A predictive factor for patients with acute respiratory distress syndrome: CT lung volumetry of the well-aerated region as an automated method

（急性呼吸窮迫症候群患者の予後予測因子：自動法による含気良好域の肺容量測定）

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Abstract

Purpose: Acute respiratory distress syndrome (ARDS) is an acute inflammatory lung injury that frequently shows fatal outcomes. As radiographic predictive factors, some reports have focused on the region of ill-aerated lung, but none have focused on well-aerated lung. Our objective was to evaluate the relationship between computed tomography (CT) volume of the well-aerated lung region and prognosis in patients with ARDS.

Method: This retrospective observational study of a single intensive care unit (ICU) included patients with ARDS treated between April 2011 and May 2013. We identified 42 patients with ARDS for whom adequate helical CT scans were available. CT images were analyzed for 3-dimensional reconstruction, and lung region volumes were measured using automated volumetry methods. Lung regions were identified by CT attenuation in Hounsfield units (HU).

Results: Of the 42 patients, 35 (83.3%) survived 28 days and 32 (76.2%) survived to ICU discharge. CT lung volumetry was performed within 144.5 ± 76.6 seconds, and inter-rater reliability of CT lung volumetry for lung regions below -500 HU (well-aerated lung region) were near-perfect. Well-aerated lung region showed a positive correlation with 28-day survival (P=0.020), and lung volumes below -900 HU correlated positively with 28-day survival and ICU survival, respectively (P=0.028, 0.017). Survival outcome was better for percentage of well-aerated lung region/predicted total lung capacity ≥40% than for <40% (P=0.039).

Conclusions: CT lung volumetry of the well-aerated lung region using an automated method allows fast, reliable quantitative CT analysis and potentially prediction of the clinical course in patients with ARDS.

Background

Acute respiratory distress syndrome (ARDS) is an acute inflammatory lung injury characterized by increases in pulmonary vascular permeability and extravascular lung water and decreases in aerated lung area, and frequently displays fatal outcomes [1,2]. Although previous studies have provided substantial insights into ARDS, limited information has been accumulated regarding epidemiology, recognition, management, and outcomes for patients with ARDS. Several predictors of mortality for ARDS have been reported, but no predictive factors have been established in guidelines for the management of ARDS [1,3].

Computed tomography (CT) can reflect pathological changes in the lung and reveal morphological features of lung diseases. In the Berlin definition [1], as the standard criterion for diagnosing ARDS, CT findings such as increased pulmonary vascular permeability and loss of aerated lung tissue are hallmarks of ARDS. Several investigations have revealed the possibility of predicting mortality for ARDS [4-6]. Those studies focused on ill-aerated lung regions on CT, reflecting fibroproliferative changes pathologically, but applied only subjective, visual-based evaluations by radiologists.

As an objective method of lung analysis, estimation of lung volumes has been used in patients with various lung disease, including asthma, chronic obstructive pulmonary disease (COPD), interstitial lung diseases, and oncological diseases [7]. Nowadays, to achieve objective and speedy assessments, methods of automated lung CT segmentation have become extensively available [8, 9]. However, automated lung segmentation for ARDS is generally difficult to perform, because non-aerated lung areas are hard to differentiate from close CT-dense structures such as the chest wall and mediastinum [10]. Manual methods allow segmentation of non-aerated lung areas, but estimation of lung volumes using manual processes does not show good reproducibility and are strongly dependent on the clinical

expertise of the rater in routine clinical applications [11]. Otherwise, automated lung CT segmentation would allow fast, reliable quantitative analysis of well-aerated lung regions [11,12].

The extent of well-aerated lung is a well-known predictor of complications in the perioperative phase of lung cancer surgery [13,14]. However, the region of well-aerated lung has not been focused on as a predictor of outcomes in patients with ARDS. We hypothesized that the volume of well-aerated lung would be related to mortality in patients with ARDS, and an approach using this relationship would allow the establishment of rapid, objective assessments. We estimated the volume of well-aerated lung in patients with ARDS using an automated CT volumetry method. The main goal of this study was to evaluate the relationship between CT volumes of well-aerated lung and prognosis in patients with ARDS.

Methods

Subjects

This study was approved by the ethics committee of our institute and the need to obtain written informed consent was waived because of the retrospective study design (approval number: 2903). We initially assessed all 49 patients who had been hospitalized in the intensive care unit (ICU) of our institute between April 2011 and March 2013 who met the Berlin criteria for ARDS [1]. Exclusion criteria comprised: age <18 years (n=1); lack of adequate CT images (0.5-mm or 1.0-mm slice images; n=4); lack of adequate clinical data (height, which is needed to calculate predicted total lung capacity (pTLC); n=2); severe emphysema (n=0); and pregnancy (n=0). In total, 7 patients were excluded, and the remaining 42 patients were enrolled. We continued follow-up of patients until 56 days after diagnosis.

Clinical parameters

We assessed the following variables from medical charts: age; sex; height; body weight; body mass index (BMI); mean acute physiology and chronic health evaluation (APACHE) II score; sequential organ failure assessment (SOFA) score; primary cause of ARDS; arterial partial pressure of oxygen (PaO_2)/fraction of inspired oxygen (F_IO_2) ratio; and severity of ARDS. We collected the following outcomes from medical charts: 1) survival at 7 days, 14 days, 28 days, and 56 days; and 2) ICU survival (discharge from the ICU ≤ 56 days after diagnosis).

Multidetector row computed tomography (MDCT)

All patients underwent MDCT (Aquilion 64® or Aquilion ONE®; Canon Medical Systems, Tochigi, Japan) from the thoracic inlet to the diaphragm at the time of diagnosis. No contrast medium was used. MDCT scan parameters were as follows: helical mode; collimation, 0.5 mm; tube voltage, 120 kV; gantry rotation time, 0.5 seconds; use of automatic exposure control; slice thickness, 0.5 mm; helical pitch, 65; and pitch factor, 0.83. A whole-lung CT scan was performed at full inspiration, sustained by a portable ventilator (Oxylog® 3000 Plus, Dräger, Medical Japan Ltd, Tokyo, Japan) with the same settings as applied in the ICU. All images were reconstructed using standard reconstruction algorithms with a slice thickness of 0.5 mm or 1.0 mm and a reconstruction interval of 0.5 mm or 1.0 mm.

CT volumetry

CT lung volumetry was performed by delineation of lung regions of interest within each lung CT slice using a VirtualPlace Fujin Raijin 360 ® version 3.6009 workstation (AZE, Kanagawa, Japan). We used automated lung volumetry software with a region-growing algorithm. Hilar structures of the lung, trachea, and main bronchus were eliminated using manual methods, as needed. Lung regions were classified into 4 categories by CT attenuation

densities: 1) hyperinflated, density between -1000 and -901 Hounsfield units (HU); 2) normally aerated, density between -900 and -501 HU; 3) poorly aerated, density between -500 and -101 HU; and 4) non-aerated, density between +100 and -100 HU [12]. To certify reproducibility, a radiologist (A.N.) and a respiratory physician (N.K.) created 3-dimensional images and editing for volumetry. The volume of each lung region was divided by pTLC to correct for differences in physique among patients [15]. We considered hyperinflated and normally aerated regions (density below -500 HU) as well-aerated lung regions for this study and defined the well-aerated group and less-aerated group based on the median percentage of well-aerated lung region/pTLC.

Statistical analysis

Data are expressed as mean (±standard deviation). After confirming and examining that parameters were normally distributed, all following comparisons were performed using the Mann-Whitney *U* test as appropriate. Fisher's exact test was used to compare severity of ARDS, primary cause of ARDS, and treatment with methylprednisolone between 28-day survivors and non-survivors, and ICU survivors and non-survivors, respectively. To assess inter-rater reliability of CT lung volumes, the intraclass correlation coefficient (ICC) was calculated using a two-way random-effects model. CT lung volumes and clinical parameters were compared between 28-day survivors and non-survivors, and between ICU survivors and non-survivors using the Mann-Whitney *U* test. Relationships between CT lung volumes and 28-day mortality were assessed using Kaplan-Meier methods and comparisons were performed using log-rank testing. For all statistical analyses, the level of significance was set at values of $P<0.05$. All statistical analyses were performed using JMP version 13.0 software (SAS Institute, Cary, NC).

Results

Patient characteristics

The clinical parameters of the 42 patients (28 men, 14 women) are shown in Table 1. Mean age was 64.2 ± 17.1 years. Mean BMI was 22.8 ± 5.3 kg/m$_2$. Mean APACHE II score was 30.2 ± 9.5 and mean SOFA score was 10.3 ± 4.3. Mean PaO_2/ F_IO_2 ratio was 125.1 ± 57.7. Severity of ARDS was as follows: mild (n=3), 7.1%; moderate (n=21), 50.0%; and severe (n=18), 42.9%. Primary cause of ARDS was pneumonia (n=9, 21.4%), sepsis (n=7, 16.7%), trauma (n=2, 4.8%), surgery (n=5, 11.9%), aspiration (n=10, 23.8%), and others (n=9, 21.4%). Prognosis was as follows: 40 of 42 patients (95.2%) survived to 14 days, 35 of 42 patients (83.3%) survived to 28 days, and 31 of 42 patients (73.8%) survived to 56 days. Of the 42 patients, 32 (76.2%) survived to ICU discharge. Neither severity of ARDS nor primary cause of ARDS displayed any significant relationship with 28-day survival (P=0.835) or ICU survival (P=0.105), respectively. All patients underwent treatment with mechanical ventilatory support using a low tidal volume of 6-8 mL/kg and positive end-expiratory pressure (PEEP) within the range of plateau pressures ≤20 cmH_2O (lower PEEP) and adequate antibiotic therapy. Twenty of the 42 patients (47.6%) underwent treatment with intravenously administered corticosteroids, such as low-dose methylprednisolone (1-2 mg/kg body weight/day). No significant differences in 28-day survival (P=0.229) or ICU survival (P=0.477) were evident between groups with and without intravenous methylprednisolone. No patients were treated with prone positioning.

CT measurements

CT lung volumetry was performed within 144.5 ± 76.6 seconds (range: 92-519 seconds). The results of CT measurement are shown in Table 2. CT lung region volumes were as follows: total lung, 2754.8 ± 851.9 mL; well-aerated lung, 2166.0 ± 828.8 mL; hyperinflated

lung, 312.1 ± 401.3 mL; normally aerated lung, 1853.8 ± 603.4 mL; poorly aerated lung, 520.9 ± 298.1 mL; non-aerated lung, 46.0 ± 42.2 mL. ICCs between the two raters for lung region volumes were as follows: total lung, 0.92 [95% confidence interval 0.85 – 0.96]; well-aerated lung, 0.99 [0.98 – 0.99]; hyperinflated lung, 0.99 [0.98 – 1.00]; normally aerated lung, 0.97 [0.95 – 0.99]; poorly aerated lung, 0.99 [0.83 – 0.95]; and non-aerated lung, 0.02 [-0.24 – 0.30]. CT lung region volumes corrected to pTLC were as follows: total lung volume/pTLC, 55.23 ± 16.34%; well-aerated lung/pTLC, 40.13 ± 16.57%; hyperinflated lung/pTLC, 6.16 ± 7.65%; normally aerated lung/pTLC, 37.25 ± 12.45%; poorly aerated lung/pTLC, 10.50 ± 6.01%; and non-aerated lung/pTLC, 0.89 ± 0.74%. Representative colormap 3-dimensional images of 28-day survivors and non-survivors are shown in Figure 1.

Correlations between clinical parameters, CT measurements, and prognosis

Correlations between clinical parameters and survival outcomes, and between CT measurements and survival outcomes, are shown in Tables 1 and 2, respectively. The PaO_2/FiO_2 ratio of ICU survivors (132.4 ± 50.4) was significantly higher than that of ICU non-survivors (101.9 ± 71.7; *P*=0.040). Total lung volumes (2896.4 ± 817.0 mL), well-aerated lung volumes (2317.9 ± 798.8 mL), hyperinflated lung volumes (361.0 ± 420.5 mL), and normally aerated lung volumes (1956.9 ± 582.7 mL) were higher in 28-day survivors than in 28-day non-survivors (2046.8 ± 644.5 mL, *P*=0.018; 1406.3 ± 488.1 mL, *P*=0.005; 67.6 ± 103.5 mL, *P*=0.015; and 1338.6 ± 410.6 mL, *P*=0.011), respectively. Also, well-aerated lung volumes (2320.7 ± 818.5 mL) and hyperinflated lung volumes (387.5 ± 430.2 mL) were higher in ICU survivors than in ICU non-survivors (1670.8 ± 647.4 mL, *P*=0.026; and 71.0 ± 89.4 mL, *P*=0.013, respectively). Well-aerated lung region/pTLC was significantly higher for 28-day survivors (45.99 ± 16.58%) than for 28-day non-survivors (30.46 ± 8.49%; *P*=0.020), and well-aerated lung region/pTLC for ICU survivors (45.91 ± 17.34%) showed no significant

difference from that of ICU non-survivors (35.37 ± 10.33%; *P*=0.065). Also, hyperinflated area/pTLC of 28-day survivors (7.13 ± 7.99%) and ICU survivors (7.66 ± 8.16%) were higher than those of 28-day non-survivors (1.26 ± 1.78%; P=0.028) and ICU non-survivors (1.35 ± 1.53%; P=0.017), respectively (Figure 2). No other factors showed any significant relationships with prognosis.

The median percentage of well-aerated lung region/pTLC was 40.13%, which was used as the threshold for dividing well-aerated and less-aerated group. Kaplan-Meier survival curves for the percentage of well-aerated lung region/pTLC about the median (≥40% vs. <40%) within 28 days are shown in Figure 3. Kaplan-Meier analysis for 28-day survival showed significant differences between the well-aerated group and the less-aerated group (log-rank test, *P*=0.039).

Discussion

The main findings of this study were that CT lung volumetry represents a reproducible assessment and is feasible without excessive effort in routine clinical settings. Patients with well-aerated lung region/pTLC ≥40% showed a better 28-day survival curve.

In our study, interrater variability of CT lung volumetry for well-aerated lung was near-perfect (0.98-0.99). High interrater reliability and high reproducibility were shown. In a past report, volumetric differences in automated CT lung volumetry between different software packages were small [7]. Moreover, CT lung volumetry and estimation of each lung region volumes were performed within about 3 min. Ichikado et al. reported that visual-based analysis of CT score predicted the prognosis of patients with ARDS and showed good interobserver variability (κ=0.75, 0.68-0.82, 0.63-0.83) [4-6]. However, visual-based analysis generally

requires a long time to perform. Our methods are simple and could be performed with minimal effort.

The group with well-aerated lung region/pTLC ≥40% showed better survival outcome. Some reports have noted that patients with large ill-aerated lung regions experience poorer prognosis than patients with small ill-aerated lung regions [4-6,16], but no reports have focused on the well-aerated lung region of patients with ARDS. This is the first report to describe the relationship between well-aerated lung region and prognosis in patients with ARDS.

Pulmonary function parameters are considered as prognostic predictors of several lung conditions. The percentage of predicted forced expiratory in 1 s ($FEV_{1.0}$) is a hallmark for obstructive pulmonary diseases, such as COPD and asthma. The percentage diffusing capacity of the lung for carbon monoxide (%DL_{CO}) reflects the ability of the lungs to transfer gas from inhaled air into red blood cells in pulmonary capillaries, and declines in interstitial lung disease, emphysema, and pulmonary hypertension [17,18]. $FEV_{1.0}$ <40% and %DL_{CO} <40% indicate an increased risk of perioperative complications in lung cancer operations [13,14,19], and patients with idiopathic pulmonary hypertension and %DL_{CO} <45% displayed worse exercise performance and a lower survival rate than patients with %DL_{CO} ≥45% [20]. Moreover, among patients with COPD, high-resolution CT lung densities reflect respiratory function and dyspnea perception [21]. $FEV_{1.0}$ correlates with CT lung volume below -900 HU in COPD and asthma [22,23]. Extensive abnormalities on HRCT were associated with lower DL_{CO} in interstitial lung disease [24,25] . Volume of CT lung regions below -950 HU was associated with decreased DL_{CO} in COPD [26]. The well-aerated region in ARDS was suggested to reflect pulmonary function, although performing respiratory function examinations is difficult in ARDS subjects.

The value for hyperinflated region/pTLC correlated positively with both 28-day survival rate and ICU survival rate. In patients with COPD, the lung region below -900 HU (considered a hyperinflated lung) is considered the low attenuation area (LAA). The percentage of LAA is associated with poor prognosis [27]. On the other hand, in patients with ARDS, the alveolar recruitment area is associated with good prognosis [28]. Vieira et al. reported that a region with CT attenuation below -900 HU among patients with ARDS is an aeration-improved region on application of PEEP, and an alveolar recruitment area [29]. In this study, all patients underwent CT at full inspiration, sustained using a respiratory bag. The hyperinflated region is considered to correspond to an alveolar recruitment region.

Clinical severity scores (APACHE II and SOFA) have been used to assess the severity of critically ill patients, showing relationships to the prognosis of patients with multi-organ dysfunction syndrome in previous studies, particularly for predicting discharge from hospital and long-term mortality [30-32]. On the other hand, these scores were not always suitable for use as short-term predictors [33-35]. The finding, that APACHE II and SOFA scores represent significant predictors for patients with ARDS in thus controversial. No definitive predictors for the clinical course of patients with ARDS have been identified, and further studies are needed to support and validate our findings in the near future.

Mechanical ventilatory support with low tidal volume and low plateau pressure is strongly recommended as a treatment in the management of patients with ARDS [3,36,37]. In the present study, all patients were treated in this manner. Low-dose corticosteroid therapy is reportedly associated with reductions in mortality, duration of mechanical ventilation and length of stay in the ICU, but the available evidence remains contradictory [38-40]. No significant differences in 28-day survival or ICU survival were seen between patients with or without corticosteroid therapy in our results. All patients had been treated with antibiotic therapy because inappropriate or delayed antibiotics raise the risk and accelerate the

progression of ARDS [41]. In recent studies, treatment using prone positioning for at least 12 h/day has been strongly recommended [37], but this was not a well-established treatment during the study period, so no patients underwent such treatment. Gravity-dependent CT lung densities shift from dorsal to ventral when the patient is turned prone, and mean lung densities were gradually higher in the supine position than in the prone position [42]. In our study, no positional differences in CT lung densities were apparent.

We applied a region-growing algorithm to delineate the lung area. This method utilizes a simple computation based on the density range of lung tissue and is widely employed in commercially available workstations. First, a seed point presenting with normal density is determined. Then, a 3-dimensional region is grown from the seed point to neighboring pixels presenting with similar density [43]. This approach works well for well-aerated lung regions theoretically [10], and interrater reliability was almost perfect in volumetry for hyperinflated lung and normally aerated lung using the region-growing algorithm [44]. However, automatic volumetry using the region-growing algorithm for the high-density lung region, which shows similar density to non-lung soft-tissue regions, and measurement of volumes for non-aerated regions might be problematic [44]. Examples include methods based on registration, adaptive border matching, texture analysis and deep learning [44-46], which may show some potential for correctly segmenting even poorly aerated and non-aerated regions.

Limitations

This study had several limitations that need to be considered when interpreting the results. First, because of the retrospective nature of the evaluation and the single-center design, several selection biases may have been at play in the present cohort. Second, the sample size was small. We hope to expand upon our findings another cohort study using a multi-center design with, a much larger number of subjects. Third, causes of ARDS were not evaluated, and patients with pulmonary and extrapulmonary ARDS were not identified. Fourth, we evaluated

CT images in the early phase of patients with ARDS and did not evaluate CT images in the late phase or temporal changes in CT images.

Conclusions

In conclusion, our results demonstrate that CT lung volumetry of well-aerated lung (region below -500 HU) using an automated method allows fast, reliable quantitative CT analysis and might predict the clinical course in patients with ARDS.

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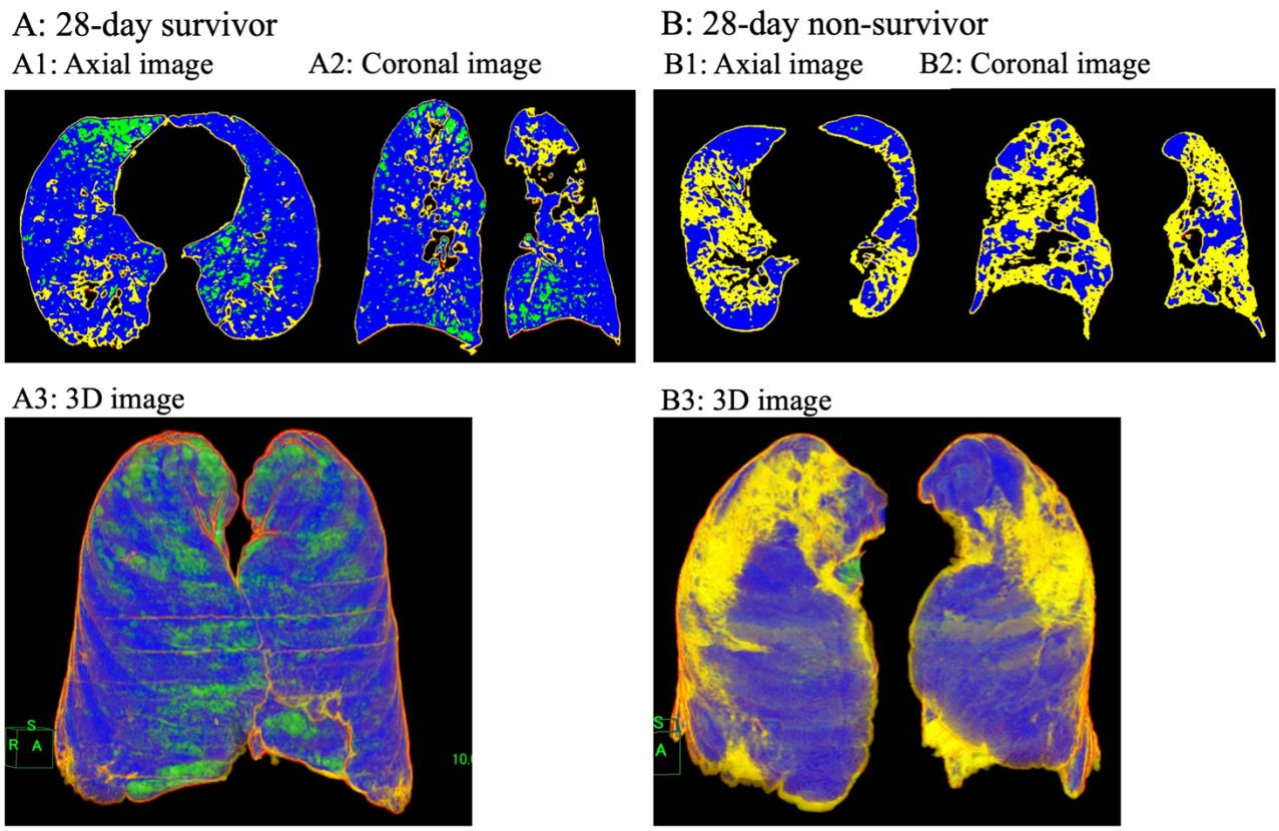
Fig. 1. Colormap CT images of patients with ARDS.

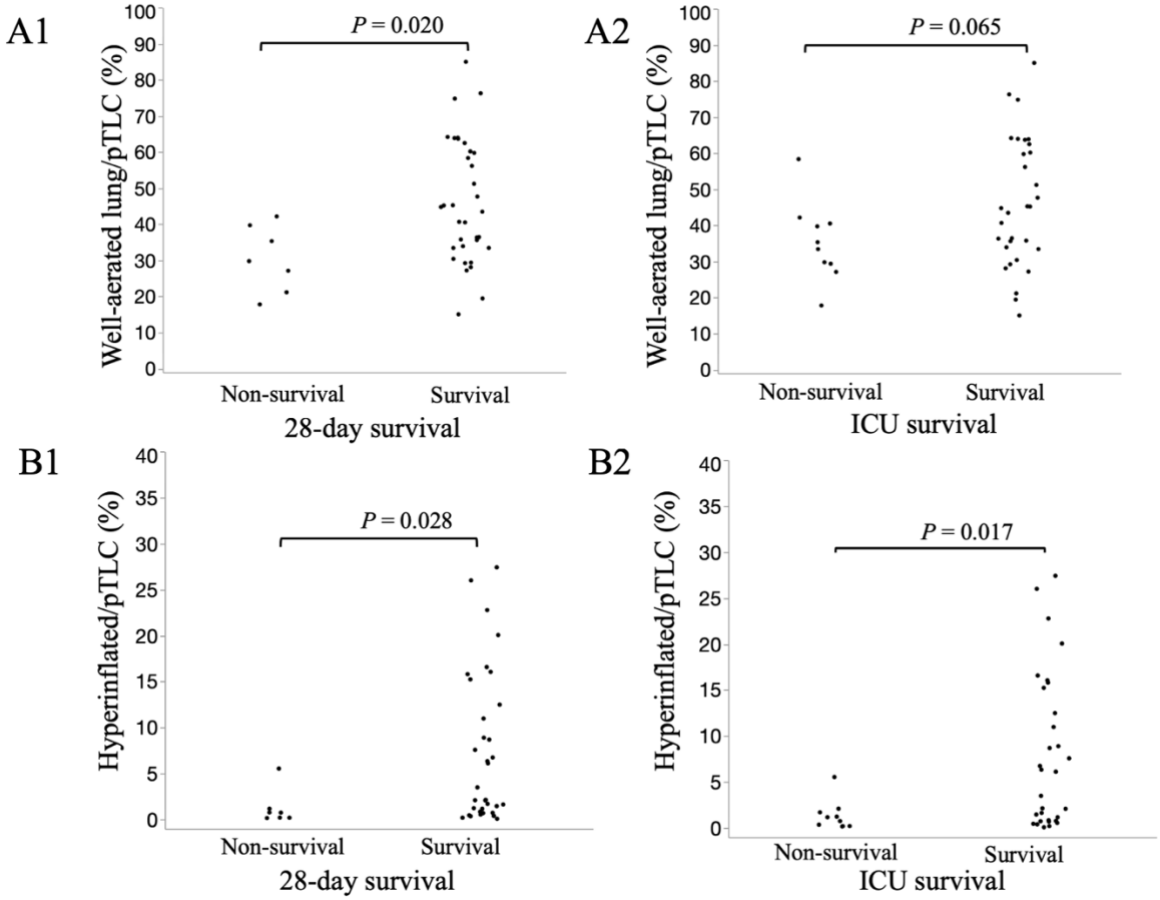


A1-A3: 28-day survivor; B1-B3: 28-day non-survivor.

Green: hyperinflated region; Blue: normally aerated region; Yellow: poorly aerated region;

Red: non-aerated region.

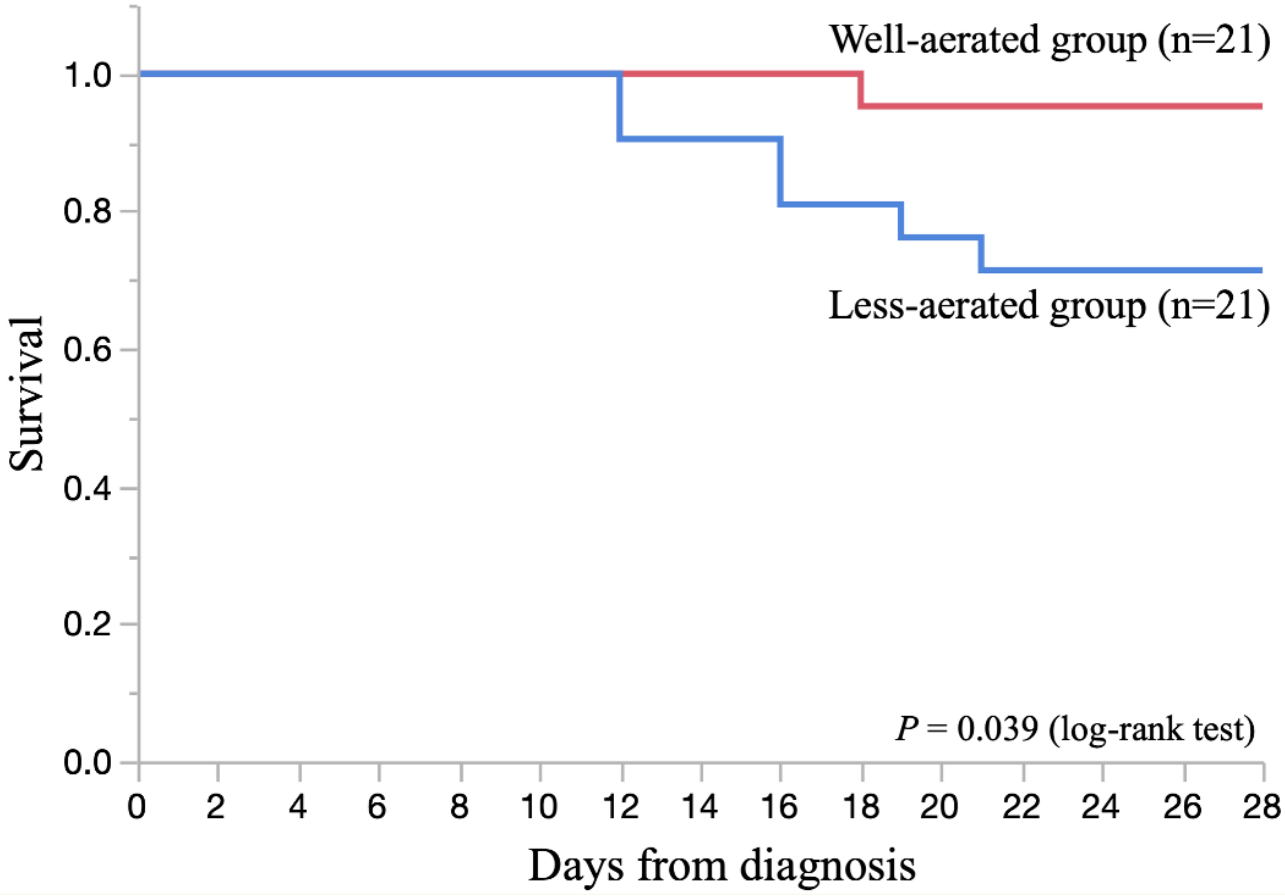
Fig. 2. Dot-plot analysis of 28-day survival and ICU survival of patients with ARDS.



A1: Well-aerated lung region/pTLC was significantly higher in 28-day survivors than in 28-day non-survivors (*P*=0.020).

B1 and B2: Hyperinflated area/pTLC was significantly higher in 28-day survivors and ICU survivors than in 28-day non-survivors (*P*=0.028) and ICU non-survivors (*P*=0.017), respectively.

Fig. 3. Kaplan-Meier analysis for 28-day survival.



Kaplan-Meier analysis shows significant differences in 28-day survival between well-aerated group (well-aerated lung region/pTLC ≥40%) and less-aerated group (well-aerated lung region/pTLC <40%) (log-rank test, *P*=0.039).

Table 1. Comparison of patient characteristics between groups as divided by 28-day survival and ICU survival

	Overall	28-day survival			ICU survival		
		Survival (n=35)	Non-survival (n=7)		Survival (n=32)	Non-Survival (n=10)	
	mean ± SD	mean ± SD	mean ± SD	*P*	mean ± SD	mean ± SD	*P*
Sex (male/female)	28 (66.7%) / 14 (33.3%)	25 (71.4%) / 10 (28.6%)	3 (42.9%) / 4 (57.1%)	0.154	23 (71.9%) / 9 (28.1%)	5 (50.0%) / 5 (50.0%)	0.212
Age (years)	64.2 ± 17.1	65.3 ± 16.5	58.6 ± 19.0	0.458	64.4 ± 17.5	63.6 ± 16.0	**0.028**
Height (cm)	161.6 ± 8.6	162.3 ± 7.8	157.9 ± 10.9	0.408	163.5 ± 8.0	155.6 ± 7.7	**0.028**
Body weight (kg)	60.2 ± 17.8	59.7 ± 17.9	62.6 ± 17.4	0.840	61.4 ± 19.5	56.6 ± 9.6	0.523
BMI (kg/m^2)	22.8 ± 5.3	22.4 ± 5.4	24.7 ± 4.1	0.237	22.7 ± 5.8	23.3 ± 2.9	0.460
APACHE II score	30.2 ± 9.5	30.1 ± 9.1	30.7 ± 11.0	0.821	29.9 ± 8.1	31.2 ± 12.9	0.718
SOFA score	10.3 ± 4.3	10. 1 ± 3.8	11.1 ± 6.0	0.720	9.8 ± 3.3	11.6 ± 6.2	0.527
PaO_2/ F_IO_2 ratio	125.1 ± 57.7	125.4 ± 52.7	123.7 ± 77.8	0.601	132.4 ± 50.4	101.9 ± 71.7	**0.040**
Severity of ARDS (PaO_2/ F_IO_2)							
Mild (201-300 mmHg)	3/42 (7.1%)	2/35 (5.7%)	1/7 (14.3%)	0.835	2/32 (6.3%)	1/10 (10.0%)	0.105
Moderate (101-200 mmHg)	21/42 (50.0%)	18/35 (51.4%)	3/7 (42.9%)		19/32 (59.4%)	2/10 (20.0%)	
Severe (≤100 mmHg)	18/42 (42.9%)	15/35 (42.9%)	3/7 (42.9%)		11/32 (34.4%)	7/10 (70.0%)	
Primary cause of ARDS							
Pneumonia	9/42 (21.4%)	7/35 (20.0%)	2/7 (28.6%)	0.250	7/32 (21.9%)	2/10 (10.0%)	0.425
Sepsis	7/42 (16.7%)	6/35 (17.1%)	1/7 (14.3%)		4/32 (12.5%)	3/10 (30.0%)	
Surgery	5/42 (11.9%)	4/35 (11.4%)	1/7 (14.3%)		4/32 (12.5%)	1/10 (10.0%)	
Aspiration	10/42 (23.8%)	10/35 (28.6%)	0/7 (0.0%)		8/32 (25.0%)	2/10 (20.0%)	
Trauma	2/42 (4.8%)	2/35 (5.7%)	0/7 (0.0%)		2/32 (6.3%)	0/10 (0.0%)	
Others	9/42 (21.4%)	6/35 (17.1%)	3/7 (42.9%)		7/32 (21.9%)	2/10 (20.0%)	

ICU, intensive care unit; SD, standard deviation; BMI, body mass index; APACHE, acute physiology and chronic health evaluation; SOFA, sequential organ failure assessment; ARDS, acute respiratory distress syndrome; PaO_2, arterial partial pressure of oxygen; F_IO_2, fraction of inspired oxygen
Significant *P* values (< 0.05) are given in bold type.

Table 2. Comparison of CT measurements between groups as divided by 28-day survival and ICU survival

	Overall	28-day survival			ICU survival		
		Survival (n=35)	Non-survival (n=7)		Survival (n=32)	Non-survival (n=10)	
	mean ± SD	mean ± SD	mean ± SD	*P*	mean ± SD	mean ± SD	*P*
Total lung volumes (mL)	2754.8 ± 851.9	2896.4 ± 817.0	2046.8 ± 644.5	**0.018**	2900.0 ± 820.0	2290.1 ± 782.7	0.079
Well-aerated lung volume (mL)	2166.0 ± 828.8	2317.9 ± 798.8	1406.3 ± 488.1	**0.005**	2320.7 ± 818.5	1670.8 ± 647.4	**0.026**
Hyperinflated lung volume (mL)	312.1 ± 401.3	361.0 ± 420.5	67.6 ± 103.5	**0.015**	387.5 ± 430.2	71.0 ± 89.4	**0.013**
Normally aerated lung volume (mL)	1853.8 ± 603.4	1956.9 ± 582.7	1338.6 ± 410.6	**0.011**	1933.2 ± 581.2	1599.7 ± 602.9	0.111
Poorly aerated lung volume (mL)	520.9 ± 298.1	507.1 ± 301.9	589.6 ± 267.4	0.380	507.2 ± 298.0	564.5 ± 294.0	0.647
Non-aerated lung volume (mL)	46.0 ± 42.2	46.4 ± 43.5	43.6 ± 35.4	0.544	45.9 ± 44.9	46.2 ± 32.1	0.988
Total lung/pTLC (%)	55.23 ± 16.34	57.37 ± 16.4	44.56 ± 11.02	0.098	57.26 ± 17.02	48.7 ± 11.8	0.209
Well-aerated lung /pTLC (%)	40.13 ± 16.57	45.99 ± 16.58	30.46 ± 8.49	**0.020**	45.91 ± 17.34	35.37 ±10.33	0.065
Hyperinflated lung/pTLC (%)	6.16 ± 7.65	7.13 ± 7.99	1.26 ± 1.78	**0.028**	7.66 ± 8.16	1.35 ± 1.53	**0.017**
Normally aerated lung/pTLC (%)	37.25 ± 12.45	38.86 ± 12.58	29.19 ± 7.72	0.068	38.26 ± 12.98	34.0 ± 9.89	0.375
Poorly aerated lung/pTLC (%)	10.50 ± 6.01	9.98 ± 5.76	13.08 ± 6.57	0.140	9.94 ± 5.73	12.27 ± 6.54	0.247
Non-aerated lung/pTLC (%)	0.89 ± 0.74	0.90 ± 0.77	0.87 ± 0.59	0.607	0.88 ± 0.79	0.93 ± 0.53	0.505

ICU, intensive care unit; SD, standard deviation; pTLC, predicted total lung capacity.

Significant *P* values (< 0.05) are given in bold type.

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