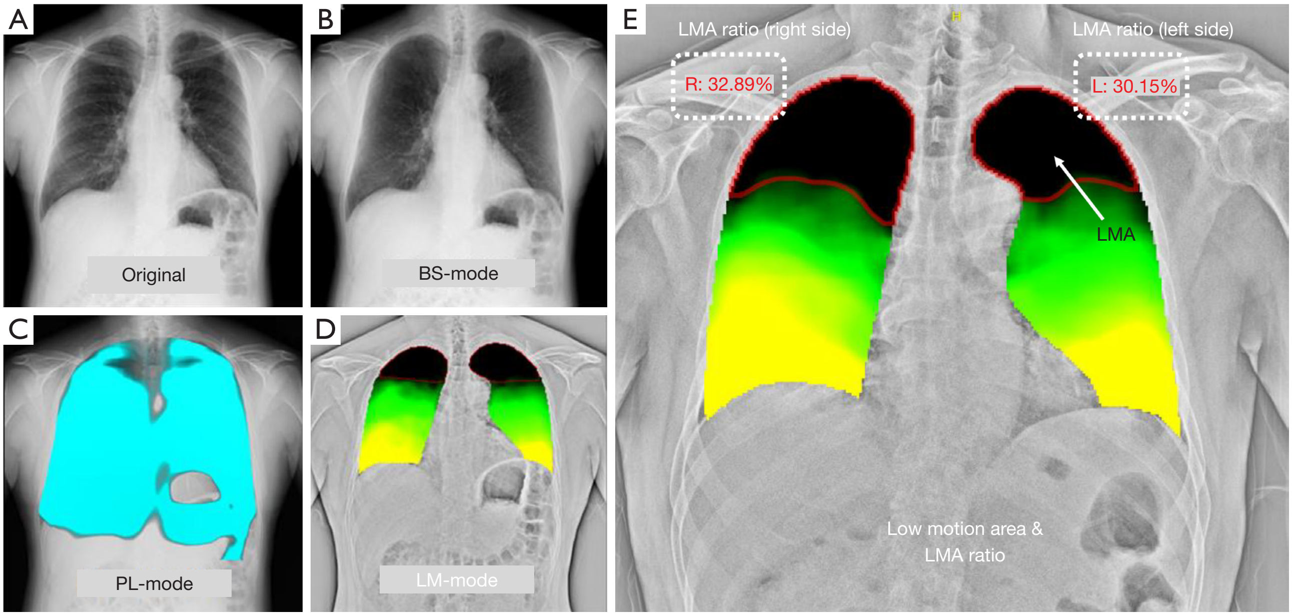

Figure 1 Several dynamic images obtained by DCR. Original DCR (A) is a simple dynamic image. In BS-mode (B), the clavicle and ribs are erased. PL-mode (C) is for ventilation and shows the dynamic ventilation image with a blue shadow in the position where the lung tissue is expanded by breathing. LM-mode (D) visualizes the upward movement of the lungs during expiration. The colorless area shows where there is little movement, it is defined as the LMA. The LMA ratio (E) is a percentage obtained by dividing the LMA by the lung field area of the surgical side. DCR, dynamic chest radiography; BS, bone suppression processing; PL, reference frame ratio calculation processing; LM, lung motion tracking processing; LMA, low motion area.

defined this as the LMA (*Figure 1E*). On the other hand, green indicates moderate movement and yellow indicates high movement.

Preoperative assessment of pleural adhesions using DCR

Preoperative evaluations were performed by 2 thoracic surgeons with >15 years of experience in thoracic surgery and a certificate of specialty. The PL mode was first examined. If a blue shadow appeared across all respiratory phases, the patient was considered free of pleural adhesions. However, if the blue shadow disappeared in certain lung regions, pleural adhesions were suspected. The BS mode was then used for a more detailed observation of lung movement.

Pleural adhesions were defined as those involving more than 20% of the thoracic cavity and/or necessitating more than 5 minutes for dissection (11). The duration of adhesion dissection was recorded by reviewing the operative video. The video was assessed by both the operating surgeon and an additional surgeon. In addition, the extent of adhesion was classified into four categories: grade 1, where the adhesion area covered less than one-third of the thoracic cavity; grade 2, more than one-third but less than two-thirds; grade 3, incomplete adhesion in the thoracic cavity but more than two-thirds; and grade 4, complete adhesion in the thoracic cavity. Grades 2 to 4 were considered extensive adhesions. Based on this definition, the accuracy of preoperative DCR assessment for pleural adhesions was determined by comparison with intraoperative findings for each patient.

Analysis of the LMA ratio and relevance of pleural adhesions

The LMA ratio (*Figure 1E*) was calculated using an analysis workstation for DCR (KINOSIS; Konica Minolta, Tokyo, Japan). The LMA ratio is the percentage obtained by dividing the LMA (mm^2) by the lung field area of the surgical side (mm^2). A retrospective analysis was conducted to examine the correlation between the LMA ratio and pleural adhesions.

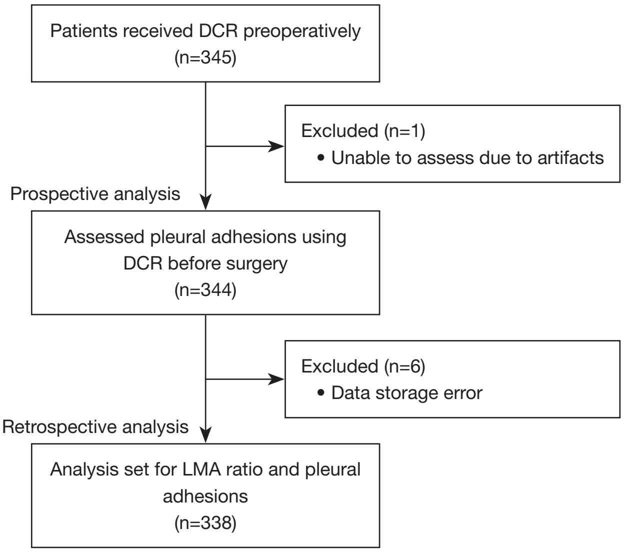

Figure 2 The study consort diagram. DCR, dynamic chest radiography; LMA, low motion area.

Statistical analysis

The Student's *t*-test and Kruskal-Wallis test were used for the analysis of continuous variables. Statistical significance was set at P<0.05. All statistical analyses, including the receiver operating characteristic (ROC) curves and the area under the curve (AUC) for the LMA ratio and pleural adhesions, were conducted using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan) (23).

Results

Patients

The consort diagram of the study is shown in *Figure 2*. A total of 345 patients underwent DCR. Only one patient (0.3%) had artifacts caused by body movement during image acquisition, and he was excluded from the analysis. The patients' clinical characteristics are presented in *Table 1*. The most common thoracic disease during surgery was primary lung cancer (n=225). Pulmonary comorbidities such as emphysema and/or interstitial pneumonia were found in 102 patients. In terms of the surgical procedures,

Table 1 Clinical background of the patients (n=344)

Characteristic	Value
Age, years	71 [15–88]
Sex	
Male	218 (63.4)
Female	126 (36.6)
Thoracic disease	
Primary lung cancer	225 (65.4)
Benign lung tumor	42 (12.2)
Metastatic lung cancer	29 (8.4)
Mediastinum tumor	20 (5.8)
Infectious lung diseases	11 (3.2)
Pleural tumor	7 (2.0)
Vascular malformation	5 (1.5)
Others†	5 (1.5)
Pulmonary comorbidity	
Emphysema	89 (25.9)
Interstitial lung disease	33 (9.6)
Surgical procedure	
Lobectomy	155 (45.1)
Segmentectomy	68 (19.8)
Wedge resection	80 (23.2)
Tumor resection	30 (8.7)
Sympathectomy	4 (1.2)
Combined procedure‡	7 (2.0)
Surgical approach	
Thoracotomy	125 (36.3)
M-VATS	107 (31.1)
U-VATS	76 (22.1)
RATS	36 (10.5)

Data are presented as median [range] or n (%). †, Palmar hyperhidrosis, n=4; diffuse lung disease, n=1. ‡, lobectomy + segmentectomy, n=3; lobectomy + wedge resection, n=1; segmentectomy + wedge resection, n=3. M-VATS, multiportal video-assisted thoracoscopic surgery; U-VATS, uniportal video-assisted thoracoscopic surgery; RATS, robotic-assisted thoracoscopic surgery.

Table 2 Findings of dynamic chest radiography and consistency of the preoperative assessment for pleural adhesions

Category	Value
Total analyzed patients	344
Suspected pleural adhesions using DCR	
Yes	56 (16.3)
No	288 (83.7)
Pleural adhesion	
Absence	279 (81.1)
Presence	65 (18.9)
Adhesion level	
Grade 1	38
Grade 2	15
Grade 3	5
Grade 4	7
Consistency of preoperative evaluation	
Accurate	305 (88.7)
Inaccurate	39 (11.3)

Data are presented as n or n (%). DCR, dynamic chest radiography.

lobectomy was performed in 155 (45.1%), segmentectomy in 68 (19.8%) and wedge resection in 80 (23.2%). Tumor resection was performed in 30 patients (8.7%). Regarding the surgical approach, 125 patients underwent thoracotomy, 183 patients underwent video-assisted thoracoscopic surgery, and 36 patients underwent robot-assisted thoracoscopic surgery.

Consistency of the preoperative assessment for pleural adhesions (prospective analysis)

The details are presented in *Table 2*. Of the 344 patients available for preoperative assessment of pleural adhesions, 305 assessments were accurate, while 39 were inaccurate. The sensitivity was 63.1%, the specificity 94.6%, the positive predictive value 73.2%, and the negative predictive value 91.7%. False-negatives (no adhesion was suspected) were present in 24 patients. The adhesions in these patients were located in the mediastinum (n=11), apex (n=6), lung field (n=6), and interlobe (n=1).

Association between the LMA ratio and pleural adhesions (retrospective analysis)

Of the 344 patients, the LMA ratio could be calculated for 338 patients, excluding 6 patients due to data storage errors. Among 338 patients, 65 (19.2%) had adhesions. The median LMA ratio was 56.0% in patients with pleural adhesions and 41.5% in those without. Thus, the LMA ratio was significantly higher in patients with pleural adhesions than in those without (P<0.001, *Figure 3*). The ROC curve showed that the cutoff value of the LMA ratio was 49.3%, and the AUC was 0.696. In patients with pulmonary comorbidities, such as emphysema or interstitial pneumonia (n=102), the median LMA ratio was 56.0% with adhesions and 41.0% without adhesions; a similar significant difference was observed (P<0.001) (Figure S1).

The median lung field change rate was 28.2%. Analysis of patients with a lung field change rate exceeding this value (n=169) revealed that the median LMA ratio was 52.0% in patients with adhesions and 36.9% in patients without adhesions (*Figure 4*). The AUC was 0.748 and the accuracy was even higher than that of the total patient analysis. In addition, when patients with adhesions were divided into 2 groups: low-grade (n=38) with grade 1 adhesions and high-grade (n=27) with grades 2–4 adhesions, the median LMA ratio in the low-grade group was 49.8%, while that in the high-grade group was 66.1%, which amounted to a significant difference (*Figure 5*).

Discussion

The LMA ratio in DCRs has been shown to be predictive of pleural adhesions, with a cutoff value of 49.3% and an AUC of 0.696. The LMA ratio is applicable across a broad range of thoracic diseases and age groups, and its calculation is straightforward. It serves as a highly objective measure for the preoperative assessment of pleural adhesions. Preoperative identification of pleural adhesions is important for planning the surgical approach and for predicting operative duration and blood loss. Concerning the association between the LMA ratio and adhesions, the LMA ratio had a higher adhesion detection power in patients with a higher lung field change rate, that is, with greater respiratory motion. In other words, it should be noted that the detection power may be reduced in elderly patients with poor respiratory motion. In addition, pleural adhesions

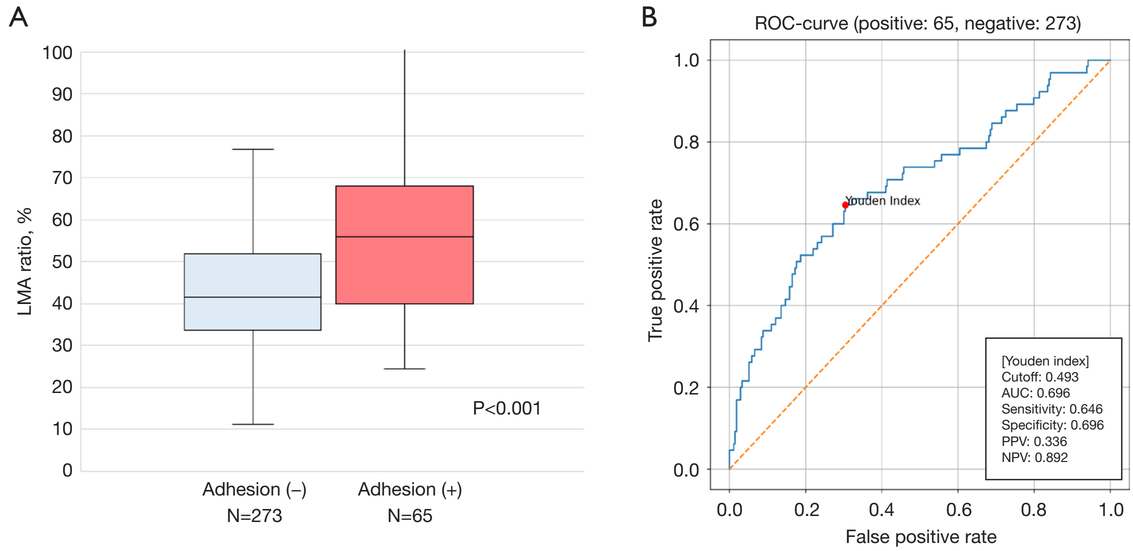

Figure 3 Comparison of the LMA ratio with and without pleural adhesions. (A) The box-plot shows that the LMA ratio was significantly larger in the patients with pleural adhesions than in those without pleural adhesions. (B) The ROC curve. LMA, low motion area; ROC, receiver operating characteristic; PPV, positive predictive value; NPV, negative predictive value; AUC, area under curve.

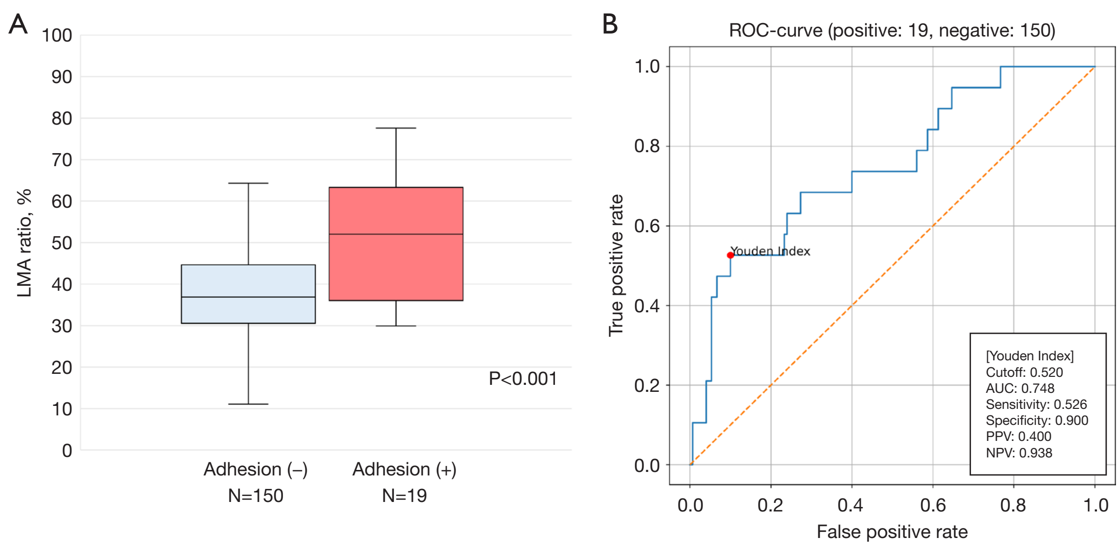

Figure 4 Comparison of the LMA ratio with and without pleural adhesions in patients with a lung field change rate of ≥28.2%. (A) The box-plot shows that the LMA ratio was also significantly larger in patients with pleural adhesions than in those without pleural adhesions. (B) The ROC-curve. LMA, low motion area; ROC, receiver operating characteristic; AUC, area under curve.

were classified into 4 grades according to their extent. When the extent of adhesions was greater than one-third of the thoracic cavity (grade ≥2 or higher), the ability of the LMA ratio to detect adhesions was higher. This means that adhesions with a greater impact on surgery are more easily detected, which is a very important factor from a surgical perspective. Only one previous report used the LMA ratio to predict thoracic adhesions (24). The cutoff value of the LMA ratio for determining adhesion was 49.0%, which is almost the same as that in the main analysis of our study (49.3%). However, the study had fewer cases than ours, and the important difference between the previous study and

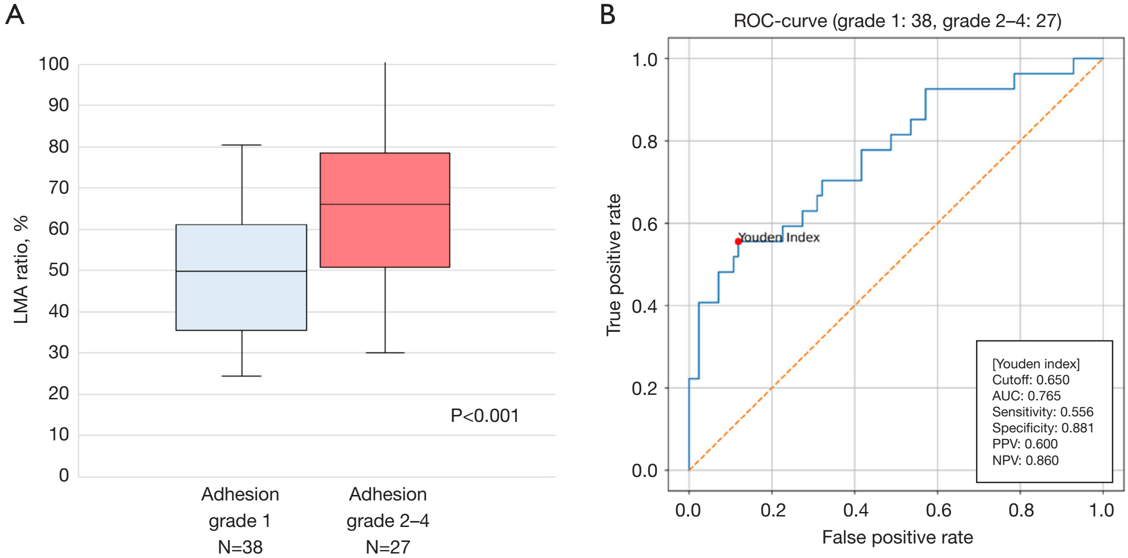

Figure 5 Comparison of the LMA ratio divided into 2 groups according to adhesion grade (low 1 *vs.* high 2–4). (A) Box-plot shows that the LMA ratio was significantly higher in the high-grade group. (B) The ROC curve. LMA, low motion area; ROC, receiver operating characteristic; AUC, area under curve.

our study is that it included some adhesions that did not affect surgery. Since we analyzed 340 cases, the definition of "pleural adhesions" was pleural adhesions that affected surgery, and we consider our study to be more practical and closer to the surgeon's point of view.

This study has several limitations. First, it was conducted at a single institution. Second, adhesions were defined as those requiring more than 5 minutes for dissection, and the surgeon's skill may have influenced the results. Third, data from six patients were improperly stored, preventing analysis of the LMA ratio. This issue arose when the software used for analysis was upgraded due to insufficient storage capacity, which is now being addressed by increasing storage. Additionally, this study could not analyze the LMA ratio based on the site of adhesion. Due to the characteristics of DCR, detecting adhesions on the mediastinal side or at the pulmonary apex is challenging, which also impacts the LMA ratio. Since cases with adhesions solely in the mediastinum or pulmonary apex are rare and have lower detection rates, this study primarily evaluates the overall performance of the LMA ratio for adhesions in general.

Future prospects include setting the LMA ratio cutoff at approximately 50% (the value calculated in this study and) using it in combination with conventional PL-mode-based evaluation to further improve the ability to detect adhesions preoperatively. In addition, since the level of respiratory motion affected the detection ability, it may be important to analyze body size data and diaphragm motion calculated by the DM-mode. Combining these factors could enhance the discriminatory power of the LMA ratio, which is currently moderate.

The LMA ratio can be measured with the press of a button using the Analysis Workstation, which is very easy to use (although a license and network connection may be required depending on the environment). In addition, the measurement of the LMA ratio does not require a dedicated process, and DCR can be taken in the same manner as in the past. As shown in this study, the LMA ratio can be measured in a wide variety of chest diseases and at all ages.

Conclusions

In line with our previous study reporting the utility of DCR in thoracic surgery for the preoperative detection of pleural adhesions, this study evaluated the overall utility of the LMA ratio. The LMA ratio can be measured in a wide variety of thoracic diseases at all ages, and its calculation is extremely simple. The LMA ratio is useful as a completely objective index for the preoperative evaluation of pleural adhesions.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at: https://qims.amegroups.com/article/view/10.21037/qims-24-1247/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-24-1247/coif). N.M. reports that he is employed by Konica Minolta, Inc., where he receives a salary. The company holds patents on the software program used in this research, and he is credited as one of its inventors. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Seirei Mikatahara General Hospital (approval No. 23-02, 2023) and individual consent for this retrospective analysis was waived.

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