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Original Article

Quantitative analysis of muscle volumes in COVID-19 pneumonia with an automated segmentation system

COVID-19 pnömonisinde kas morfolojisinin otomatik segmentasyon sistemi ile kantitatif analizi

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ABSTRACT

Aim: The aim of this study was to quantitatively analyze volume of the erector spinae muscle in COVID-19 pneumonia using an artificial intelligence-based automated segmentation program, and to investigate the relationship between pulmonary infiltration ratio and volume of the erector spinae muscle.
Methods: In this retrospective study, thoracic CT images of patients who tested positive for SARS-CoV-2 on RT-PCR and had COVID-19 pneumonia were analyzed. Based on the percentage of pulmonary involvement, the study cohort was divided into two groups (Group I: less than 25% involvement and Group II: more than %25 involvement). Volume of the erector spinae muscle and severity of lung involvement were quantitatively analyzed using an artificial intelligence-based automated segmentation program. The data of group I and group II were compared.
Results: The study population consisted of 74 subjects; 35 in Group I and 39 in Group II. Significant negative correlations were observed between the total pulmonary infiltration ratio and the volume of the erector spinae muscle. Furthermore, the analysis demonstrated that lung density, total lung infiltration volume, serum C-reactive protein (CRP) level, serum ESR level, and total erector spinae muscle volume can serve as valuable indicators for assessing the severity of lung involvement in patients with COVID-19 pneumonia.
Conclusion: Measurement of erector spinae muscle volume may be useful for assessment of pulmonary infiltration in patients with COVID-19 pneumonia.

Keywords: Erector spinae muscle volume, COVID-19 pneumonia, pulmonary infiltration, automated segmentation, artificial intelligence

ÖZ

Amaç: Bu çalışmanın amacı, yapay zeka tabanlı otomatik bir segmentasyon programı kullanarak COVID-19 pnömonisindeki erektör spina kas hacmini kantitatif olarak analiz etmek ve pulmoner infiltrasyon oranı ile erektör spina kas hacmi arasındaki ilişkiyi araştırmaktır.
Yöntem: Bu retrospektif çalışmada, RT-PCR'de SARS-CoV-2 testi pozitif çıkan ve COVID-19 pnömonisi olan hastaların toraks BT görüntüleri analiz edildi. Akciğer tutulum yüzdesine göre çalışma kohortu iki gruba ayrıldı (grup I: %25'in altında tutulum ve grup II: %25'in üzerinde tutulum). Erektör spina kas hacmi ve akciğer tutulumunun ciddiyeti, yapay zeka tabanlı bir otomatik segmentasyon programı kullanılarak kantitatif olarak analiz edildi. Grup I ve grup II verileri karşılaştırıldı.
Bulgular: Çalışmaya; I. grupta 35, II. grupta 39 olmak üzere 74 kişi dahil edildi. Toplam pulmoner infiltrasyon oranı ile erektör spina kasının hacmi arasında anlamlı negatif korelasyonlar gözlendi. Ayrıca analiz, akciğer yoğunluğunun, toplam akciğer infiltrasyon hacminin, serum CRP seviyesinin, serum ESR seviyesinin ve toplam erektör spina kas hacminin, COVID-19 pnömonisi olan hastalarda akciğer tutulumunun ciddiyetini değerlendirmek için değerli göstergeler olarak hizmet edebileceğini göstermiştir.
Sonuç: Erektör spina kas hacminin ölçülmesi, COVID-19 pnömonisi olan hastalarda pulmoner infiltrasyonların değerlendirilmesinde fayda sağlayacaktır.

Anahtar kelimeler: Erektör spina kas hacmi, COVID-19 pnömonisi, pulmoner infiltrasyon, otomatik segmentasyon, yapay zeka

INTRODUCTION

The outbreak of COVID-19, which is caused by the SARS-CoV-2 virus belonging to the Coronaviridae family, emerged in late 2019 in Wuhan, China, and rapidly escalated into a global pandemic, prompting the World Health Organization (WHO) to declare it a major global health crisis (1,2). Until June 7, 2023, the COVID-19 pandemic has been officially documented across nearly all nations worldwide, affecting close to 767 million individuals and resulting in approximately 6.94 million reported fatalities on a global scale (3).

The gold standard method for confirming SARS-CoV-2 infection is the reverse-transcription polymerase chain reaction (RT-PCR) test, commonly employing samples from the upper respiratory tract. Nevertheless, earlier research indicates that certain RT-PCR tests exhibit reduced sensitivity (4). Chest computed tomography (CT) has demonstrated higher sensitivity in detecting infection when compared to the reverse-transcription polymerase chain reaction (RT-PCR) (5). Among adults, the utilization of thorax CT plays a crucial role as a diagnostic tool for identifying COVID-19 pneumonia (6). The clinical presentation of COVID-19 encompasses a wide range of symptoms, varying from individuals who show no symptoms to those experiencing mild to severe respiratory illness, and in some cases, respiratory failure resulting in death. Several factors and underlying medical conditions have been recognized as influential in determining the prognosis (7).

Research has demonstrated a positive association between overall patient well-being and muscle quality, indicating that quantitative assessments of muscle can serve as a valuable prognostic indicator across various health conditions such as pulmonary disorders (8,9), cirrhosis (10), different types of malignancies (11-13), and surgical outcomes (14,15). Moreover, the presence of low muscle mass has been linked to decreased immune resilience and heightened susceptibility to infectious diseases, including pneumonia (16). Several noninvasive techniques can estimate muscle quantity; among them, magnetic resonance imaging and computed tomography (CT) are considered to be optimal (17). While there are studies in the literature that assess the relationship between muscle mass and COVID-19 pneumonia using different methods in various muscle groups, there is currently no standardized evaluation method available (18,19).

However, to our knowledge, the relationship between the total volume of the erector spinae muscle, measured using an automated segmentation program between the T1-T12 vertebrae, and the lung infiltration ratio in COVID-19 pneumonia has not been investigated. Therefore, our study aimed to perform a quantitative analysis of volume of the erector spinae muscle in COVID-19 pneumonia using an artificial intelligence-based automated segmentation program. Additionally, we aimed to assess the relationship between lung infiltration and volume of the erector spinae muscle.

METHODS

In this retrospective study, thorax CT images of patients with COVID-19 pneumonia were analyzed. The study protocol was approved by the Institutional Ethics Committee (approval number: 2023/21). Patients with incomplete or insufficient data, inadequate CT images, negative results on SARS-CoV-2 RT-PCR testing, a history of surgical procedures, or a cancer diagnosis were excluded from the study (n=37). Between January 2021 and June 2021, a total of 74 symptomatic patients who tested positive for SARS-CoV-2 on RT-PCR underwent standard protocol chest CT scans to evaluate COVID-19 pneumonia. Age, gender, type of medical care (either as inpatient or outpatient), comorbidities, RT-PCR results, laboratory characteristics, such as erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), aspartate and alanine transaminases (AST and ALT), creatine kinase (CK), D-dimer were recorded from patients' files and institutional database. Thorax CT examinations were performed using a 64-slice CT device (General Electric Revolution EVO, 64x2 slices). The scanning range extended from the apex to the base of the lung. Scans were acquired during deep inspiration and breath-hold without contrast administration. The CT scanning protocol included the following parameters: tube voltage of 120 kVp, tube current ranging from 70 to 400 mA, rotation time of 0.5 s, pitch of 1.375, and slice thickness of 5 mm. The Digital Imaging and Communication in Medicine (DICOM) standard images of patients with COVID-19 pneumonia findings on CT were retrospectively obtained from our hospital's Picture Archiving and Communication System (PACS) database. The CT images were imported into the 3D Slicer software using the DICOM standard. The 3D reconstruction module called Editor and Models (version 5.2.2) in 3D Slicer was utilized for calculating the volumes of the erector spinae muscle (between T1-T12 vertebrae), lung volume, lung density, and pulmonary infiltration volume. The lung infiltration ratio was determined by dividing the pulmonary infiltration volume by the lung volume. Figure 1 displays the evaluation of lung infiltration and erector spinae muscle using 3D Slicer. Based on the percentage of pulmonary involvement, the study cohort was divided into two groups. Based on the percentage of pulmonary involvement, the study cohort was divided into two groups. Group I included subjects with a pulmonary infiltration ratio (PIR) less than or equal to 25%, while Group II comprised subjects with a pulmonary infiltration ratio (PIR) of 26% or greater.

Statistical analyses

Statistical analyses were performed using SPSS 18 software (IBM Co, Chicago, Il, USA). Normality analysis of the study variables was conducted using the Kolmogorov-Smirnov test. Variables that followed a normal distribution were analyzed using independent samples t-test and presented as mean and standard deviation. Non-normally distributed variables were presented as median (min-max) and compared using the Mann-Whitney U test. Categorical variables were compared between study groups using the chi-square test and reported as numbers and percentages. ROC analysis was conducted to assess the specificity and sensitivity of the study parameters in detecting pulmonary infiltrations greater than 25%. A p-value less than 0.05 was considered statistically significant.

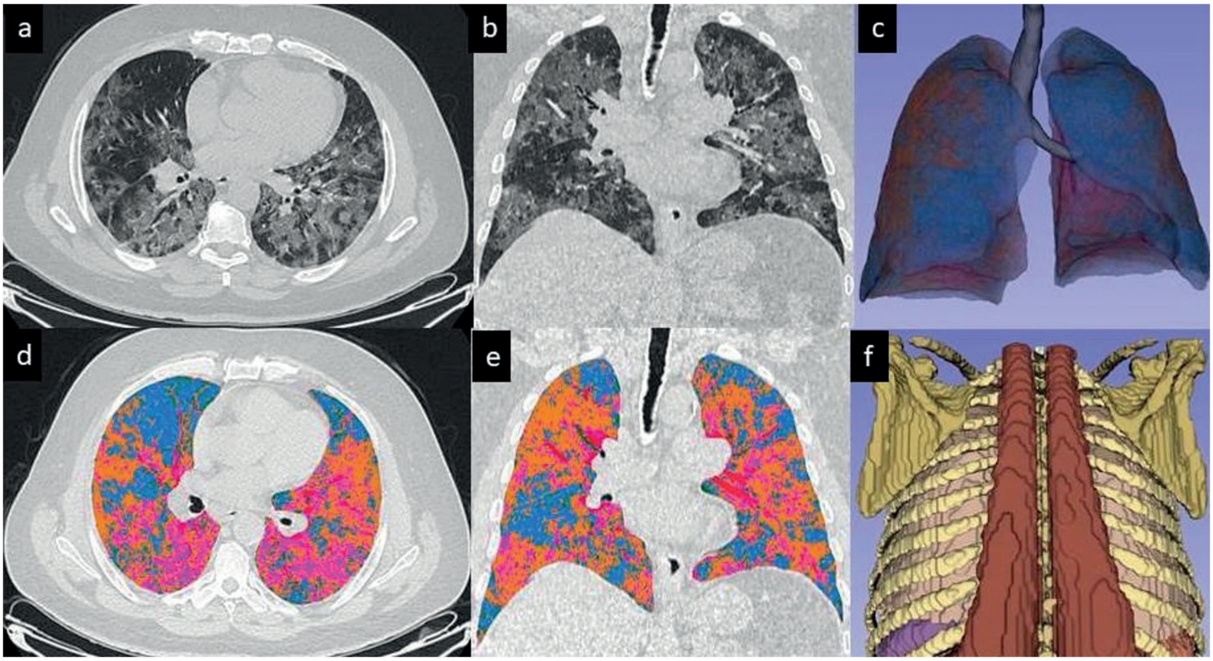

Figure 1. Images of a patient with COVID-19 pneumonia; axial (a), coronal (b) Chest CT images, three-dimensional volumetric (c), axial (d), coronal (e) lung, and erector spinae muscle (f) images obtained using 3D Slicer.

RESULTS

The study population consisted of 74 subjects: 35 in Group I (pulmonary infiltration ratio ≤ 25%) and 39 in Group II (pulmonary infiltration ratio > 25%). The mean ages of Group I and Group II were 56.5 ± 2.3 years and 59.9 ± 2.5 years, respectively (p=0.25). 18 (51%) of Group I and 17 (44%) of Group II were women. Gender of the study and control groups was not statistically different (p=0.50). Table 1 shows the demographic characteristics of the study population.

There were no statistically significant differences between group I and group II in terms of AST (p=0.51), ALT (p=0.18), D-dimer (p=0.09), and CK (p=0.67) levels.

There were no statistically significant differences in comorbidities between the two groups (p=0.13).

The rate of inpatient medical care was significantly higher in Group 2 patients (p=0.02).

Serum ESR (p=0.03) and CRP (p<0.001) levels of Group I and Group II were significantly different.

The mean lung density of subjects in Group I and Group II was (-855 ± 9.5) HU and (-834 ± 6) HU, respectively (p < 0.001).

The mean volumes of right lung infiltration (p < 0.001), total lung infiltration (p < 0.001), left lung dorsal infiltration (p < 0.001), right lung ventral infiltration (p < 0.001), volume of the right erector spinae muscle (p < 0.001), volume of the left erector spinae muscle (p < 0.001), and volume of the total erector spinae muscle (p < 0.001) were found to be significantly different between subjects in Group I and Group II.

Table 1. Demographic characteristics of the study population.

		Group I (n=35)	Group II (n=39)	p
Gender (n,%)	Women	18 (51%)	17 (44%)	0.25
	Men	17 (49%)	22 (56%)	0.25
Age (years)		56.5 ± 2.3	59.9 ± 2.5	0.50

The median volumes of the right lung (p < 0.001), left lung (p < 0.001), total lung (p < 0.001), left lung infiltration (p < 0.001), right lung dorsal infiltration (p < 0.001), left lung ventral infiltration (p < 0.001), and total pulmonary infiltration ratio (p < 0.001) were found to be significantly different between patients in Group I and Group II. Table 2 summarizes the data of group I and group II.

Serum CRP level was significantly and positively correlated with lung density (r: 0.4, p<0.001) and total lung infiltration volume (r: 0.34, p= 0.003). On the other hand, lung density was positively correlated with total lung infiltration volume (r: 0.62, p<0.001). Furthermore, a negative correlation was observed between the total pulmonary infiltration ratio and the volumes of the right erector spinae muscle (r: 0.57, p<0.001), left erector spinae muscle (r: 0.59, p<0.001), and total erector spinae muscle (r: 0.58, p<0.001). Additionally, the analysis revealed a negative association between age and erector spinae muscle volume (r: 0.38, p=0.001).

In ROC analysis, a lung density higher than -845 HU demonstrated 100% sensitivity and 91% specificity in detecting a pulmonary infiltration ratio of 26% or greater (AUC: 0.98, p < 0.001, 95% CI: 0.96-1). A total lung infiltration volume higher than 848 cm3 exhibited 85% sensitivity and 74% specificity in detecting a pulmonary infiltration ratio of 26% or greater (AUC: 0.88, p < 0.001, 95% CI: 0.80- .96). A serum CRP level higher than 75 mg/L showed 72% sensitivity and 74% specificity in detecting a pulmonary infiltration ratio of 26% or greater (AUC: 0.74, p < 0.001, 95% CI: 0.63-0.85). A serum ESR level higher than 69 mm/h demonstrated 69% sensitivity and 63% specificity in detecting a pulmonary infiltration ratio of 26% or greater (AUC: 0.65, p = 0.031, 95% CI: 0.51-0.78). A total erector spinae muscle volume lower than 488 cm3 exhibited 80% sensitivity and 72% specificity in detecting a pulmonary infiltration ratio of 26% or greater (AUC: 0.82, p < 0.001, 95% CI: 0.72-0.92) (Figure 2).

Table 2. Comparative overview of data of group I and group II.

	Group I (n=35)	Group II (n=39)	
	Mean ± Std	**Mean ± Std**	**p**
Lung density (HU)	-855 ± 9.5	-834 ± 6	< **0.001**
Right lung infiltration volume (cm³)	400 ± 82	597 ± 158	< **0.001**
Total lung infiltration volume (cm³)	752 ± 158	1113 ± 306	< **0.001**
Left lung dorsal infiltration volume (cm³)	221 ± 66	318 ± 101	< **0.001**
Right lung ventral infiltration volume (cm³)	140 ± 29	221 ± 67	< **0.001**
Right erector spinae muscle volume (cm³)	287 ± 62	221 ± 41	< **0.001**
Left erector spinae muscle volume (cm³)	284 ± 60	218 ± 40	< **0.001**
Total erector spinae muscle volume (cm³)	571 ± 121	439 ± 79	< **0.001**
	Median (min-max)	**Median (min-max)**	**p**
Right lung volume (cm³)	2060 (1461-3611)	1727 (1078-2736)	< **0.001**
Left lung volume (cm³)	1898 (1226-2994)	1403 (1011-2345)	< **0.001**
Total lung volume (cm³)	4178 (2687-6235)	3263 (2240-4919)	< **0.001**
Left lung infiltration volume (cm³)	332 (208-613)	507 (301-912)	< **0.001**
Right lung dorsal infiltration volume (cm³)	399 (226-580)	572 (379-993)	< **0.001**
Left lung ventral infiltration volume (cm³)	121 (86-238)	185 (102-353)	< **0.001**
Total pulmonary infiltration ratio (%)	20 (8-25)	33 (28-51)	< **0.001**
AST (U/L)	36 (16-514)	38 (18-140)	p=0.51
ALT (U/L)	34 (9-119)	28 (6-81)	p=0.18
D- dimer (μ/mL)	0,66 (0,1-10)	0,90 (0,1-3)	p=0.09
CK (U/L)	106 (7-1402)	108 (8-2038)	p=0.67
ESR (mm/h)	37 (7-140)	52 (13-140)	**p=0.03**
CRP (mg/L)	39 (0.1-234)	123 (0.1-350)	< **0.001**

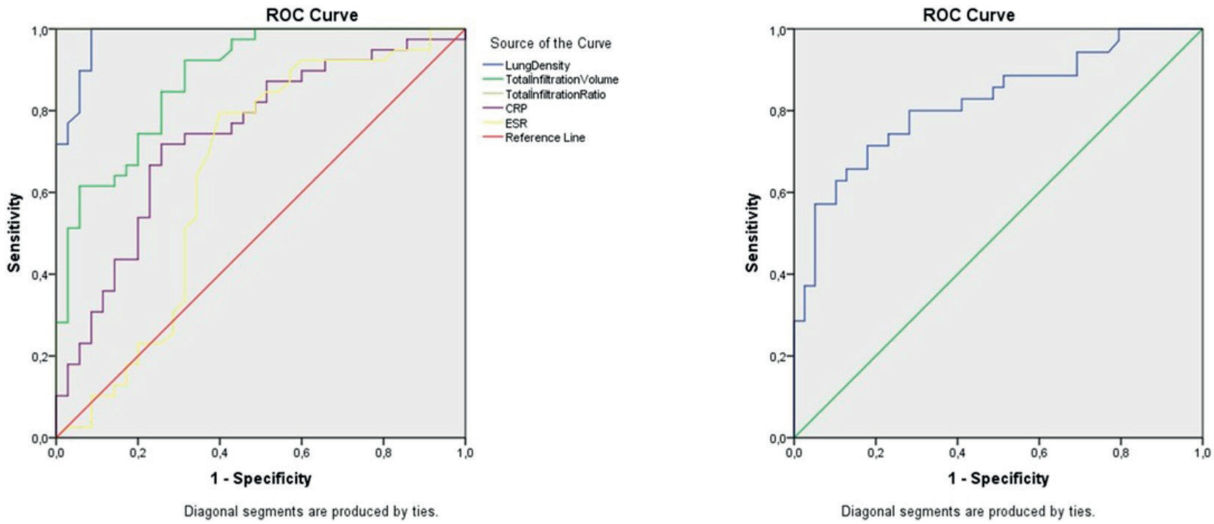

Figure 2. ROC curves of the variables in detecting higher pulmonary infiltration.

DISCUSSION

In our study, we utilized an artificial intelligence-based automated segmentation program to quantitatively analyze the volume of the erector spinae muscle in COVID-19 pneumonia. The findings of our study revealed significant differences in the volumes of the erector spinae muscle and lung infiltrations among patients with varying degrees of pulmonary involvement. Furthermore, significant associations were observed among different variables.

Serum CRP exhibited significant positive correlations with lung density and total lung infiltration volume. Lung density showed a positive correlation with total lung infiltration volume. Conversely, lung density displayed a negative correlation with the volume of the erector spinae muscle. The ROC analysis indicated that lung density, total lung infiltration volume, serum CRP level, serum ESR level, and total erector spinae muscle volume could potentially serve as indicators for detecting a higher pulmonary infiltration ratio. These results emphasize the importance of assessing the volume of the erector spinae muscle and its association with lung infiltration in providing valuable insights into the severity and prognosis of COVID-19 pneumonia.

The relationship between low muscle volumes and mortality has been reported in different populations with various lung diseases, such as chronic obstructive pulmonary disease (COPD) (8), cancer (11), and idiopathic pulmonary fibrosis (20). Moreover, it is associated with surgical outcome in subject with pancreas cancer (12). Computed tomography-based measurements of muscle primarily demonstrate a correlation with the degree of health condition severity. Similarly, there are studies that report the correlation between muscle volume and density and the severity of COVID-19 pneumonia. Hocaoglu et al.[21] reported that the use of CT-derived measurements of the pectoralis muscle can serve as a valuable predictor for determining the severity of COVID-19 pneumonia and the mortality rate in adult patients. Similarly, Beltrão et al.[22] have reported that in their investigation conducted on the first slice, which includes the lung bases, low muscle mass and high visceral fat mass are predictive factors for mortality in patients hospitalized with moderate-to-severe COVID-19. In addition, Giraudo et al.[23] have observed that reduced muscle mass can be used as an indicator for predicting the need for intensive care unit (ICU) hospitalization in patients with COVID-19. Furthermore, it has been reported that low muscle mass is associated with mortality in patients with COVID-19, regardless of other demographic risk factors (18). These findings further support the association between muscle mass and disease severity in COVID-19 patients. The results of our study support the existing literature by demonstrating that lower erector spinae muscle volume is associated with higher levels of lung infiltration and a higher rate of hospitalization in patients with COVID-19.

Additionally, it has been noted in the literature that age and accompanying comorbidities can impact muscle volume (24). However, our study revealed no significant differences in age and accompanying comorbidities between the groups. This finding suggests that low muscle mass may independently serve as a marker for increased lung infiltration in COVID-19 patients.

C-reactive protein serves as a systemic marker of acute-phase response, indicating inflammation, infection, and tissue damage, and can be utilized as an indicator of inflammation (25). Previous studies have suggested that CRP levels can aid in the diagnosis of COVID-19 patients and predict the outcomes of COVID-19 infections (26). Wang27 and Chen et al.[28] have documented a positive correlation between CRP levels and the severity of COVID-19. On the other hand, ESR is another inflammatory marker that primarily reflects changes in various plasma proteins. In COVID-19 patients with pneumonia and severe disease, ESR levels were found to be elevated. However, its prognostic value was limited. The sensitivity and specificity values for pneumonia, intensive care needs, and mortality were lower than those of CRP (29). Additionally, CRP and CRP-based indicators were suggested as predictors of mortality in the CLEAR COVID study (30). According to the results of our study, serum ESR and CRP levels are higher in COVID-19 patients with high lung infiltration. Furthermore, a positive correlation has been observed between CRP and lung infiltration rate, with CRP demonstrating higher sensitivity and specificity compared to ESR.

Limitations of the present study include its retrospective design, single-center nature and relatively small study cohort. However, to the best of our knowledge, our present study is the first in the literature to perform a quantitative analysis of total erector spinae muscle volume in COVID-19 pneumonia using an automated segmentation system.

In conclusion, we found significant differences in muscle volume and lung infiltrations among patients with varying degrees of pulmonary involvement. These results suggest that measuring erector spinae muscle volume may be useful in assessing pulmonary infiltrations in patients with COVID-19 pneumonia.

Ethics Committee Approval: The study protocol was approved by the Institutional Ethics Committee (2023/21).

Conflict of Interest: The authors have declared that they have no conflict of interest.

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