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Evaluation of supraspinatus muscle-to-fat infiltration for rotator cuff tear patients using dual-energy computed tomography

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Background: This study aimed to assess fatty infiltration of the supraspinatus muscle (Ssp) using dual-energy computed tomography (CT) in patients with rotator cuff tear.
Methods: This study examined 44 patients (49 shoulders; 21 men, 23 women; mean age, 69 years) who underwent magnetic resonance imaging (MRI) and dual-energy CT. Three orthopedic surgeons evaluated fatty infiltration of the Ssp using the Goutallier classification of MRI, and three orthopedic surgeons measured attenuation (in Hounsfield units) for the same slice using dual-energy CT. We evaluated the following: 1) interobserver reliability of the Goutallier classification, 2) correlations between intramuscular muscle-to-fat ratio and tear size in the rotator cuff or Goutallier classification, and 3) the spectrum curve of attenuation for each energy level of the Goutallier stage.
Results: The κ value for interobserver reliability was 0.721. Significant positive correlations were identified between intramuscular muscle-to-fat ratio and cuff tear size and intramuscular muscle-to-fat ratio and Goutallier classification. Moreover, the Ssp showed no change in attenuation at Goutallier stage 0, but as Goutallier stage increased, attenuation decreased at low energy.
Conclusion: We investigated the evaluation of fatty infiltration in Ssp using dual-energy CT in patients with rotator cuff tears. Positive correlations were seen between the Goutallier classification from MRI and rotator cuff intramuscular fat ratio from dual-energy CT. Moreover, changes in attenuation showed that higher Goutallier stages contained more fat. Our data suggest the potential utility of dual-energy CT for evaluating fatty infiltration of rotator cuff muscles.

Rotator cuff tear (RCT) is a common injury in the elderly, and rotator cuff repairs are a common surgery worldwide. Various factors have been reported to influence postoperative clinical outcomes, including patient age,[16] tear size,[10] and surgical techniques.[11] Preoperative fatty infiltration of the rotator cuff muscles is a particularly important factor affecting the outcome of rotator cuff repair.[4] Fatty infiltration is often evaluated using the Goutallier classification,[8] but significant interobserver variability is seen with this method.[19] Variability is primarily attributable to the subjective, visual nature of the evaluation. Recent reports have described quantitative measures of fatty infiltration using magnetic resonance imaging (MRI), such as the Dixon method[14] and the iterative decomposition of echoes of asymmetrical length method.[12] However, MRI may not be applicable in all cases due to patient factors, such as the presence of metal in the patient (eg, pacemakers, clinical devices, etc.) or conditions such as claustrophobia. This imaging modality takes more time and money than general imaging examinations. On the other hand, computed tomography (CT) involves exposure to radiation, but offers ease of imaging and requires short period of time. The use of CT for examining various aspects of RCTs has been reported, such as the relationship between rotator cuff healing and clinical score,[3] RCTs and bone mineral density,[18] and the characteristics of acromion morphology.[7] These reports have shown the utility of CT for examining RCTs. The conventional CT is single-energy CT (SECT), which uses a single X-ray. Different materials thus appear as the same material if they show the same attenuation value (measured in Hounsfield units [HUs]). In this study, we used dual-energy CT (DECT), which uses two different X-ray sources. This provides better imaging with decreased use of contrast agents and can change the energy (units: kiloelectron volts). As a result, materials can be distinguished and identified based on the change in attenuation value.[15] We evaluated

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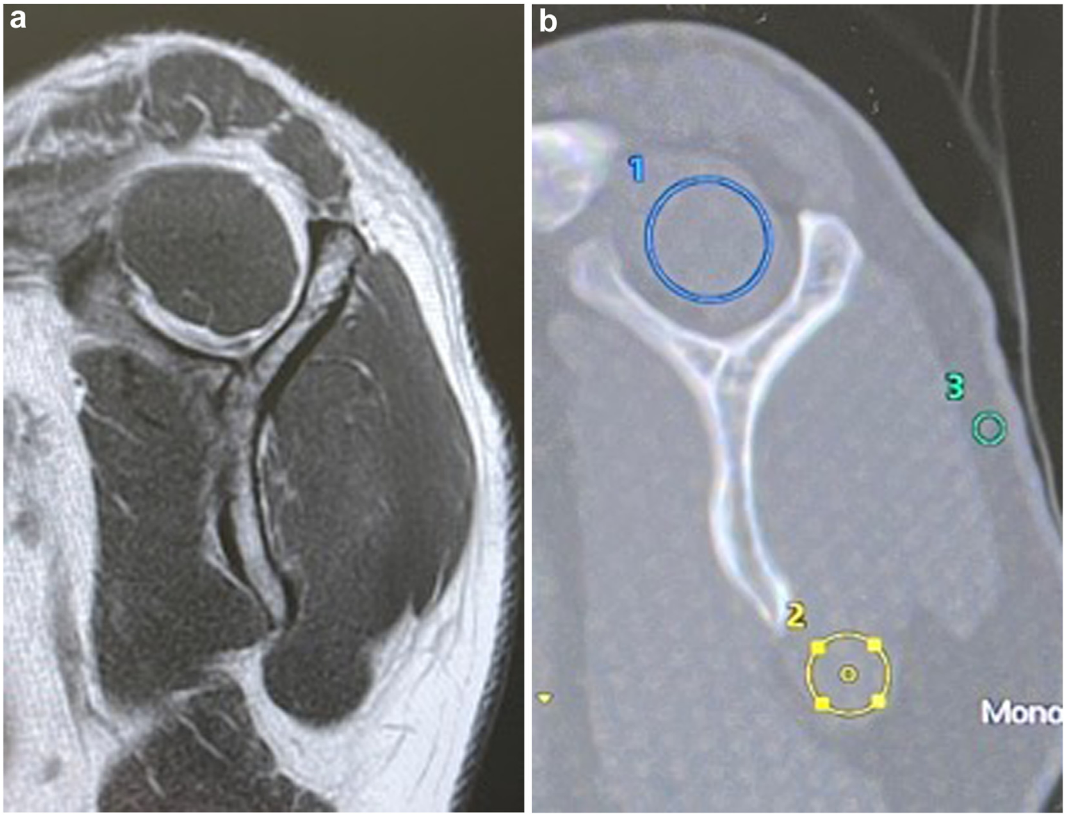

Figure 1 The evaluation site is taken from the lateral-most image of the scapular spine in contact with the scapular body. We measured attenuation at the supraspinatus muscle (Ssp) (1), teres major muscle (2), and subcutaneous fat (3) in dual-energy computed tomography. (**a**): magnetic resonance imaging; (**b**): dual-energy computed tomography.

Table I
Goutallier classifications by each observer.

	Stage 0	Stage 1	Stage 2	Stage 3	Stage 4
Observer 1	3	26	9	6	5
Observer 2	5	24	9	4	7
Observer 3	6	23	11	4	5

rotator cuff muscle using DECT and hypothesized that DECT can allow quantitative measurement of fatty infiltration in place of the more subjective Goutallier classification using MRI.

The purpose of this study was to evaluate the relationship between the Goutallier classification using MRI and CT attenuation in HU at various energy levels using DECT for the supraspinatus muscle (Ssp) in patients with RCTs.

Materials and methods

This research was approved by the institutional review board.

Study population

This prospective study compared MRI and DECT findings. The participants in this study were 44 patients (49 shoulders; 21 men, 23 women) who were diagnosed with RCT by MRI and underwent DECT between January 2024 and April 2024 in our hospital. The exclusion criteria were age under 18 years, the absence of a prior medical history of shoulder pain, or the absence of informed consent to participate in this study. The mean age at the time of examination was 69 years (range, 42-84 years). Tear size according to preoperative MRI was incomplete in 13 shoulders, a small tear (<1 cm) in 6 shoulders, medium tear (<3 cm but ≥1 cm) in 13 shoulders, large tear (<5 cm but ≥3 cm) in 9 shoulders, and massive tear (≥5 cm) in 8 shoulders according to the classification of DeOrio and Cofield.[5]

Imaging techniques

MRI

We assessed the severity of RCT and muscle fatty infiltration using 1.5-T MRI (SIGNA Explorer version SV25.2; GE Healthcare, Milwaukee, WI, USA) with a 16-channel, GEM large flex coil (GE Healthcare, Milwaukee, WI, USA). The patient lay supine with the arm in neutral rotation alongside the chest. Imaging parameters for this sequence were as follows: two-dimensional imaging; fast spin echo; propeller; field of view, 180 × 180 mm^2; acquisition matrix size, 260 × 260 mm^2; slice thickness, 4 mm × 0.4 mm; repetition time, 684 ms; echo time, 24.4 ms; echo train length, 6; and the number of excitations, 1.5. The acquisition time of this sequence was 2 minutes and 16 seconds. MRI costs 20,000 Japanese yen per scan for the shoulder and takes approximately 20 min in our hospital.

DECT

All patients underwent noncontrast CT of the shoulder using a DECT scanner (Aquilion ONE PRISM Edition, version 10.12; Canon Medical Systems Corporation, Tochigi, Japan), with tube voltages set at 80/135 kV. The patient was scanned in a supine position similar to the position used in MRI. Slice thickness was 3.0 mm, and automatic exposure control was used to change the nominal volume CT dose index (CTDIvol) according to the body size of the individual patient. Both SECT and DECT cost 15,000 Japanese yen per scan for the shoulder and take approximately 5 min in our hospital.

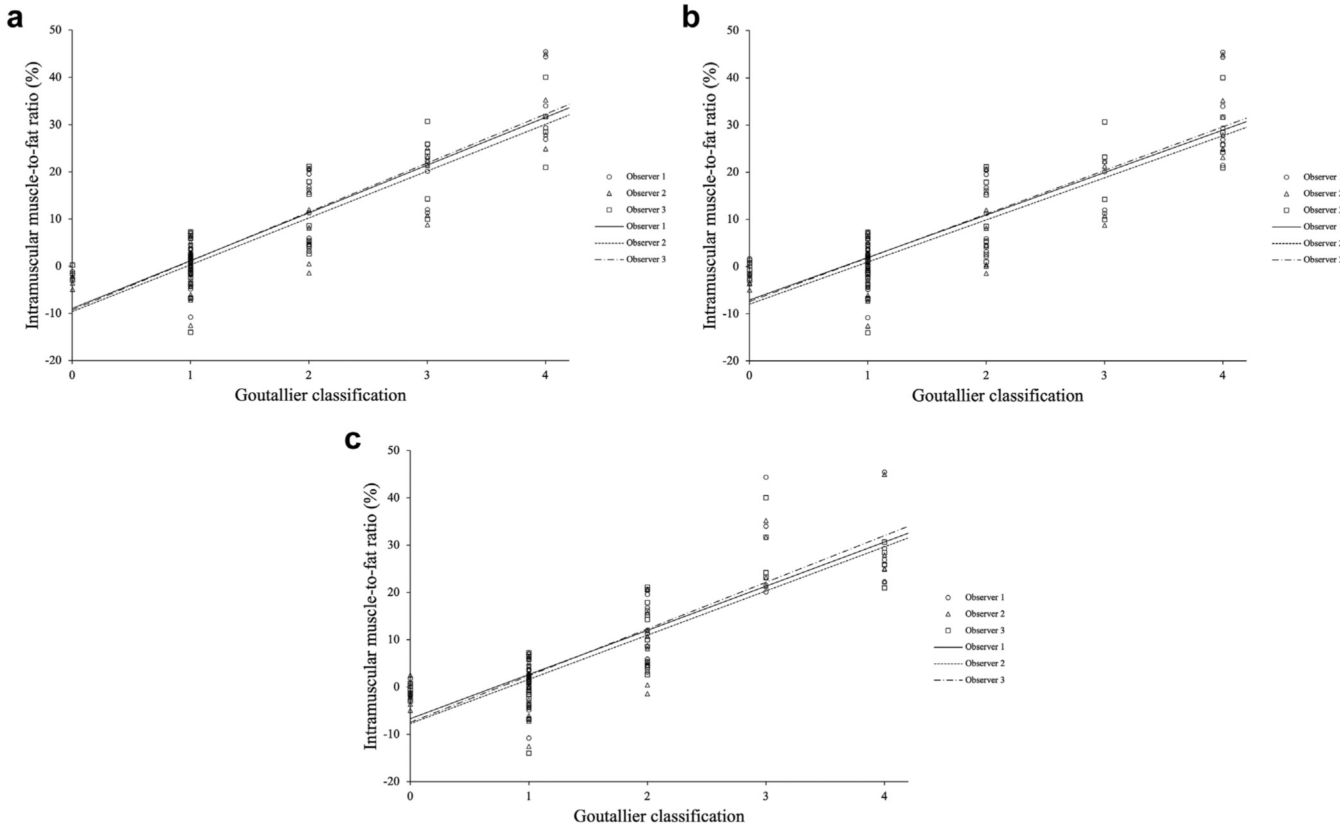

Figure 2 A significant positive correlation is seen for all three observers. (**a**): Goutallier classification observer 1- intramuscular muscle-to-fat ratio observer 1: $\rho = 0.870$, $P < .001$; observer 2: $\rho = 0.811$, $P < .001$; observer 3: $\rho = 0.838$, $P < .001$. (**b**): Goutallier classification observer 2- intramuscular muscle-to-fat ratio observer 1: $\rho = 0.840$, $P < .001$; observer 2: $\rho = 0.790$, $P < .001$; observer 3: $\rho = 0.801$, $P < .001$. (**c**): Goutallier classification observer 3- intramuscular muscle-to-fat ratio observer 1: $\rho = 0.852$, $P < .001$; observer 2: $\rho = 0.784$, $P < .001$; observer 3: $\rho = 0.826$, $P < .001$.

Evaluations

MRI

We evaluated the Ssp on the lateral-most image showing the scapular spine in contact with the scapular body on a T1-weighted oblique-sagittal view, as described by Thomazeau et al.[20] Three expert shoulder surgeons independently evaluated each case once using the Goutallier classification[8] (Fig. 1, *a*).

DECT

CT images were evaluated in the same slice as the MRI oblique-sagittal view. Three orthopedic surgeons placed a region of interest (ROI) to include the rotator cuff muscle, normal muscle tissue, and fat tissue and then measured CT attenuation in HU. We chose the Ssp as the rotator cuff muscle, the teres major muscle as the normal muscle tissue, and subcutaneous fat as the normal fat tissue for individual standardization. ROIs were set as perfect circles to fit within each tissue (Fig. 1, *b*). Based on each attenuation value, the intramuscular muscle-to-fat ratio was calculated using the following equation, as described by Baillargeon et al[1]:

Intramuscular muscle-to-fat ratio (%) = [attenuation of teres major (HU) − attenuation of Ssp (HU)]/[attenuation of teres major (HU) − attenuation of subcutaneous fat (HU)] × 100

Statistical analysis

Kappa analysis with 95% confidence intervals (95% CIs) was used to evaluate interobserver reliability for the Goutallier classification. Spearman's rank correlation coefficient was used to measure rank correlation between intramuscular muscle-to-fat ratio and RCT size or Goutallier classification. All data were analyzed using SPSS for Mac version 26 (IBM Corp., Armonk, NY, USA). The values of $P < .05$ were considered significant. We created a spectrum curve from attenuation (HU) at each energy level of the Goutallier stage.

Results

Interobserver reliability of the Goutallier classification

Goutallier classification according to each observer is shown in Table I. For overall interobserver reliability, kappa statistical analysis revealed a κ value of 0.721 ($P < .001$, 95%CI 0.718-0.724). Interobserver reliability at each stage was as follows: stage 0, $\kappa = 0.605$ (95% CI 0.600-0.610); stage 1, $\kappa = 0.810$ (95% CI 0.804-0.815); stage 2, $\kappa = 0.828$ (95% CI 0.823-0.833); stage 3, $\kappa = 0.447$ (95% CI 0.442-0.453); and stage 4, $\kappa = 0.667$ (95% CI 0.662-0.673).

Correlation between intramuscular muscle-to-fat ratio and RCT size or Goutallier classification

A significant positive correlation was seen between intramuscular muscle-to-fat ratio and RCT size (Observer 1: $\rho = 0.825$, $P < .001$; observer 2: $\rho = 0.785$, $P < .001$; and observer 3: $\rho = 0.820$, $P < .001$). Furthermore, a significant positive correlation between intramuscular muscle-to-fat ratio and Goutallier stage was seen for each observer, with the strongest positive correlation at 70 keV (Fig. 2).

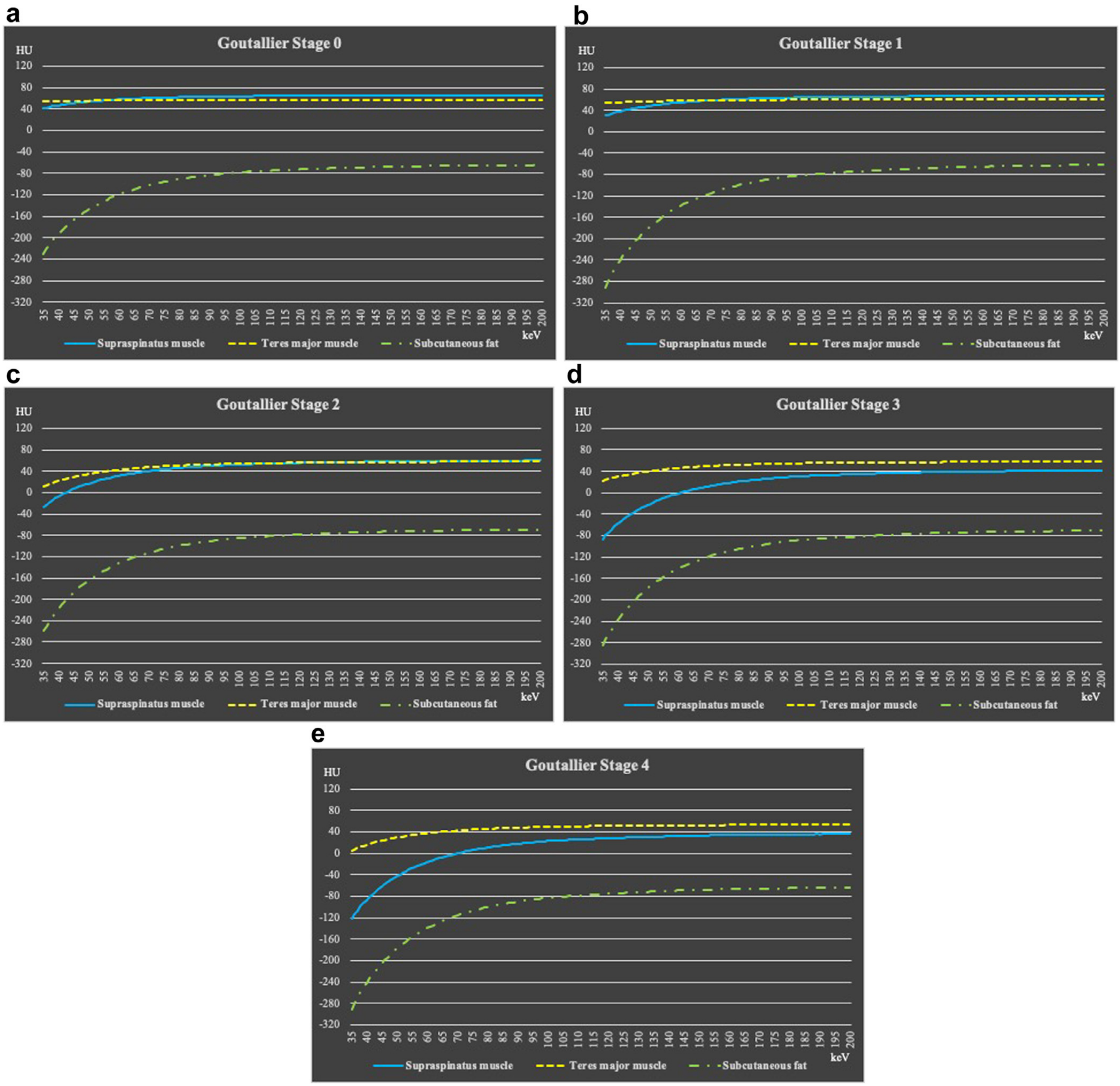

Figure 3 Attenuation in the Ssp at Goutallier stage 0 does not decrease at lower energy, unlike normal muscle tissue. However, as Goutallier stage increased and attenuation of Ssp decreased, similar to attenuation of normal fat tissue. (**a**): Goutallier stage 0, (**b**): Goutallier stage 1, (**c**): Goutallier stage 2, (**d**): Goutallier stage 3, (**e**): Goutallier stage 4.

Spectrum curve from attenuation for each energy level of the Goutallier stage

Spectrum curves for each Goutallier stage are shown in Figure 3. Subcutaneous fat, representing normal adipose tissue, showed decreased attenuation at low energy in all stages. On the other hand, teres major muscle, as normal muscle tissue, showed no change at low energy in any stages. Ssp showed no change at Goutallier stage 0, but as Goutallier stage increased, attenuation decreased at low energy.

Discussion

The Goutallier classification has been used worldwide for evaluating the rotator cuff muscles, but the interobserver variability identified was attributed to subjective visual evaluation.[19] Interobserver reliability in our study was $\kappa = 0.721$, by three expert shoulder surgeons, each with over 10 years of experience in this field. Interobserver reliability was not high, supporting previous reports.[19] New methods for quantitatively evaluating new methods of determining fat infiltration using MRI have thus been examined recently. We focused on the evaluation of fatty infiltration using CT in this study. In particular, we used DECT to distinguish between substances of differing CT attenuation. Reports have described the application of DECT to shoulder joint pathologies, such as the evaluation of the glenoid labrum,[6] reduction of artifacts after arthroplasty,[17] and humeral head necrosis after proximal humeral fracture.[9] In particular, only one report appears to have evaluated rotator cuff muscle. Baillargeon et al[1] compared the relationship

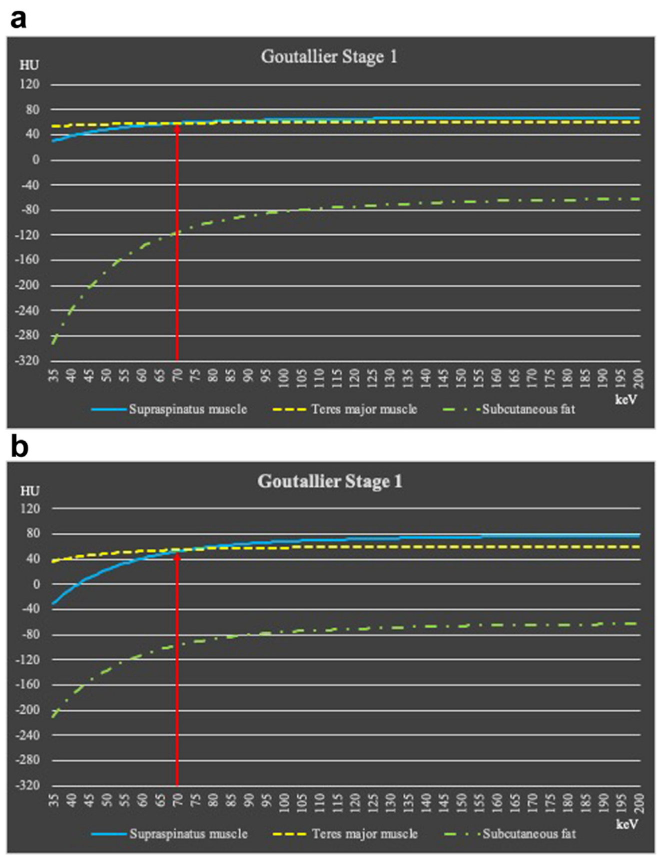

Figure 4 Even though attenuation of Ssp was almost the same as normal muscle tissues at 70 keV, at lower energy values attenuation either remained unchanged (**a**) or showed a decrease (**b**).

between fat fraction and Goutallier classification using SECT and DECT, finding no significant difference, but a more positive correlation with DECT than with SECT. However, that study did not limit participants to only patients with RCT, and the energy used was only 70 keV. We therefore chose only patients with RCT and evaluated relationships between intramuscular muscle-to-fat ratio and RCT size or Goutallier classification using various energy levels. First, a significant positive correlation was identified between RCT size and intramuscular muscle-to-fat ratio. This indicated that fat content within the rotator cuff muscle increased with larger tears. Barry et al examined the relationship between fat infiltration and the severity of the RCT for the Ssp.[2] Our result suggests that DECT might also be able to assess the relationship between fat infiltration and RCT size. Furthermore, a significant positive correlation was seen between intramuscular muscle-to-fat ratio and Goutallier stage at all energy levels from 35 keV to 200 keV. Among these, 70 keV showed the highest correlation among all observers, with a correlation coefficient close to 0.8 at 70 keV, similar to the results reported by Baillargeon et al.[1] The intramuscular muscle-to-fat ratio obtained by DECT may thus be related to Goutallier classification.

Regarding the beam energy of 70 keV showing the highest correlation, Matsumoto et al have reported that approximately 70 keV by DECT yielded lower image noise and higher quality than a conventional CT,[13] so our results indicated 70 keV as the most reliable energy level for evaluating muscle tissues.

This study evaluated changes in attenuation for each tissue using energy differences from spectrum curves. In general, the HU of fat tissues in the human body decreases with lower energy X-rays, but muscle tissues do not show such a decrease. Our results indicated that the attenuation of subcutaneous fat decreased with lower energy in all Goutallier stages. On the other hand, Ssp containing a large amount of fat reflecting high Goutallier stage showed that attenuation decreased with lower energy, similar to subcutaneous fat. We confirmed that the degree of fat content in muscle can be assessed by changes in energy level using DECT.

In addition, spectrum curves at the same Goutallier stages were compared. It is something even more interesting that, at 70 keV (equivalent to the 120 keV used in SECT), even though attenuation is almost the same as in normal muscle tissues, some cases showed that HU decreased or did not decrease at lower energy (Fig. 4). This suggests that DECT has potential for evaluating intramuscular fat components that are difficult to visualize by Goutallier classification using MRI and SECT using a single energy level.

In general, MRI is more expensive and takes longer than CT, and this is the case in our hospital. On the other hand, SECT and DECT cost the same and take the same amount of time. DECT is thus cheaper and more convenient than MRI and more accurate than SECT.

This study involved various limitations that should be considered when interpreting the results. First, the small sample size. Second, the use of a circular ROI in the rotator cuff muscle meant that correlations may have been overestimated. Third, we did not consider the degree of muscle atrophy or RCT size. Fourth, we only evaluated the Ssp in this study, so changes in other rotator cuff muscles remain unknown. Fifth, we did not evaluate the fatty ratio of the whole rotator cuff muscle. In addition, we did not directly evaluate intramuscular fat tissue because values obtained in this study were attenuation values in HU. Identifying various causes of fat infiltration was therefore difficult. However, the evaluation of rotator cuff muscles using DECT appears to have potential to evaluate muscle conditions that are difficult to assess using conventional SECT and MRI. We consider DECT as a new evaluation tool. We hope to perform additional investigations in the future to evaluate other rotator cuff muscles and relationships with quantitative measures of fatty infiltration using MRI. Moreover, we want to clarify differences in attenuation and clinical results among similar Goutallier stages.

Conclusion

We investigated evaluations of fat content in rotator cuff muscles using DECT for patients with RCT. A positive correlation was seen between Goutallier classification of MRI and rotator cuff intramuscular muscle-to-fat ratio using DECT by all three observers. Moreover, changes in attenuation due to changes in energy level showed that higher Goutallier stage reflected greater fat content. This result suggested that DECT may be useful as a new tool for evaluating fat infiltration in rotator cuff muscles.

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