


The thickness of erector spinae muscles can be easily measured by computed tomography for the assessment of physical activity

An observational study

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Abstract

The loss of muscle mass and changes in muscle composition are important factors for assessing skeletal muscle dysfunction. The cross-sectional area (CSA) of muscle is usually used to assess skeletal muscle function. However, the CSA of skeletal muscle can be difficult for clinicians to measure because a specific 3D image analysis system for computed tomography (CT) scans is needed. Therefore, we conducted a study to develop a new method of easily assessing physical activity, in which the thickness of the erector spinae muscles (ESM_T) was measured by CT, and to compare ESM_T to the CSA of the erector spinae muscles (ESM_{CSA}) in patients with nontuberculous mycobacteria (NTM) pulmonary infections who underwent surgery after some preoperative examinations, such as laboratory tests, chest CT scans, spirometry, and 6-minute walk tests (6MWT). We retrospectively studied adult patients with NTM pulmonary infections who underwent a lobectomy at Fukujiji Hospital from April 2010 to March 2016. We assessed the correlations between ESM_T and different variables, including ESM_{CSA}. Sixty-one patients with NTM pulmonary infections were included. The median ESM_T and ESM_{CSA} were 1371 mm² (IQR 1178–1784 mm²) and 28.5 mm (IQR 25.4–31.7 mm), respectively, and a very strong linear correlation was observed between ESM_T and ESM_{CSA} ($R = 0.858$, $P < .001$). ESM_T and ESM_{CSA} were positively associated with body weight (ESM_T: $R = 0.540$, $P < .001$, ESM_{CSA}: $R = 0.714$, $P < .001$), body mass index (ESM_T: $R = 0.421$, $P < .001$, ESM_{CSA}: $R = 0.560$, $P < .001$), the 6MWT value (ESM_T: $R = 0.413$, $P = .040$, ESM_{CSA}: $R = 0.503$, $P = .010$), vital capacity (ESM_T: $R = 0.527$, $P < .001$, ESM_{CSA}: $R = 0.577$, $P < .001$), and the forced expiratory volume in 1 second (ESM_T: $R = 0.460$, $P < .001$, ESM_{CSA}: $R = 0.532$, $P < .001$). We demonstrated that compared to ESM_{CSA}, ESM_T is easily measured by CT and can be a useful parameter for clinically evaluating physical activity. Furthermore, ESM_T and ESM_{CSA} were related to physical activity, as measured by the 6MWT and spirometry.

Abbreviations: 6MWT = 6-minute walk test, BMI = body mass index, COPD = chronic obstructive pulmonary disease, CSA = cross-sectional area, CT = computed tomography, ESM_{CSA} = the cross-sectional area of the erector spinae muscles, ESM_T = thickness of the erector spinae muscles, FEV₁ = forced expiratory volume in 1 second, IQR = interquartile range, MRI = magnetic resonance imaging, NTM = nontuberculous mycobacteria, VC = vital capacity.

Keywords: cross-sectional area, erector spinae muscle, nontuberculous mycobacteria, physical activity, thickness

1. Introduction

The loss of muscle mass and change in muscle composition are important factors for assessing skeletal muscle dysfunction,^[1] and loss of skeletal muscle mass relates to the severity of patients with pulmonary diseases, such as chronic obstructive pulmonary

disease (COPD) and lung cancer.^[1–6] Generally, skeletal muscle mass can be evaluated by the cross-sectional area (CSA) of muscles because the CSA of muscles is correlated with total body muscle mass.^[7] Tanimura et al^[8] reported the CSA of erector spinae muscles (ESM_{CSA}) as a measurement that correlated with the severity of COPD. ESM_{CSA} is usually measured by using a

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The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

The study was approved by the Institutional Review Board of Fukujiji Hospital. Consent was obtained from all patients. The decisions made by this board are based on and in accordance with the Declaration of Helsinki.

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computer-associated 3D imaging software system such as the SYNAPSE VINCENT volume analyzer (FUJIFILM Medical Co., Ltd., Tokyo, Japan) on computed tomography (CT) scans. However, the software has not been introduced in all hospitals, and measurements in the software are complicated; hence, measuring ESM_{CSA} is typically difficult for clinicians. Other methods of measuring skeletal muscle mass include ultrasound,^[9–13] magnetic resonance imaging (MRI),^[14,15] and surface electromyography.^[16] However, ultrasound and MRI require an additional examination to measure the erector spinae muscles because pulmonary diseases are not usually examined by ultrasound of the muscles or chest MRI.^[17,18] Surface electromyography also uses a special device.^[16,19] Accordingly, an easy method of assessing skeletal muscle mass is lacking for clinicians. Therefore, we conducted a study to develop a new easy method of assessing erector spinae muscles for physical activity, such as measuring the thickness of the erector spinae muscles (ESM_T) with CT scans. We compared ESM_T and ESM_{CSA} in patients with nontuberculous mycobacteria (NTM) pulmonary disease who underwent a surgical procedure after some preoperative examinations, such as laboratory tests, chest CT scans, spirometry, and 6-minute walk tests (6MWT).

2. Methods

2.1. Study design and setting

We retrospectively studied adult patients (age ≥ 18 years old) with NTM pulmonary infections who underwent a lobectomy at the Respiratory Disease Center of Fukuji Hospital from April 2010 to March 2016. A total of 156 patients underwent the surgical procedure within this period. We included 61 patients who underwent a lobectomy and could be followed up for 6 months after the surgery. Patients who did not undergo a chest CT scan as a preoperative examination or had spinal diseases or orthopedic diseases were excluded. We demonstrated a correlation between ESM_T and each variable. The main aim of our study was to reveal the correlation between ESM_T and ESM_{CSA} . Data were collected regarding the 6MWT, spirometry, species of NTM, laboratory findings, and other relevant findings. This study was approved by the Institutional Review Board of Fukuji Hospital. Patient consent was not needed. The decisions made by this board are based on and in accordance with the Declaration of Helsinki (study number: 19022).

2.2. Definitions

ESM_T and ESM_{CSA} were measured at the level of the 12th thoracic vertebra on a single-slice axial chest CT scan (Fig. 1), referring to a previous report that measured ESM_{CSA} at the level of the 12th thoracic vertebra.^[8] ESM_T was measured

from the length of the costotransverse joint to the end of the erector spinae muscles vertically. The starting point for measurement of ESM_T was decided as the muscle edge connecting with or close to the costotransverse joint, and the ending point was decided as an intersection of parallel lines of spinous process from the starting point and an edge of muscle at the body surface side. ESM_{CSA} was calculated as the CSA of the erector spinae muscles, as measured by the CT scan using a SYNAPSE VINCENT volume analyzer; the protocol was a modified version of that described in a past report.^[8] Each ESM_T or ESM_{CSA} measurement was calculated as an average of the data from both the right and left sides. Two observers (a doctor and a radiological technician) measured ESM_T independently, and we used the average of the ESM_T measurements made by each observer in this study. Furthermore, we assessed the agreement of the data between the two observers and within the two measurements made by the same observer. The chest CT scan was obtained with 0.5 mm collimation. Patients with NTM pulmonary infections were identified to have characteristic symptoms, compatible radiology findings, and two or more positive sputum samples of the same NTM species or one positive bronchial wash/lavage or compatible histopathological findings with one positive culture. The characteristic symptoms were chronic or recurring cough, sputum production, fatigue, malaise, dyspnea, fever, hemoptysis, chest pain, weight loss, and other factors. Compatible radiology findings were bronchiectasis, bronchial wall thickening, mucus plugging, tree-in-bud opacity, consolidation, nodular change, and cavitation on chest radiograph or CT scan.^[20,21] The patients had symptoms such as cough, sputum production, fatigue, malaise, dyspnea, fever, hemoptysis, chest pain, and weight loss. The patients who had a Brinkman Index of 400 pack-years or more were identified as patients with a history of smoking. The comorbidities were considered either respiratory diseases or nonrespiratory diseases. The respiratory diseases included bronchial asthma, pneumonia, pulmonary tuberculosis, bronchial ectasias, pneumothorax, interstitial pneumonitis, and pulmonary aspergillosis.

2.3. The 6-minute walk test

The 6-minute walk test was conducted in 25 patients. The patients walked at their own pace for 6 minutes along a hospital corridor, and the total distance walked was recorded; this protocol was based on that provided by the American Thoracic Society.^[22]

2.4. Pulmonary function test

The pulmonary function test was conducted according to the American Thoracic Society protocol.^[23] Vital capacity (VC)

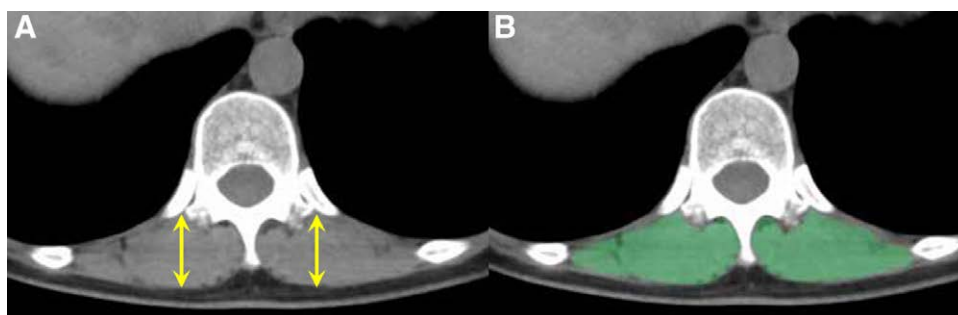


Figure 1. Measurements of the cross-sectional area of skeletal muscles on computed tomography scans. (A) The line drawn vertically from the costotransverse joint to the end of the erector spinae muscles was measured as the ESM_T (yellow arrow). (B) The ESM_{CSA} was calculated as the area within the drawing of the outermost border of the erector spinae muscles (green area). ESM_{CSA} = the cross-sectional area of the erector spinae muscles, ESM_T = thickness of the erector spinae muscles.

and forced expiratory volume in 1 second (FEV_1) were measured from the flow-volume curve obtained with a spirometer (CHESTAC-8900, Chest M.I., Inc., Tokyo, Japan). The predicted pulmonary function values were calculated on the basis of the Japanese Respiratory Society guidelines.^[24]

2.5. Statistical methods

All of the data were analyzed and processed using EZR, version 1.35.^[25] Spearman correlation analysis was performed to identify relationships among the different variables because our data did not show a normal distribution by the Shapiro-Wilk normality test. The interpretation of Spearman correlation was based on the Dancy and Reidy criteria as follows: perfect $R = 1$ or -1 , strong $1 > R \geq 0.7$ or $-1 > r \geq -0.7$, moderate $0.7 > R \geq 0.4$ or $-0.7 > r \geq -0.4$, weak $0.4 > R \geq 0.1$ or $-0.4 > r \geq -0.1$, zero $R = 0$.^[26] The level of statistical significance was set at $P = .05$ (2-tailed).

3. Results

The patients' baseline characteristics are shown in Table 1. The median age was 57 years old (IQR: 43–64), and there were 27 males (44.3%). The NTM species included the *Mycobacterium avium complex* in 45 patients, *Mycobacterium abscessus* in 11 patients, and *Mycobacterium szulgai* in 2 patients. *Mycobacterium massiliense*, *Mycobacterium gordonae*, and *Mycobacterium xenopi* were found in 1 patient. There were 24 patients (39.3%) with symptoms such as cough, sputum production, hemoptysis, dyspnea, and fever. All patients received multiple-drug therapy. The laboratory findings showed normal white blood cell (median 5080/ μ L, interquartile range [IQR] 4350–5920/ μ L), C-reactive protein (median 0.07 mg/dL, IQR 0.03–0.121 mg/dL), and serum albumin levels (median 4.28 g/dL, IQR 4.12–4.48 g/dL). The median percent vital capacity (%VC, 87.4%, IQR 77.8–95.6%) and predicted forced expiratory volume in one second (FEV_1 %, 82.3%, IQR 78.6–85.5%) showed normal respiratory function in spirometry. The median 6MWT was 510 m (IQR 457–550 m). The median ESM_{CSA} and ESM_T were 1371 mm² (IQR 1178–1784 mm²) and 28.5 mm (IQR 25.4–31.7 mm), respectively. All the patients were alive at 6 months after the surgery.

ESM_T had a strong, proportional relationship with ESM_{CSA} ($R = 0.858$, $P < .001$) (Fig. 2). Among the ESM_T measurements taken by the 2 observers (a doctor and a radiological technician), strong linear correlations were observed between the observers ($R = 0.968$, $P < .001$), and the median difference was 0.44 mm (IQR: -0.33 to 0.88) (Fig. 3A). Moreover, regarding the two ESM_T measurements taken by the same observer, strong linear correlations were observed ($R = 0.998$, $P < .001$), and the median difference was 0.02 mm (IQR: -0.60 to 0.51) (Fig. 3B).

Table 2 shows the linear correlation of ESM_T and ESM_{CSA} to several variables. Linear correlations were observed between ESM_T and body weight ($R = 0.540$, $P < .001$) and body mass index (BMI) ($R = 0.421$, $P < .001$), similar to those of ESM_{CSA} (body weight ($R = 0.714$, $P < .001$) and BMI ($R = 0.560$, $P < .001$)). ESM_T and ESM_{CSA} were moderately related to 6MWT (ESM_T : $R = 0.413$, $P = .040$, ESM_{CSA} : $R = 0.503$, $P = .010$), VC (ESM_T : $R = 0.527$, $P < .001$, ESM_{CSA} : $R = 0.577$, $P < .001$), and FEV_1 (ESM_T : $R = 0.460$, $P < .001$, ESM_{CSA} : $R = 0.532$, $P < .001$). Age and laboratory data (white blood cell, C-reactive protein, and serum albumin levels) were not associated with ESM_T or ESM_{CSA} .

4. Discussion

This study demonstrated a strong linear correlation between ESM_T and ESM_{CSA} . ESM_T and ESM_{CSA} were related to many

variables that assess physical activity, such as body weight, BMI, 6MWT, VC, and FEV_1 . In addition, ESM_T could be measured with reproducibility because of strong relationships between 2 observers or 2 measurements taken by the same observer. Therefore, we believe that ESM_T could be a useful and easy clinical evaluation parameter for physical activity instead of ESM_{CSA} , which needs to be measured with special software. Generally, sarcopenia, which is defined as a loss in the amount and strength of skeletal muscle mass in the elderly population, predicts frailty, poor quality of life, and mortality.^[7] Several factors, such as reduced physical activity, appetite loss, and nutritional deficiencies, are involved in the physiopathology of muscle changes.^[27] Therefore, the assessment of skeletal muscle mass might be very important.

Skeletal muscle function is associated with physical activity,^[1,27,28] and muscle mass/strength is related to the severity of COPD or malignancy in patients.^[1–4] Many reports have demonstrated that erector spinae muscle and limb muscle wasting are associated with worsening COPD severity, such as a higher Global Initiative for COPD stage, multiple admissions due to COPD exacerbation, lower FEV_1 , lower BMI, and elderly age.^[1–3,8] The latissimus muscle, abdominal muscles, and quadriceps muscle are also related to COPD severity, although the rectus femoris is not related to disease severity.^[1,3,28] Furthermore, in stage IV non-small cell lung carcinoma patients, an early drop

Table 1
The characteristics of this study.

	n = 61
Age, median (IQR), years	57 (43–64)
Sex (male/female)	27/34
Species of NTM	
MAC, n (%)	45 (73.8)
<i>M abscessus</i> , n (%)	11 (18.0)
<i>M szulgai</i> , n (%)	2 (3.3)
<i>M massiliense</i> , n (%)	1 (1.6)
<i>M gordonae</i> , n (%)	1 (1.6)
<i>M xenopi</i> , n (%)	1 (1.6)
Symptomatic, n (%)	24 (39.3)
Comorbidity, n (%)	44 (72.1)
Respiratory disease, n (%)	15 (23.4)
Non-respiratory disease, n (%)	41 (67.2)
Smoking history, n (%)	9 (14.8)
Body height, median (IQR), cm	165.1 (158.5–171.0)
Body weight, median (IQR), kg	53.4 (48.4–61.9)
BMI, median (IQR), kg/m ²	20.0 (18.6–22.0)
Antibiotic therapy, n (%)	61 (100%)
Laboratory findings	
WBC, median (IQR)/ μ L	5080 (4350–5920)
Neutrophils, median (IQR)/ μ L	2926 (2371–3612)
Lymphocytes, median (IQR)/ μ L	1348 (1141–1723)
CRP, median (IQR), mg/dL	0.07 (0.03–0.21)
Albumin, median (IQR), g/dL	4.28 (4.12–4.48)
Spirometry results	
VC, median (IQR), L	2.88 (2.48–3.42)
%VC, median (IQR), %	87.4 (77.8–95.6)
FEV_1 , median (IQR), L	2.30 (1.98–2.79)
FEV_1 predicted, median (IQR), %	82.3 (78.6–85.5)
6MWT, median (IQR), m ¹	510 (457–550)
ESM_{CSA} , median (IQR), mm ²	1371 (1178–1784)
ESM_T , median (IQR), mm	28.5 (25.4–31.7)

6MWT = six-minute walk test, BMI = body mass index, CRP = C-reactive protein, ESM_{CSA} = the cross-sectional area of the erector spinae muscles, ESM_T = the erector spinae muscles, FEV_1 = forced expiratory volume in one second, IQR = interquartile range, MAC = *Mycobacterium avium complex*, *M abscessus* = *Mycobacterium abscessus*, *M gordonae* = *Mycobacterium gordonae*, *M massiliense* = *Mycobacterium massiliense*, *M szulgai* = *Mycobacterium szulgai*, *M xenopi* = *Mycobacterium xenopi*, NTM = nontuberculous mycobacteria, VC = vital capacity, WBC = white blood cell.

*n = 25.

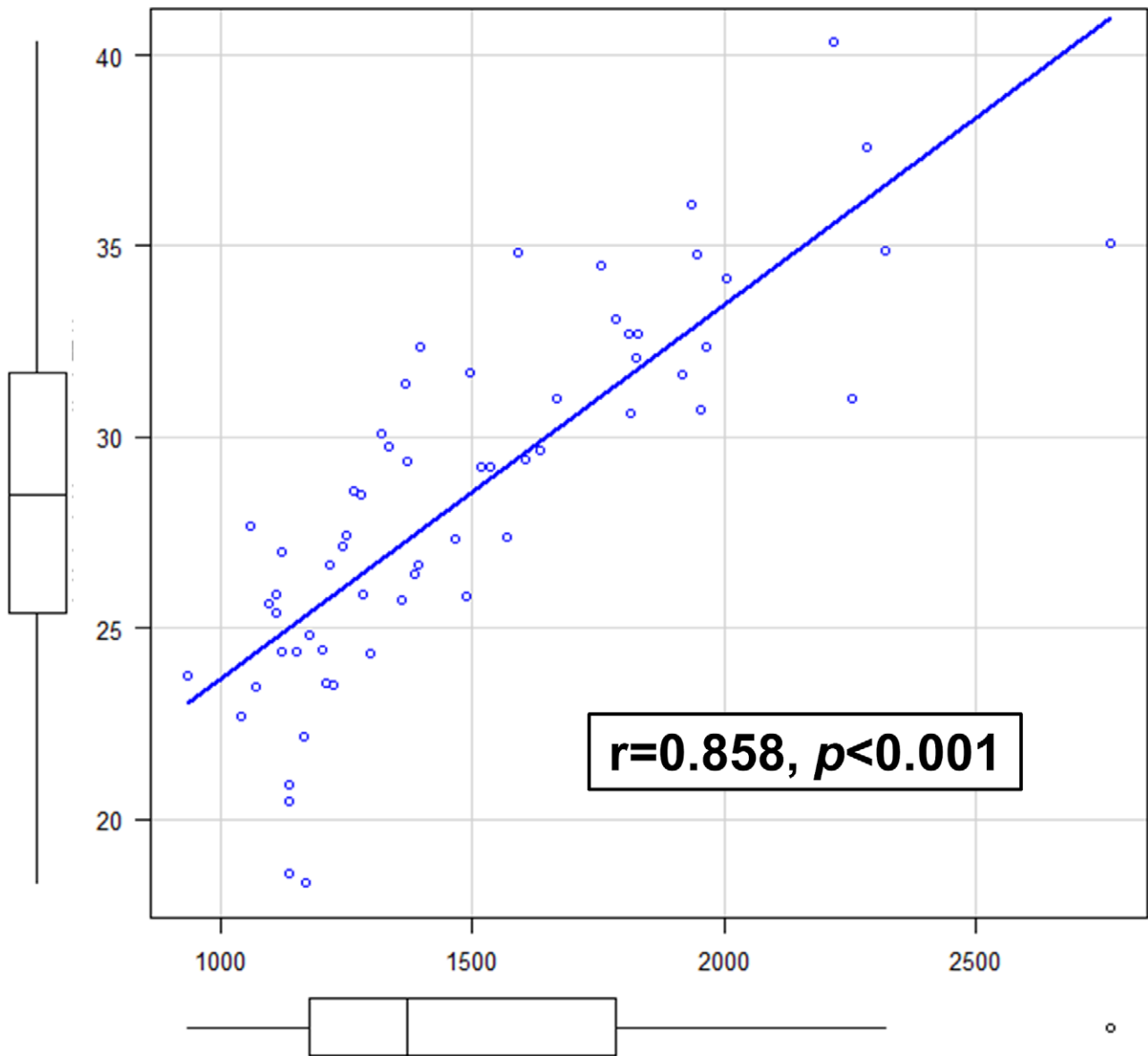


Figure 2. Pearson correlation analysis between ESM_T and ESM_{CSA} . ESM_T had a very strong, proportional relationship with ESM_{CSA} ($R = 0.886$, $P < .001$). ESM_{CSA} = the cross-sectional area of the erector spinae muscles, ESM_T = thickness of the erector spinae muscles.

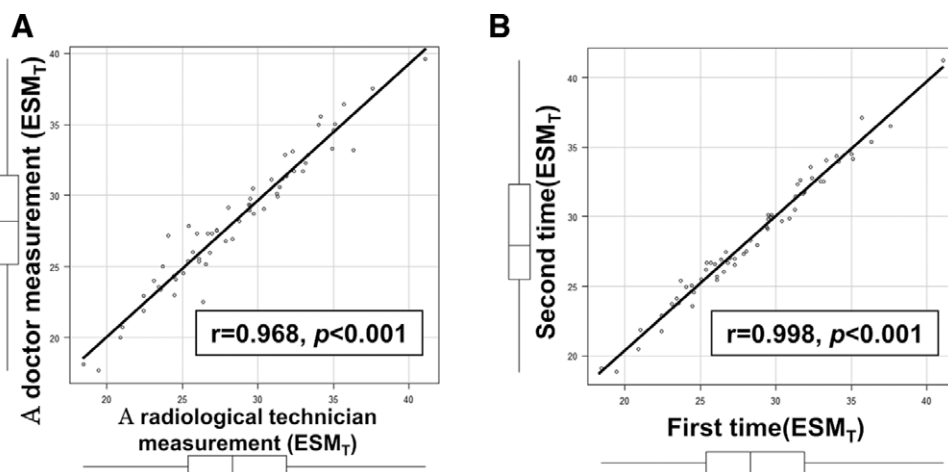


Figure 3. Linear correlations among the ESM_T measurements indicating accuracy. (A) Between the doctor and radiological technician. (B) The two measurements made by the same observer. ESM_T = thickness of the erector spinae muscles.

Table 2
Pearson correlation analysis for ESM_T and ESM_{CSA}*

	ESM _T		ESM _{CSA}	
	r	P value	r	P value
Age	-0.256	.047	-0.181	.163
Body weight	0.540	<.001	0.714	<.001
BMI	0.421	<.001	0.560	<.001
6MWT distance	0.413	.040	0.503	.010
Spirometry VC	0.527	<.001	0.577	<.001
Spirometry %VC	0.369	.003	0.265	.039
Spirometry FEV ₁	0.460	<.001	0.532	<.001
Spirometry FEV ₁ %	-0.056	.670	0.070	.594
WBC count	0.209	.106	0.217	.092
Neutrophils count	0.174	.179	0.139	.284
Lymphocytes count	0.044	.737	0.128	.324
CRP level	-0.185	.153	-0.048	.716
Serum albumin level	0.129	.321	0.041	.748

6MWT = six-minute walk test, BMI = body mass index, CRP = C-reactive protein, ESM_{CSA} = the cross-sectional area of the erector spinae muscles, ESM_T = the erector spinae muscles, FEV₁ = forced expiratory volume in one second, VC = vital capacity, WBC = white blood cell.

in the CSA of skeletal muscle during first-line chemotherapy is a poor prognostic factor.^[41] Those reports evaluated the CSA of skeletal muscles by using computer-associated imaging software for CT scans.^[11-4,81] Our hospital introduced a 3D image analysis system named the SYNAPSE VINCENT volume analyzer; the system is very useful for evaluating respiratory function, surgical simulation function, virtual bronchoscopic navigation, and other parameters.^[29-31] However, the software has not been introduced in all hospitals. In addition, not all patients can be assessed with the ESM_{CSA} measurement because of the labor-intensive process, even if the hospital installs the software. Conversely, ESM_T can be simply measured in a short time for all patients who undergo chest CT scans. While ultrasound can also easily evaluate the CSAs and the thicknesses of various muscles,^[10-13,32-34] pulmonary diseases are not usually examined with an ultrasound evaluation of the muscles; thus, ultrasound would be an additional examination.^[17] Chest CT scans that include the erector spinae muscles are usually performed to aid in the diagnosis, evaluation, and/or exclusion of pulmonary diseases.^[8] In addition, our data showed that ESM_T could evaluate physical activity thorough ESM_T and was related to body weight, BMI, 6MWT, VC, and FEV₁, similar to ESM_{CSA}. Therefore, among patients with pulmonary disease, ESM_T can be a more useful and easier parameter for assessing skeletal muscle mass without the need for a 3D image analysis system than the parameters of other skeletal muscles.

We demonstrated that ESM_T could evaluate the physical activity of patients with NTM pulmonary infections, similar to ESM_{CSA}. According to the study by Tanimura et al, ESM_{CSA} was significantly correlated with body weight, VC, and FEV₁ in patients with COPD.^[8] These findings were similar to our results; however, our patients suffered from NTM pulmonary infections. NTM is caused by acid-fast-staining bacteria and induces chronic pulmonary disease.^[20,21,35] The main treatment for NTM lung disease is chemotherapy. In some patients who are difficult to treat by chemotherapy, surgical treatment should be considered.^[20,36] Patients with NTM pulmonary diseases showed lower FVC and FEV₁ values than healthy controls,^[37] and the disease severity can affect body weight and nutrition status.^[38] In our study, the physical activity of patients with NTM pulmonary diseases might be related to skeletal muscle mass. According to a past report, the thickness of the quadriceps femoris muscle measured by ultrasonography relates to nutritional risk measurements, such as the Modified Nutrition Risk in Critically Ill score, in intensive care.^[33] The Modified Nutrition Risk in Critically Ill score is associated with mortality in critically ill

patients.^[39] Therefore, ESM_T might be useful for severity evaluations in patients with several diseases, including NTM pulmonary diseases. However, all our patients underwent surgical procedures; therefore, the physical activity level of our patients might be relatively high. Future studies comparing severity with a large number of patients are required to reveal the relationship between skeletal muscle mass and physical activity in patients with NTM pulmonary disease.

This investigation had several limitations. The study was conducted retrospectively in a single center. All of our patients suffered from NTM pulmonary diseases and underwent surgical procedures. We measured ESM_T and ESM_{CSA} at the level of the 12th thoracic vertebra level only and did not measure ESM_T and ESM_{CSA} at other thoracic levels. ESM_T and ESM_{CSA} were not compared in each right and left side of muscle. Data for the evaluation of physical activities other than 6MDT and spirometry, such as grip strength and gait speed, were absent; therefore, ESM_T should also be confirmed as useful for various severity levels and other diseases. In Figure 2, some low ESM_T values appeared to be outliers from the linear correlation. It is necessary to note that patients with low ESM_T values might appear to have less muscle mass than they actually do.

5. Conclusion

We demonstrated that measuring ESM_T, instead of ESM_{CSA}, can be a useful and easy clinical method to evaluate physical activity using CT scans. Furthermore, ESM_T was related to physical activities through assessments such as the 6MWT and spirometry results, similar to ESM_{CSA}.

Author contributions

MS was a major contributor in writing the manuscript. HS conceived and designed the work with the corresponding author. ST, YS, NY, KM, YT, and KO collected patient data. All authors read and approved the final manuscript.

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