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# Evaluation of muscle tears in professional athletes using diffusion-weighted imaging and apparent diffusion coefficient: preliminary results

*Elisabetta Antonia Nocerino*[1], *Alberto Aliprandi*[2], *Rodolfo Tavana*[3], *Stefano Mazzoni*[4], *Gianni Di Leo*[5], *Eugenio Annibale Genovese*[6]

[1] Radiology Unit, IRCCS Policlinico San Donato Milanese, San Donato, Italy; [2] Radiology Unit, Istituti Clinici Zucchi, Monza, Italy; [3] Medical doctor, Torino FC, Torino, Italy; [4] Medical doctor Milan AC, Milano, Italy; [5] Department of Biomedical Sciences for Health, Università degli Studi di Milano, San Donato Milanese, Italy; [6] Insubria University-Intermedica-Columbus Clinical Medical Center

**Summary.** *Purpose:* Many studies have evaluated the role of DWI in musculoskeletal diseases but less is known on muscle tears. Especially for professional athletes, muscle injuries are responsible for large time lost. The aim of this study was to investigate on potential relationship between the muscle tear degree and the diffusion characteristics. *Methods:* In this retrospective study, patients signed a comprehensive consent form according to Good Clinical Practice guidelines before proceeding with all examinations. It satisfied all the requirements of the Declaration of Helsinki and the Italian national law for the protection of personal data. We have analyzed 38 professional athletes (36 males; mean age±standard deviation 27±8 years) with a muscle tear. They were 26 football and 12 athletics players, with clinically suspected injuries of the lower limbs muscles. All of patients underwent a 1.5-T MRI with standard protocol (STIR, TSE T2, SE T1, PD T2, PD fat sat T2) plus the DWI sequences with 0, 400 and 800 B-values (s/mm$^2$). Per each B value, an experienced radiologist measured the signal intensity (SI, in arbitrary units [au]) using a region of interest (ROI) placed within the tear on DWI images. SI drop off at the third B value was calculated referred to the first B value. Similarly, ADC was measured using the ADC map in a small ROI within the tear. Bivariate associations were evaluated using the Student t test. Logistic regression was performed using the tear degree as dependent variable. Data were given as mean±standard deviation. *Results:* According the Muller-Wohlfarth classification, the 38 muscle tears were classified in type 3a in 22/38 cases and 3b in 16/38 cases. At bivariate analysis, 3a-tears had a SI at the third B value (24±9 au) lower (P=0.003) than that of 3b-tears (34±9 au). Similarly, 3a-tears had a SI drop off (73±10%) lower (P=0.008) than that of 3b-tears (82±9%). ADC was not significantly associated to tear degree (P=0.093). At regression analysis, SI at the third B value was the only independent predictor of the tear degree (P=0.032), while the SI drop off was borderline significant (P=0.070). *Conclusion:* This preliminary data showed a positive correlation between the degree of muscle tears and the SI at the third B-value. Compared to 3a- tears, 3b-tears tend to show higher SI and a higher SI drop off. (www.actabiomedica.it)

**Key words:** muscle tear, DWI, professional athlete

## Introduction

Magnetic resonance (MR) diffusion-weighted imaging (DWI) is highly sensitive to tissue water diffusivity. This MR sequence has been successfully used in several neurological and oncological conditions (1-3).

In the field of musculoskeletal, many studies have evaluated the role of DWI mainly in oncological diseases (4). In particular, it was used to differentiate between benign and malignant bone tumors through a threshold of the apparent diffusion coefficient (ADC). Apart from the general evidence on a trend for a lower ADC in malignant lesions, data are still conflicting (5). Similarly, this trend appears to be true for soft-tissue tumors (6). Moreover, DWI appears to perform well in the assessment of the response to chemotherapy of bone and soft-tissue tumors, with an increasing ADC from baseline in responders (7).

From a technical point of view, the DWI sequence is characterized by the so-called *b* values, that is a technical parameter to be managed during acquisition. When $b$=0 s/mm$^2$ (or close to), DWI provides mostly a T2-weighted image. Conversely, when *b* is as high as 800 s/mm$^2$ a genuine diffusion-weighted image is obtained, generally with poorer spatial resolution and signal to noise ratio. Diffusion-weighted MR images must therefore be assessed visually, comparing images obtained with a low *b* value to those obtained with a high *b* value, with the difference in signal between these two images being related to water diffusion. Conversely, ADC quantitative analysis is the first line assessment method for diffusion data.

According to the recent guidelines (8) for muscle injuries, muscle tears may be evaluated using a fat-suppressed fluid-sensitive (e.g. short tau inversion recovery [STIR]) sequence, which allow for the detection of edematous changes around the myotendinous and myofascial junctions; and a T1-weighted spin-echo sequence, that are less sensitive to edematous changes within the muscle in acute injury but may be useful in the assessment of subacute hemorrhage or hematoma. This imaging protocol allows to defining the site, extension, and muscle retraction. Moreover, it allows to define a prognosis and a correct patient management (9).

Muscle tears are specific issues for professional athletes, representing a relevant source of time lost from competition, with strong external pressure for a rapid return to play (RTP). ISMuLT guidelines suggest a prognosis depending on the muscle tear degree. In particular, for the structural 3a and 3b muscle injuries it is recomanded 15-18 and 25-35 days off of competition, respectively (10). Impotantly, an inaccurate estimation of the tear degree may prompt an inappropriate prognosis with the risk of an early RTP and an increase risk of recurrent tear (11).

To our knowledge, the role of DWI in the evaluation of muscle tears has never been assessed. In our clinical practice, DWI is added to the standard imaging protocol thanks to its capability in the evaluation of soft tissues. In fact, high degree tears are expected to involve a large part of muscle fibers and, consequently, a higher diffusivity of water molecules.

The aim of this preliminary study was to retrospectively investigate on potential relationship between the muscle tear degree and the diffusion characteristics.

## Materials and methods

### *Study design and population*

In this retrospective study, patients signed a comprehensive consent form according to Good Clinical Practice guidelines before proceeding with all examinations. It satisfied all the requirements of the Declaration of Helsinki and the Italian national law for the protection of personal data.

We analyzed consecutive 38 elite professional athletes (36 males; mean age±standard deviation 27±8 years). They were 26 football and 12 athletics players with a clinically suspected injury of the lower limb muscles without a direct trauma (10).

### *Imaging protocol*

All patients underwent a 1.5-T MR imaging between 48 and 72 hours from the indirect trauma (10) with the standard protocol (Avanto, Siemens Medical Solution, Erlangen, Germany; or Achieva, Philips Medical System, Eindhoven, Netherlands) and a body matrix coil phased array 16 channels. The imaging protocol included a coronal STIR, an axial T2-weighted turbo spin-echo (Achieva) or a proton density (Avanto), an axial proton density fat saturated, and an axial T1-weighted spin echo. Moreover, for each patient, an axial DWI sequence with parallel imaging (acceleration factor 2) was acquired using $b_1$=0 s/mm$^2$, $b_2$=400 s/mm$^2$, and $b_3$=800 s/mm$^2$. Further details are provided in Table 1 and 2.

**Table 1.** Achieva, Philips Medical System, Eindhoven, Netherlands, MRI characteristics

| Sequence | Plane | TR (ms) | TE (ms) | Matrix (mm) | GAP (mm) | FOV (mm) | Thinkness (mm) |
|---|---|---|---|---|---|---|---|
| STIR[1] | Coronal | 3000-6000 | 50 | 272x220 | 0.8 | 400-500 | 4 |
| T2 TSE[2] | Axial | 3500-6000 | 100 | 448x327 | 0.8 | 400-500 | 4 |
| PD Fat Sat[3] | Axial | 3500-6000 | 80 | 324x247 | 0.8 | 400-500 | 4 |
| SE T1[4] | Axial | 450-500 | 18 | 380x219 | 0.8 | 400-500 | 4 |
| DWI[5] | Axial | 7000-13000 | 55 | 140x138 | 0.8 | 400-500 | 4 |

1. short tau inversion recovery; 2. T2 turbo spin-echo; 3. proton density fat saturation; 4. spin echo T1; 5. diffusion-weighted imaging

**Table 2.** Avanto, Siemens Medical Solution, Erlangen, Germany, MRI characteristics

| Sequence | Plane | TR (ms) | TE (ms) | Matrix (mm) | GAP (mm) | FOV (mm) | Thinkness (mm) |
|---|---|---|---|---|---|---|---|
| STIR[1] | Coronal | 5000-6000 | 118 | 320x320 | 0.6 | 400-500 | 3 |
| PD[6] | Axial | 3000-6000 | 12-123 | 238x384 | 0.6 | 400-500 | 4 |
| PD Fat Sat[3] | Axial | 3000-6000 | 12-123 | 238x384 | 0.8 | 400-500 | 4 |
| SE T1[4] | Axial | 636 | 10 | 224x320 | 0.8 | 400-500 | 4 |
| DWI[5] | Axial | 4000-8000 | 70 | 160x160 | 0.8 | 400-500 | 4 |

1. short tau inversion recovery; 2. T2 turbo spin-echo; 3. proton density fat saturation; 4. spin echo T1; 5. diffusion-weighted imaging; 6. proton density

*Image analysis*

Muscle tears were evaluated according to the Muller-Wolhlfahrt classification (12). In this classification muscle injuries are classified as non-structural and structural as reported in Table 3.

Per each *b* value, an experienced radiologist (more than 15 years of experience in musculoskeletal radiology) measured the signal intensity (SI, in arbitrary units [au]) on DWI images in a point region of interest (ROI) placed within the tear using T2 images to accurately place the ROI (Figure 1). ADC was measured using the ADC map in a ROI within the tear.

*Statistical analysis*

The Shapiro-Wilks test was used to ascertain whether the distribution of the continuous variables was normal. The SI drop off at $b_3$ was calculated respect to $b_1$.

The association between the muscle tear degree and ADC, SI drop off, and the SI at $b_3$ was calculated using the ANOVA. Bivariate correlations were estimated using the Pearson correlation coefficient. Multivariate regression analysis was performed using the SI drop off as dependent variable and with both the muscle tear degree and ADC as predictors. Finally, a

**Table 3.** Muller-Wolhlfahrt classification (12)

| | | |
|---|---|---|
| Non-structural Injury | Type 1: Overexertion-related muscle disorder | Type 1a: Fatigue-induced muscle disorder<br>Type 1b: Delayed-onset muscle soreness (DOMS) |
| | Type 2: Neuromuscular muscle disorder | Type 2a: Spine-related neuromuscular Muscle disorder<br>Type 2b: Muscle-related neuromuscular Muscle disorder |
| Structural Injury | Type 3: Partial muscle tear | Type 3a: Minor partial muscle tear<br>Type 3b: Moderate partial muscle tear |
| | Type 4: (Sub)total tear | Subtotal or complete muscle tear<br>Tendinous avulsion |

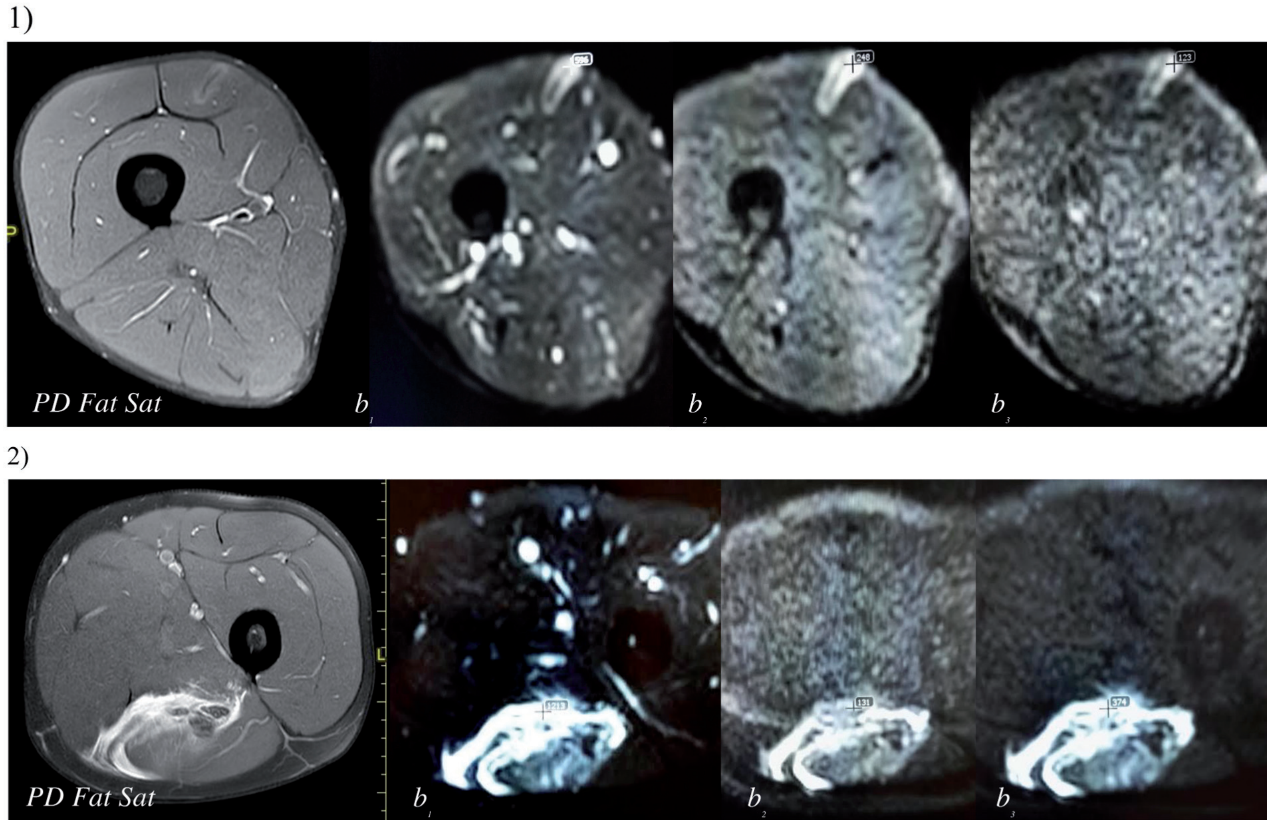


**Figure 1.** ROI placement on DWI sequences ($b_1$ , $b_2$ , $b_3$) in 3a type (1) and 3b type (2)

receiver operator characteristic (ROC) curve was built for the SI drop off and the SI at $b_3$.

Continuous data were given as mean±standard deviation or median and interquartile range, as appropriate; categorical data were given as counts and proportions. A p-value <0.05 was considered as statistically significant. SPSS software (SPSS v20, IBM Inc., Chicago, IL) was used for calculation.

## Results

According the Muller-Wohlfarth classification (12), the 38 muscle tears were classified as type 3a in 22 cases (58%) and 3b in 16 cases (42%). No avulsion injuries and no complete tendon ruptures were reported. The most commonly affected muscle was the femoral biceps (18/38 cases), followed by the rectus femoris (7/38 cases), the soleus (4/38 cases), the medial gastrocnemius (2/38 cases), vastus intermedius (2/38 cases), gluteus (1/38), medius (1/38), adductur longus (1/38), pectineus (1/38), vastus lateralis (1/38), and obturator internus (1/38). The musculotendinous junction was involved in 33/38 cases (87%); in four cases, the injury was located in the myofascial site, and in one other case, the tear was intramuscular.

All of the 38 patients showed a focal intramuscular T2 hyperintensity and this was considered to reflect a muscle injury (9). In 18/38 cases (47%) MRI findings were found as suggestive of blood products in evolution.

The mean ADC was $(2.03±0.55)·10^{-3}$ mm²/s while the SI drop off at $b_3$ was 77±10%. The 3a tears had a mean SI at $b_3$ (24±9 au) significantly lower (p=0.003) than that of 3b-tears (34±9 au). In addition, the 3a-tears had a SI drop off (73±10%) lower (p=0.008) than that of 3b tears (82±9%) (Figure 2). The ADC was borderline significantly associated to the tear degree (p=0.093). In particular, 3a tears had a mean ADC

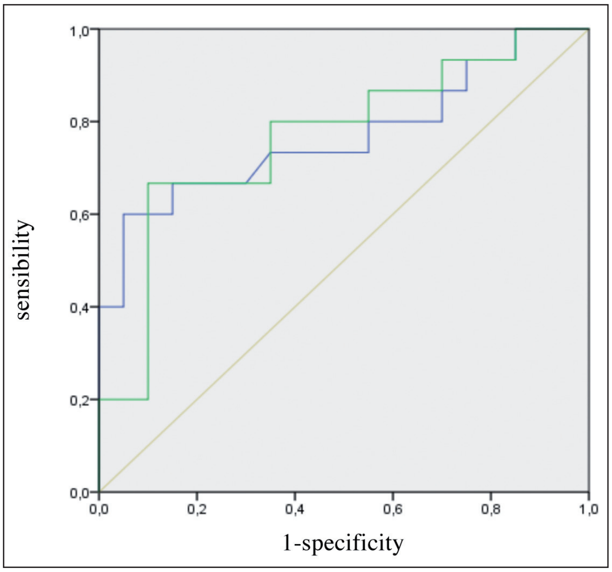


**Figure 2.** ROC curve; line green: SI drop off, line blu: SI at $b_3$

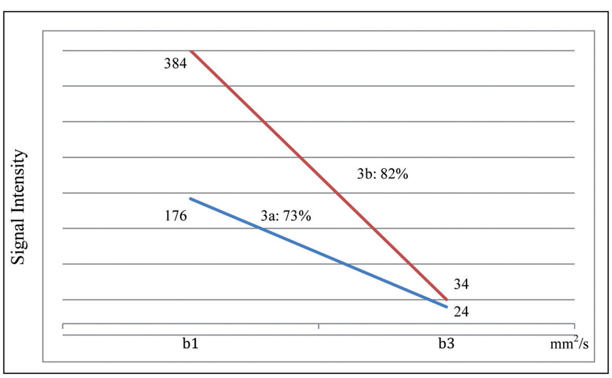


**Figure 3.** SI drop-off

$(1.91\pm0.49)\cdot10^{-3}$ mm²/s lower than that of 3b tears $(2.21\pm0.59)\cdot10^{-3}$ mm²/s.

At multivariate regression analysis, both the muscle tear degree ($p=0.033$) and the ADC ($p=0.006$) were independently associated to the SI drop off at $b_3$. At ROC analysis with the muscle tear degree as dependent variable, the area under the curve was 0.768 for the SI drop off and 0.767 for the SI at $b_3$ .

## Discussion

Muscle injuries are a common issue in elite athletes often occurring during competition or training. More than 90% of them are caused by excessive strain or contusion (13), causing prolonged absence from competition (14).

In these clinical setting, MR imaging is the preferred method of evaluation thanks to its high contrast resolution, reproducibility, and anatomic depiction (15). Interestingly, DWI is not routinely exploited for the assessment of the muscle injuries, being mainly applied for the characterization of soft tissue tumors (diagnosis and follow-up) and for the assessment of vertebral collapse and bone marrow cellularity (16). Indeed, symptoms and timing of the muscle injury are generally enough to make an accurate diagnosis and the role of imaging is to better evaluate the site of the injury and to determine the grading (17). One only study, to our acknowledge, included DWI in the standard MR protocol for the evaluation of the rotator cuff tears in order to improve the diagnostic accuracy of MR imaging (18).

In this study, we exploited the DWI sequence so to measure the ADC of the muscles injuries in relation to its degree. Although only with borderline significance, we demonstrated that 3a tears had a mean ADC lower than that of 3b tears. This reflects the fact that 3a tears are characterized by a lower amount of ruptured fibers compared to 3b tears, with a lower amount of free water (thus, lower ADC). This is also in line with the data reported by Agten et al. (19), being $1.81\cdot10^{-3}$ mm²/s in non-structural type-1 injuries that are characterized by an even lower amount of free water. In practice, the higher the muscle degree, the higher the ADC and we may speculate on an even higher ADC in type-4 tears. This proportionality opens a future perspective where DWI-derived ADC may be used as a predictor of the muscle injury degree. Moreover, being ADC a continuous variable, it could be used as an adjunct to the Muller-Wohlfarth classification.

In the clinical practice, the DWI sequence is typically evaluated qualitatively as a subjective radiologist's judgment, looking for SI modifications. Indeed, the ADC map is rarely calculated. As such, we have also assessed the role of the SI drop off and that of the SI at $b_3$ itself as predictor of the muscle tear degree, showing an area under the curve at ROC analysis of 0.768 and 0.767, respectively.

A limitation of this study is that the intra-observer evaluation was not evaluated. Another additional limit is represented by the study conducted retrospectly.

However, these results are still preliminary and further studies are required to validate the present data and to better elucidate the clinical application of DWI and ADC.

## Conclusion

This preliminary study showed a positive association between the degree of muscle tears and the SI at $b_3$ in DWI. Together to the SI drop off, it may be used to quantify the degree of muscle tear and could be useful in the better characterize the muscle injuries.

**Conflict of interest:** Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

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Correspondence:
Elisabetta Antonia Nocerino
Radiology Unit, IRCCS Policlinico San Donato Milanese,
Via Morandi 30 - 20097 San Donato, Italy
E-mail: elisabetta.nocerino85@gmail.com