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SCIENTIFIC ARTICLE

# The pattern of idiopathic isolated teres minor atrophy with regard to its two-bundle anatomy

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**Abstract**

**Objective** We aimed to analyze the pattern of teres minor atrophy with regard to its two-bundle anatomy and to assess its association with clinical factors.

**Materials and methods** Shoulder MRIs performed between January and December 2016 were retrospectively reviewed. Images were evaluated for the presence and pattern of isolated teres minor atrophy. Isolated teres minor atrophy was categorized into complete or partial pattern, and partial pattern was further classified according to the portion of the muscle that was predominantly affected. The medical records were reviewed to identify clinical factors associated with teres minor atrophy.

**Results** Seventy-eight shoulders out of 1,264 (6.2%) showed isolated teres minor atrophy; complete pattern in 41.0%, and partial pattern in 59.0%. Most cases of partial pattern had predominant involvement of the medial–dorsal component (82.6%). There was no significant association between teres minor atrophy and previous trauma, shoulder instability, osteoarthritis, and previous operation. The history of shoulder instability was more frequently found in patients with isolated teres minor atrophy (6.4%), compared with the control group (2.6%), although the difference was not statistically significant.

**Conclusion** Isolated teres minor atrophy may be either complete or partial, and the partial pattern may involve either the medial–dorsal or the lateral–ventral component of the muscle. The imaging findings of partial pattern teres minor atrophy indicate that the two muscle components may have separate innervation.

**Keywords** Magnetic resonance imaging · Shoulder · Rotator cuff · Teres minor · Isolated teres minor atrophy

## Introduction

The teres minor is included in a group of muscles called the rotator cuff, and is located at the postero-inferior aspect of the glenohumeral joint. It acts as an external rotator and depressor of the humerus in cooperation with the infraspinatus [1, 2]. Its function as an external rotator is especially important when the shoulder is abducted greater than 60°, a position at which the infraspinatus no longer functions as an external rotator [3]. Moreover, it has an important function in patients with massive rotator cuff tears, especially in those extensively involving the infraspinatus tendon [4, 5].

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It is difficult to detect dysfunction of the teres minor muscle based solely on physical examination, as the teres minor acts in cooperation with the infraspinatus muscle [6–8]. Therefore, it is important to recognize the presence of teres minor pathological conditions on imaging. This may be especially important in those with massive rotator cuff tendon tears undergoing reverse total shoulder arthroplasty, as the status of the teres minor muscle is known to be an important prognostic factor in patients undergoing reverse total shoulder arthroplasty [9–11]. A functional teres minor muscle with less fatty infiltration was related to improved external rotation after reverse total shoulder arthroplasty and a better clinical function [10]. The integrity of the teres minor muscle has also been reported to be important in patients undergoing latissimus dorsi tendon transfer for massive, irreparable rotator cuff tendon tears [12].

There has been increasing interest in the teres minor muscle atrophy over the past decade or so [10, 13–17]. It is known that the teres minor muscle may show fatty atrophy without a significant tear in the muscle or tendon itself [1, 6, 7, 18–20].

Teres minor muscle atrophy was initially thought to be a manifestation of quadrilateral space syndrome [21, 22]. However, more recent studies indicate that isolated teres minor atrophy may be a distinctive clinical entity, with different clinical manifestations. Patients with isolated teres minor atrophy did not present with clinical symptoms typical of quadrilateral space syndrome, the average age of the patients was older, and most of the patients had rotator cuff tendon tears [6].

Based on our clinical experience, we have found that cases of isolated teres minor atrophy do not appear identical, and may have various patterns of manifestations. However, previous studies are focused on the presence of isolated teres minor atrophy and its association with other factors, and the pattern of atrophy has not been assessed. A recent anatomical study by Hamada et al. [23] has suggested that the teres minor muscle belly consists of two distinct components. In light of the study by Hamada et al. [23], and based on our clinical experience, we hypothesized that isolated teres minor atrophy might have various patterns of involvement with regard to its two different components, and that the different patterns of involvement might have different causes. Therefore, our aim was to analyze the various patterns of isolated teres minor atrophy with regard to its two-bundle anatomy and to assess the association between the various patterns of isolated teres minor atrophy and clinical factors.

## Materials and methods

This retrospective study was approved by our institutional review board, and informed consent was waived.

### Patient selection

A search of our electronic medical record revealed MR examinations of 1,331 shoulders in 1,284 patients between the period of January 2016 and December 2016. Among these MR examinations, we excluded 67 shoulders in 67 patients for the following reasons:

1. Orthogonal imaging of the shoulder region ($n$ = 55)
2. The presence of tumor in the bone or soft tissue about the scapula or humerus affecting the evaluation of the rotator cuff muscle ($n$ = 7)
3. Absence of adequate pulse sequence to evaluate the fatty infiltration of muscle ($n$ = 1)
4. Fracture of humerus ($n$ = 1)
5. Diffuse muscle abnormality in the rotator cuff such as rhabdomyolysis or denervation due to cervical myelopathy ($n$ = 3)

As a result, the MRI of a total of 1,264 shoulders of 1,217 patients were reviewed to identify cases of isolated or disproportionate teres minor atrophy. An age- and sex-matched control group was randomly selected from the patients without isolated or disproportionate teres minor atrophy for comparison. The age- and sex-matched controls were selected based on a random number generated with Microsoft Excel. The flow diagram of patient selection is shown in Fig. 1.

### Image acquisition and analysis

Our study included both images acquired in our hospital ($n$ = 741) and images that were imported from an outside institution ($n$ = 523), and in turn images were obtained with a variety of MR imagers with magnetic field strengths ranging from 0.3 T to 3.0 T. Images included 103 MR arthrograms and 1,161 conventional MRI of the shoulder, and the imaging protocol and parameters also varied from case to case. However, we ensured that every MRI protocol satisfied the following criteria:

1. The protocol includes either a non-fat-suppressed T1- or T2- or PD-weighted sequence in at least two planes so that the fatty atrophy or infiltration of the muscles can be evaluated.
2. The coronal and sagittal images are obliquely oriented so that the images are either parallel to or perpendicular to the glenoid surface.
3. Sagittal slices are sufficient to cover the rotator cuff muscle bellies, extending medially beyond the mid-body of the scapular; the sagittal slices typically extending approximately 4–5 cm medial to the glenoid surface.

In our hospital, MRI was obtained using either a 1.5-T scanner (Gyroscan Intera, Philips Medical Systems) or a 3.0-T scanner (Achieva or Ingenia; Philips Healthcare, Best, the Netherlands), and included a sagittal T1-weighted and/or T2-weighted sequence and a coronal T2-weighted sequence. The imaging parameters for MRI taken at our institution are summarized in Table 1.

#### The teres minor muscle

The MRI was reviewed by two observers (C.G.C and Y.K., radiologists with 5 and 9 years of musculoskeletal imaging experience respectively), and discrepancies were resolved by a third observer (J.M.A, a radiologist with 25 years of musculoskeletal imaging experience). Non-fat-suppressed T1-weighted, T2-weighted or PD-weighted oblique sagittal and oblique coronal images were viewed for analysis. Fatty degeneration of the muscles were evaluated with reference to the Goutallier classification system (Table 2) [24]. The images were first reviewed to identify cases of isolated teres minor atrophy. Isolated teres minor atrophy was considered present

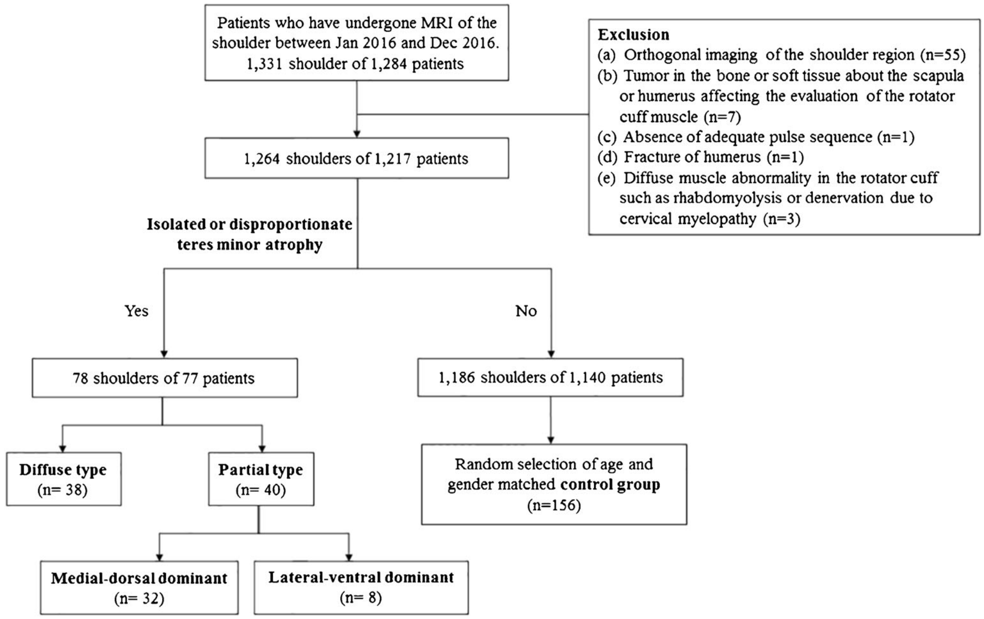


**Fig. 1** Flow diagram of patient selection

when there was an isolated or disproportionate atrophy of the teres minor muscle with reference to other rotator cuff muscles without evidence of a tear in the teres minor tendon or muscle, and without any signal intensity abnormality or atrophy of the deltoid muscle. Atrophy of the teres minor muscle was considered "isolated" when there was absolutely no fatty degeneration of the supraspinatus, infraspinatus, and subscapularis muscles (all stage 0 according to the Goutallier classification system). Atrophy of the teres minor muscle was thought to be "disproportionate" when the teres minor muscle showed fatty degeneration of a higher stage, compared with other rotator cuff muscles with an intact tendon. The atrophy of a torn rotator cuff muscle could be present in cases of disproportionate teres minor atrophy.

As for the cases identified as isolated teres minor atrophy, the pattern of atrophy was classified as either complete or partial. The teres minor muscle was evaluated on sequential oblique sagittal images, focusing on three predefined slices:

1. A slice including the scapular Y-shape.
2. A slice including the glenoid face.
3. A slice including the humeral head and coracoid process (Fig. 2).

The fatty degeneration of the teres minor muscle was graded at each slice according to the Goutallier classification system [24]. Complete pattern teres minor atrophy referred to the cases in which the teres minor showed fatty atrophy or degeneration throughout the muscle regardless of the portion of the muscle being evaluated, whereas partial pattern teres minor atrophy referred to the cases in which the teres minor muscle showed an uneven degree of fatty atrophy or degeneration according to the portion of the muscle being evaluated. If the grade allocated to the teres minor muscle at the predefined slices showed a difference, a partial pattern of teres minor atrophy was considered to be present.

**Table 1** Magnetic resonance imaging acquisition parameters

| Imaging parameter | T1-weighted image | | T2-weighted turbo spin echo | |
|---|---|---|---|---|
| | 1.5 T | 3 T | 1.5 T | 3 T |
| Imaging plane | Oblique sagittal | | Oblique sagittal, oblique coronal | |
| TR (ms)/TE (ms) | 500–700/7–16 | 500–700/10 | 4,000–4,700/80–100 | 2,400–3,500/80–100 |
| Matrix size | 224 × 224 | 256 × 256 | 224 × 224 | 256 × 256 |
| Field of view (cm) | 16 × 16 | 14 × 14 | 16 × 16 | 14 × 14 |
| Section thickness (mm) | 3 | 2.5 | 3 | 2.5 |
| Intersection gap (mm) | 0.3 | 0.25 | 0.3 | 0.25 |
| Echo train length | 3–6 | 6 | 12–16 | 14–18 |
| Number of signals acquired | 2–3 | 1–2 | 2–3 | 1–2 |

**Table 2** Goutallier classification system

| Grade | Magnetic resonance imaging findings |
|---|---|
| 0 | Completely normal muscle without fatty streaks |
| 1 | Muscle contains some fatty streaks |
| 2 | Fatty infiltration and atrophy, but still more muscle than fat |
| 3 | As much fat as muscle |
| 4 | More fat than muscle present |

Classification system of fatty infiltration/atrophy of the rotator cuff muscles developed by Goutallier et al. [24]

With reference to the study by Hamada et al. [23] and based on our clinical experience, the teres minor muscle could be divided in to two components: the medial–dorsal component and the lateral–ventral component, based on the dominant location of the muscle belly (Fig. 2). Partial pattern teres minor atrophy was further classified into either a medial–dorsal dominant partial pattern or a lateral–ventral dominant partial pattern, according to the portion of the muscle that was predominantly affected. The remaining component of the muscle could be either completely normal or show less severe fatty degeneration compared with the predominantly affected component.

In all cases with isolated or disproportionate teres minor atrophy, the insertion of the teres minor muscle was also analyzed. The insertion of the teres minor could be divided into two portions: upper tendinous insertion on the greater tuberosity and lower muscular insertion on the humeral neck (Fig. 2). The two components of the muscles and the two insertions were correlated.

### Associated factors

The quadrilateral space, bounded by the teres major muscle, teres minor muscle, the medial cortex of the humeral neck and the long head of the triceps brachii muscle, was evaluated for the presence of space-occupying lesions or abnormal obliteration of the fat within this space, which may result in quadrilateral space syndrome. The presence of osteoarthritis of the glenohumeral joint was evaluated, and the size of the inferior humeral head osteophyte was measured, when present, on an oblique coronal image using the method of Millett et al. [15].

## Demographic and clinical data analysis

Electronic medical records were reviewed to identify the indications for the MRI examinations. The electronic medical records were evaluated to identify possible causes of teres minor atrophy. The clinical history of the patients was reviewed for the presence of:

1. A previous traumatic event.
2. Shoulder instability, which was defined as a history of shoulder subluxation or dislocation or subjective glenohumeral joint instability.
3. Previous surgical procedures.

The clinical diagnosis of each patient was also listed and divided into the following categories: rotator cuff disorder (rotator cuff tear, calcific tendinitis), adhesive capsulitis, labral abnormality, tumor or others. The electromyography test results were reviewed focusing on the possibility of axillary neuropathy.

## Statistical analysis

The association between isolated teres minor atrophy and clinical factors was analyzed using either Chi-squared test or Fisher's exact test. The size of the inferior humeral osteophyte was compared between groups using the Wilcoxon signed rank test. Continuous variables are presented as mean ± standard deviation. All statistical analyses were performed using STATA (version 14.0; Stata, College Station, TX, USA). A $p$ value $< 0.05$ was considered statistically significant.

# Results

## Teres minor muscle

Among the 1,264 shoulders in 1,217 patients, 78 shoulders in 77 patients showed isolated teres minor atrophy (6.2%); atrophy of the teres minor muscle was isolated in 40 shoulders, and disproportionate in 38 shoulders. The fatty degeneration grades of the medial–dorsal component and lateral–ventral component in the 78 shoulders with isolated teres minor atrophy are summarized in Table 3. Among the 78 shoulders with teres minor atrophy, 41.0% (32 out of 78) showed complete involvement, whereas 59.0% (46 out of 78) showed partial involvement of the teres minor muscle. Most of the shoulders with partial teres minor atrophy had predominant involvement of the medial–dorsal component (82.6%, 38 out of 46), whereas 8 shoulders had predominant involvement of the lateral–ventral component. Representative cases of complete pattern, medial–dorsal-dominant partial pattern, and lateral–ventral-dominant partial pattern of isolated teres minor atrophy are shown in Figs. 3, 4, and 5 respectively. With regard to the humeral insertion of the teres minor muscle, all three observers agreed that the medial–dorsal component of the teres minor muscle had a tendinous attachment to the vertical facet of the greater tuberosity and that the lateral–ventral component had a muscular attachment to the humerus neck in all 78 cases.

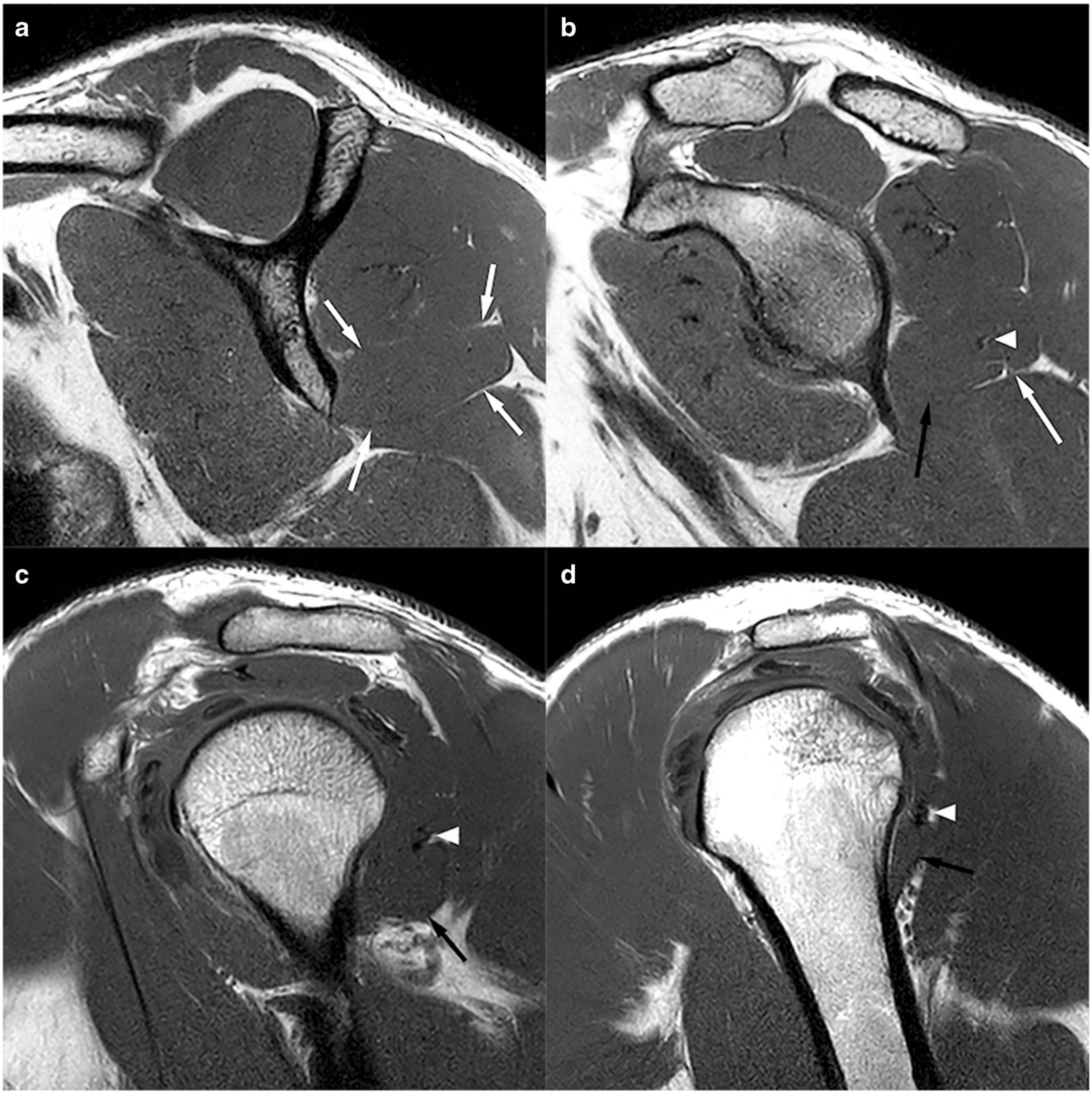


**Fig. 2** Normal teres minor muscle in a 39-year-old man. Sequential oblique sagittal T1-weighted images (TR/TE, 585/8 ms) of the shoulder are shown, at **a** the scapular Y, **b** the glenoid face, and **c**, **d** the coracoid process and humeral head. The teres minor muscle can be divided in to a medial–dorsal component (*white arrows*) and a lateral–ventral component (*black arrows*). A tendon (*white arrowhead*) is noted within the medial–dorsal component, which inserts on the greater tuberosity, whereas the lateral–ventral component has a direct muscular attachment to the humeral neck

## Comparison of the teres minor atrophy group and the control group

The indications for the MRI examinations and the final clinical diagnosis allocated to each patient are summarized in Table 4. Most patients in both groups had undergone MRI for suspected rotator cuff disorder. None of the patients was clinically suspected of quadrilateral space syndrome before MRI, nor were they diagnosed with quadrilateral space syndrome after MRI.

The clinical factors of the teres minor atrophy group and the control group are compared in Table 5. There was no statistically significant association between the presence of isolated teres minor atrophy and the presence of previous trauma, shoulder instability, osteoarthritis, and previous operation. The interval between the traumatic event and the time of MR

**Table 3** Fatty degeneration grade of the medial–dorsal component and the lateral–ventral component in patients with isolated teres minor atrophy

| | | Media–dorsal component fatty degeneration grade | | | | |
|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 |
| Lateral–ventral component fatty degeneration grade | 0 | – | – | 9 | 4 | 7 |
| | 1 | – | – | – | 9 | 8 |
| | 2 | 1 | 2 | *8* | – | 1 |
| | 3 | – | – | – | *9* | – |
| | 4 | 1 | 3 | 1 | – | *15* |

Data are number of patients. Fatty degeneration was graded according to the Goutallier classification system (stage 0, completely normal muscle; stage 1, muscle contains some fatty streaks; stage 2, more muscle than fat; stage 3, as much fat as muscle; stage 4, more fat than muscle). Entries in italics include the complete pattern of isolated teres minor atrophy. The upper right portion and the lower left portion of the table each correspond to the medial–dorsal dominant partial pattern and the lateral–ventral partial pattern of involvement respectively

examination ranged from 5 days to 30 years (median, 11 months; interquartile range, 4–24 months) in the teres minor atrophy group and 3 days to 20 years (median, 8 months; interquartile range, 4–45 months) in the control group. Traumatic events in the teres minor atrophy group included direct lateral contusion ($n = 12$), fall on out-stretched hand ($n = 3$), traffic accidents ($n = 6$), traction injuries ($n = 2$), injuries during sports activity ($n = 7$), and injuries while lifting a heavy object ($n = 2$). The size of the inferior humeral osteophyte did not differ between groups ($p = 0.282$). Although the difference was not statistically significant, history shoulder instability was more frequently found in patients with isolated teres minor atrophy (6.4%, 5 out of 78), compared with the control group (2.6%, 4 out of 156).

### Comparison between different patterns of isolated teres minor atrophy

The demographic and clinical factors of each subgroup of isolated teres minor atrophy are shown in Table 6. No statistically significant association was noted between the pattern of isolated teres minor atrophy and the presence of previous trauma, shoulder instability, osteoarthritis, and previous operation.

### Electromyography results

Among the 78 patients with isolated teres minor atrophy, electromyography results were available in 34 patients. No specific abnormality was found in most of the patients (85.3%, 29 out of 34), whereas 3 patients showed signs of axillary neuropathy partially involving the branches to teres minor muscles, and 2 other patients revealed findings suggestive of C5, C6 radiculopathy. However, these 2 patients did not show any abnormality in muscles other than the teres minor on shoulder MRI.

## Discussion

The frequency of isolated teres minor atrophy was 6.2% in our study, which is a value somewhat higher than those previously reported, which ranged from 3 to 5.5%. Sofka et al. [1] reported that 3% of the routine MRI examinations of the shoulder (61 out of 2,563) showed isolated teres minor atrophy. Another study by Friend et al. [7] showed that 3.3% of the patients presenting with shoulder complaints (2 out of 61) had isolated teres minor atrophy on MRI. A 5.5% frequency of isolated teres minor atrophy (12 out of 216) was reported by Wilson et al. [6] based on MRI. The higher prevalence of teres minor atrophy shown in our study may be partly due to the fact that we considered the partial pattern of isolated teres minor atrophy. Without knowledge of the two-bundle anatomy, the partial pattern involving the medial–dorsal component may be overlooked, if the medial portion of the muscle is not thoroughly evaluated.

In our study, we observed that the teres minor muscle could be divided into two different components; the medial–dorsal component and the lateral–ventral component. The findings of our study further support the recent anatomical study by Hamada et al. [23]. In their study, Hamada et al. suggested that the teres minor muscle consists of two distinct muscular bundles, which are independent in their origin and insertion; the upper portion inserting on the greater tuberosity and the lower portion inserting on the surgical neck of the humerus. They have stated that the two portions changed their positional relationship at the origin and the insertion. We found the terms upper and lower portions rather confusing owing to this change in positional relationship. Instead we have divided the two portions of the muscle into medial–dorsal and lateral–ventral components according to the dominant location of the muscle belly on MRI. In all patients with teres minor atrophy the medial–dorsal component inserted on the vertical facet of the greater tuberosity and the lateral–ventral component on the surgical neck of the humerus. Based on this observation, we presumptively conclude that the medial–dorsal component described in our study corresponds to the upper portion described by Hamada et al., and that the lateral–ventral component described in our study corresponds to the lower portion described by Hamada et al. [23].

The partial pattern of teres minor atrophy, predominantly involving either the medial–dorsal component or the lateral–ventral component, indicates that the two components may have separate innervation. A cadaveric study by Chafik et al. [25] reported the presence of accessory motor innervation to the teres minor. The accessory nerves were found to vary in

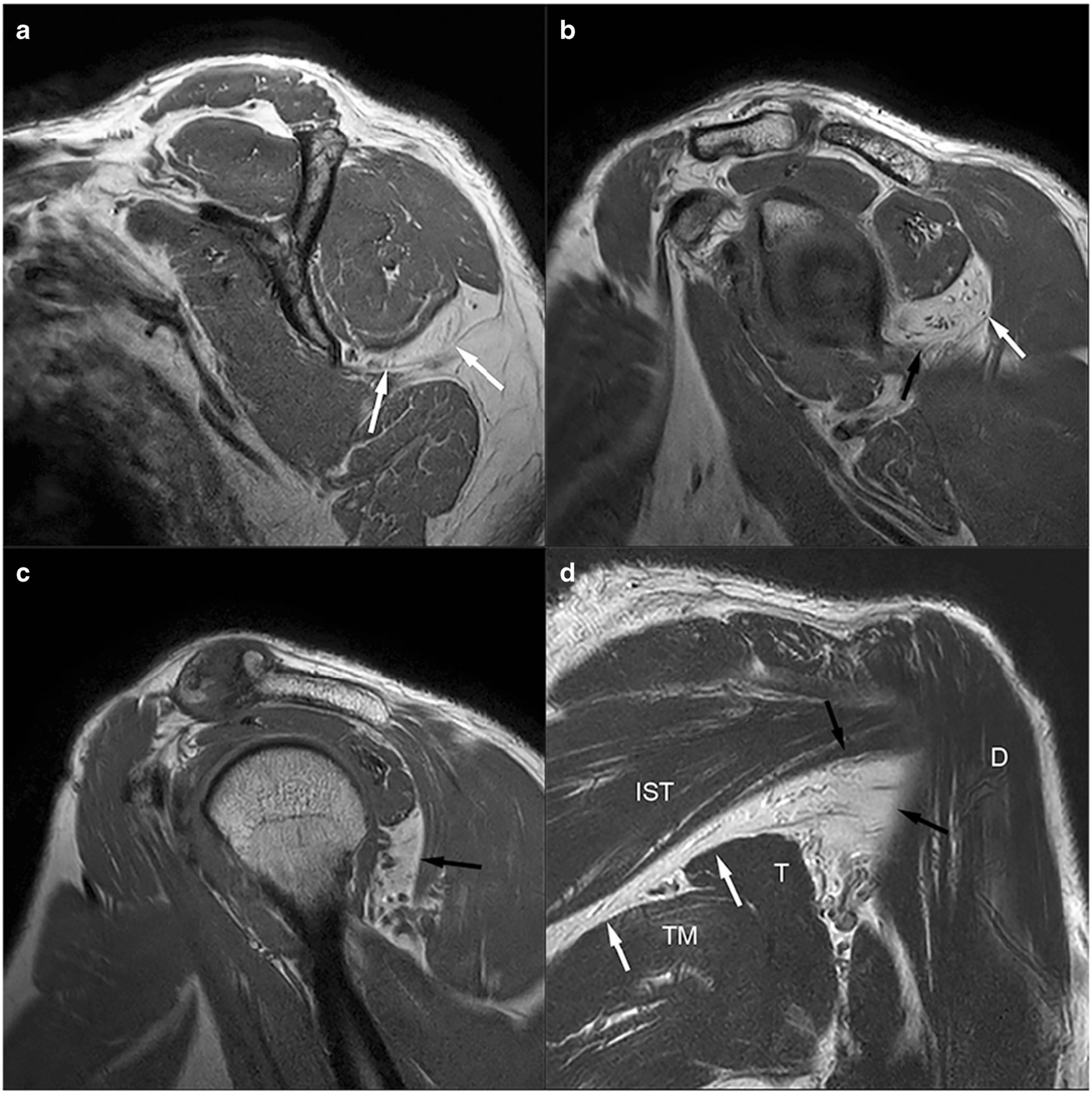


**Fig. 3** Complete pattern of isolated teres minor atrophy in a 64-year-old man. Sequential oblique sagittal T1-weighted images (TR/TE, 576/10 ms) of the shoulder are shown, at **a** the scapular Y, **b** the glenoid face, **c** the coracoid process and humeral head, and **d** an oblique coronal T2-weighted image (TR/TE, 2,483/80 ms) of the posterior shoulder is shown. Both the medial–dorsal component (*white arrows*) and the lateral–ventral component (*black arrows*) show fatty infiltration and atrophy. *TM*, teres major, *IST* infraspinatus, *T* triceps brachii, *D* deltoid

number and were small, and directly inserted on lateral aspect of the teres minor muscle. Chafik et al. [25] described the primary nerve to the teres minor muscle as having a tortuous course and it goes past a fascial sling as it enters the teres minor muscle, making it prone to compression, whereas the accessory motor nerves to the teres minor were found to have a straight, extra-fascial course, making it less vulnerable to compression. In our study, most cases of the partial pattern of teres minor atrophy involved the medial–dorsal component of the teres minor muscle with sparing of the lateral–ventral component. Based on the descriptions by Chafik et al. [25], we speculate that the lateral–ventral component might have been spared because of the accessory motor innervation.

It is also interesting to note that a lateral–ventral dominant partial pattern of isolated teres minor atrophy was also observed in our study. The lateral–ventral dominant pattern

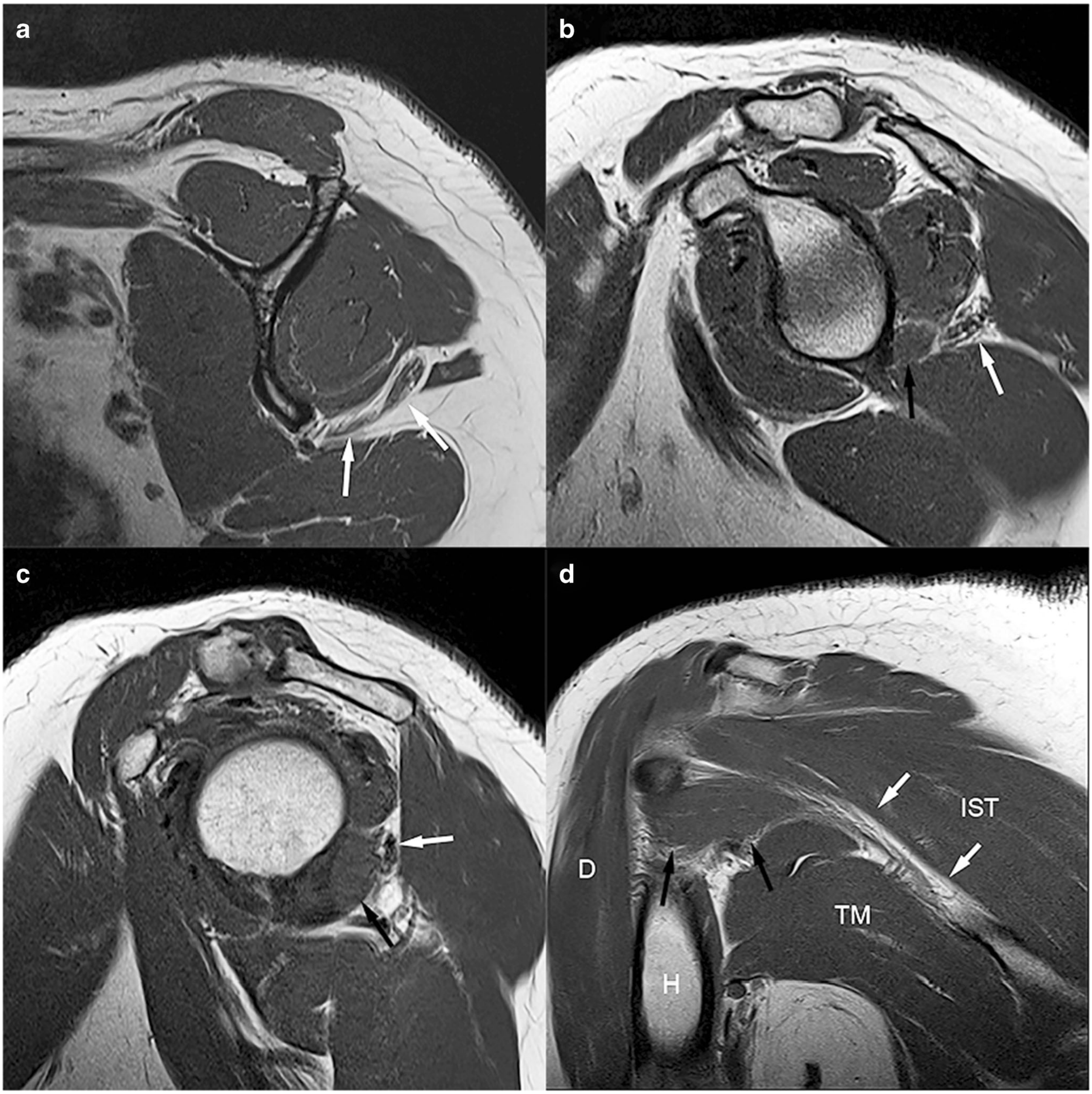


**Fig. 4** Medial–dorsal dominant partial pattern of isolated teres minor atrophy in a 63-year-old woman. Sequential oblique sagittal T1-weighted images (TR/TE, 596/14 ms) of the shoulder are shown, at **a** the scapular Y, **b** the glenoid face, **c** the coracoid process and humeral head, and **d** an oblique coronal proton density-weighted image (TR/TE, 2,400/29 ms) of the posterior shoulder is shown. The medial–dorsal component is atrophied and shows fatty infiltration (*white arrows*), whereas the lateral–ventral component appears normal without evidence for atrophy or fatty infiltration (*black arrows*). *TM* teres major, *IST* infraspinatus, *D* deltoid, *H* humerus

was less frequent than the medial–dorsal dominant pattern, comprising 17.4% of cases of partial pattern isolated teres minor atrophy (8 out of 46). Based on what has been discussed above, injury to the accessory motor nerve may have caused isolated teres minor atrophy of the lateral–ventral component. The presence of the lateral–ventral-dominant pattern indicates that the accessory motor nerve may not be an "additional" motor supply to the lateral–ventral component, but "the only" nerve supply to the lateral–ventral component of the teres minor muscle.

The cause of isolated teres minor atrophy is yet to be determined. Proposed mechanisms include traction injury to the axillary nerve [7], the presence of a fascial sling around the teres minor nerve causing compression [7], inferior glenohumeral osteophyte resulting in irritation of the nerve [15], and previous surgical procedures [26, 27]. Previous

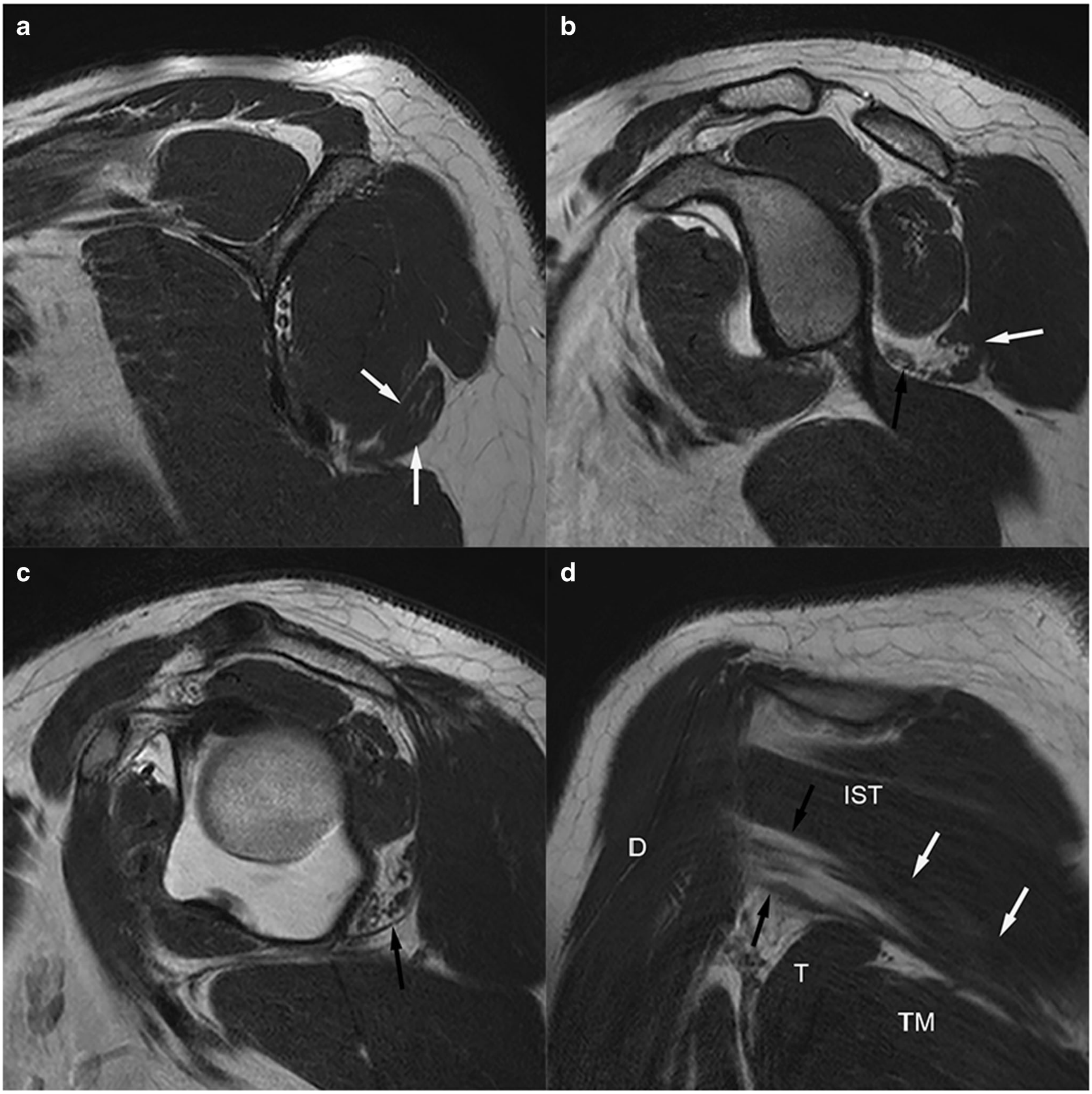


**Fig. 5** Lateral–ventral dominant partial pattern of isolated teres minor atrophy in a 19-year-old woman. Sequential oblique sagittal T2-weighted images (TR/TE, 3,298/80 ms) of the shoulder are shown, at **a** the scapular Y, **b** the glenoid face, **c** the coracoid process and humeral head, and **d** an oblique coronal T2-weighted image (TR/TE, 2,535/80 ms) of the posterior shoulder is shown. The medial–dorsal component appears relatively normal with minimal fatty infiltration (*white arrows*), whereas the lateral–ventral component has been nearly replaced with fatty tissue (*black arrows*). *TM* teres major, *IST* infraspinatus, *T* triceps brachii, *D* deltoid

studies have reported that rotator cuff tendon tears may lead to decentering of the humeral head, resulting in traction injury to the teres minor branch of the axillary nerve to stretching and subsequent denervation of the teres minor muscle [13, 28]. The history of trauma, history of previous shoulder operation, and the presence of glenohumeral osteoarthritis did not show a statistically significant difference between the teres minor atrophy group and the control group in our study. Although the difference did not reach statistical significance, shoulder instability was more commonly found in the teres minor atrophy group, indicating that shoulder subluxation or dislocation may be an important risk factor of injury of the nerve to the teres minor and subsequent isolated teres minor atrophy. Future studies are warranted to further confirm this association.

The electromyography results were available in 34 patients in our study, and only a small portion of these patients had an

**Table 4** Indications for MRI examination and final clinical diagnosis of patients

| | Isolated teres minor atrophy ($n = 78$) | Control ($n = 156$) |
|---|---|---|
| Indication for MRI examination | | |
| Rotator cuff evaluation | 51 | 103 |
| Postoperative evaluation after rotator cuff repair | 20 | 27 |
| Suspected labral tear | 4 | 7 |
| Suspected bone tumor or soft-tissue tumor | 2 | 4 |
| Others | 1 | 15 |
| Final clinical diagnosis | | |
| Rotator cuff tear | 67 | 123 |
| Calcific tendinitis | 2 | 0 |
| Adhesive capsulitis | 3 | 7 |
| Labral abnormality | 2 | 8 |
| Tumor | 2 | 6 |
| Others | 2 | 12 |

Data are the number of patients

abnormal finding. Three patients showed signs of axillary neuropathy partially involving the branch to the teres minor muscles and 2 patients were reported to have signs of C5, C6 radiculopathy. It is known that there is a technical difficulty in placing the needle in the teres minor [29]; electromyography plays a limited role in the diagnosis of quadrilateral space syndrome, and the same would apply to isolated teres minor atrophy. In addition, the presence of a partial pattern of teres minor atrophy may account for the high percentage of negative electromyography results in our study. In cases of partial pattern teres minor atrophy, the electromyography results may be false-negative, if the needle electrode is inserted into the component of the muscle that is spared. Knowledge of the two different muscle components of the teres minor with separate innervations, may aid in the positioning of needle electrodes in future electromyographic studies of the teres minor muscle.

Several limitations of our study need to be addressed. First, our study was based solely on MRI findings and the findings were not correlated with findings on physical examination, nor was the integrity of the teres minor tendon surgically confirmed. Second, most of the patients included in our study were over the age of 50 and were diagnosed with rotator cuff tendon abnormality. Previous studies have reported that the presence of extensive rotator cuff tendon tear may be associated with severe fatty infiltration of the teres minor muscle [16]. Therefore, the prevalence of isolated teres minor atrophy and the various patterns of isolated teres minor atrophy may have limited generalizability. Further studies of subjects with no pathological conditions in the shoulder may be needed. Third, the status of the teres minor muscle was qualitatively assessed and the degree of fatty infiltration and atrophy was not quantified. Fourth, the origin of the muscle could not be assessed in our study based on routine MRI of the shoulder joint. Further anatomical studies may be needed to validate the results of our study. Fifth, owing to the retrospective nature of the study, the MRI was performed using various MR scanners and imaging protocols, which may have affected the assessment of the fatty degeneration of the muscle. Finally, the time

**Table 5** Clinical factors of the teres minor atrophy group and the control group

| | Isolated teres minor atrophy ($n = 78$) | Control ($n = 156$) | $p$ value |
|---|---|---|---|
| Age | 58.9 years (range, 19–84) | 58.9 years (range, 18–84) | |
| Sex | Female:male = 40:38 | Female:male = 80:76 | |
| History of trauma | | | 0.569** |
| Absent | 46 (59.0) | 98 (62.8) | |
| Present | 32 (41.0) | 58 (37.2) | |
| Shoulder instability | | | 0.164*** |
| Absent | 73 (93.6) | 152 (97.4) | |
| Present | 5 (6.4) | 4 (2.6) | |
| Osteoarthritis | | | 0.395** |
| Absent | 62 (79.5) | 131 (84.0) | |
| Present | 16 (20.5) | 25 (16.0) | |
| History of previous shoulder operation | | | 0.456** |
| Absent | 56 (71.8) | 119 (76.3) | |
| Present | 22 (28.2) | 37 (23.7) | |
| Size of inferior humeral osteophyte (mm)* | | | |
| Median (IQR) | 2 (1–4) | 3 (2.5–4) | 0.282 |

Data are number of patients, unless indicated otherwise. Data in parentheses are percentages

*IQR* interquartile range

*Size of osteophytes were compared in 40 patients with measurable osteophytes (24 patients with teres minor atrophy, 16 control patients) using the Wilcoxon rank sum test

**Chi-squared test used for comparison

***Fisher's exact test used for comparison

**Table 6** The demographic and clinical factors of each subtype of isolated teres minor atrophy

| | Complete | Partial | | Total | *p* value |
|---|---|---|---|---|---|
| | | Medial–dorsal dominant | Lateral–ventral dominant | | |
| Number of cases | 32 | 38 | 8 | 78 | |
| Age (years) | 61.3 ± 13.9 (range, 20–84) | 57.4 ± 11.3 (range, 23–75) | 56.6 ± 19.4 (range, 19–79) | 58.9 ± 13.3 (range, 19–84) | 0.416* |
| Male:female | 16: 16 | 18: 20 | 4: 4 | 38: 40 | |
| Previous operative history | 8 (25.0) | 11 (28.9) | 3 (37.5) | 22/78 (28.2) | 0.764** |
| Trauma history | 15 (46.9) | 13 (34.2) | 4 (50) | 32/78 (41.0) | 0.504** |
| Instability | 3 (9.3) | 1 (2.6) | 1 (12.5) | 5/78 (6.4) | 0.290** |
| Osteoarthritis | 6 (18.8) | 7 (18.4) | 3 (3.8) | 16/78 (20.5) | 0.507** |

Data are number of patients, unless indicated otherwise. Data in parentheses are percentages

*One-way ANOVA used to compare the age of patients of each group

**Chi-squared test used for comparison

elapsed between the traumatic event and MRI evaluation varied. Some patients were scanned within 1 month of the trauma, a period at which the fatty changes of the muscle resulting from the trauma would not be evident on imaging. Further study is needed to elaborate the relationship between trauma and isolated teres minor atrophy.

Isolated teres minor atrophy may exhibit a complete pattern or a partial pattern, and the partial pattern may predominantly involve either the medial–dorsal component or the lateral–ventral component of the muscle. The imaging findings of partial pattern isolated teres minor atrophy indicate that the two muscle components may have separate innervation.

## Compliance with ethical standards

**Conflicts of interest** The authors declare that they have no conflicts of interest.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was waived.

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