Low Back Pain in Adolescent Elite Rowers and its Association to Skeletal Muscle Changes Detected by Quantitative Magnetic Resonance Imaging

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Abstract

Objectives:

To assess demographic data, training characteristics and low back pain (LBP) in male adolescent elite rowers, visualize structural changes in the lumbar skeletal muscle with quantitative magnetic resonance imaging (qMRI) and correlate findings to reported long- and short-term pain intensity.

Methods:

In this single-center case series, twenty male elite rowers completed a questionnaire for retrieval of anthropometric data, training characteristics and a standardized back pain questionnaire. Participants then underwent MR imaging, which included the acquisition of T1- and T2-mapping sequences and Dixon-based sequences for the Erector spinae (ES) and Multifidus (MF) muscle. Reported short- and long-term pain intensity was correlated to relaxation times and training characteristics.

Results:

Short-term pain intensity was associated with shorter T1 relaxation ($p = 0.025$ and $p = 0.022$ for ES and MF, respectively) and longer T2 relaxation times ($p < 0.001$ for ES and MF, respectively), while long-term pain intensity was associated to longer T2 relaxation times ($p < 0.001$ and $p = 0.004$ for ES and MF, respectively).

Conclusion:

Competitive adolescent rowers are at risk about developing LBP. qMRI parameters provide insight in structural changes in the lumbar skeletal muscle which are linked to reported short- and long-term pain intensity, indicating that muscular strains can account for LBP.

Introduction

Low back pain (LBP) is a multifactorial condition which is common among the general population and can result in great medical and socioeconomic burden ^[1]. Several studies have described a link between LBP and physical activity. Not only a sedentary lifestyle, but also a high physical workload including bending and flexing motions seem to negatively influence LBP ^[2–5], indicating a U-shaped relationship ^[6]. The occurrence of LBP among athletes is frequent due to factors such as higher grade of physical activity, higher training intensity and repetitive loading during sports performance ^[7, 8], but is highly variable among different disciplines ^[9]. Especially elite rowers seem to be at increased risk for developing LBP compared to aged-matched controls ^[10] and other elite sports ^[11].

LBP in adolescent athletes can arise from structural spinal injuries ^[12]. Therefore, it is important to exclude less severe, muscular injuries such as strains due to the performance focus of most athletes and

the "return to play" before full resolution of symptoms leading, which might lead to possible delayed treatment of a structural spine injury ^[13, 14]

Structural changes of the skeletal muscle can be assessed non-invasively using Quantitative Magnetic Resonance Imaging (qMRI). T1-weighted mapping sequences can be used as a biomarker for muscle atrophy and fatty muscle infiltration ^[15], while T2-weighted mapping sequences can visualize conditions such as inflammation or necrosis but also exercise-related transient tissue changes in water metabolism and therefore already have a widespread clinical use for the assessment of idiopathic myopathies, exercise injury and muscle fatigue ^[16–20]. Moreover, physical exercise can change the cross-sectional area (CSA) in the skeletal muscle, for instance due to blood vessel dilatation and the accumulation of metabolites ^[21].

In this study, the aim was to assess demographic data and reported LBP in male adolescent elite rowers and to investigate a possible relation to training characteristics, qMRI imaging parameters and CSA measurements, visualizing microstructural changes in the skeletal muscle and searching for muscular imbalances.

Methods And Materials

Study Design

This prospective single-center study was approved by the regional committee for research ethics (Ethics commission of Charité - Universitätsmedizin Berlin, EA 2/180/20) and informed consent of all participants was obtained. All research was performed in accordance with relevant guidelines and regulations

Twenty elite male rowers age 15.75 ± 1.2 years competing at state or national level were recruited through a cooperation with a local rowing club.

All participants were actively in training for upcoming competitions and had a training load of at least 15.6 ± 3.0 hours per week. Examinations were performed on 2 consecutive weekends in February 2021 after cessation of 6 hours from training. Exclusion criteria comprised a known history of chronic musculoskeletal disease linked to lower back pain and/or known history interventional or surgical procedure of the spine.

Before MRI examination, a modification of a questionnaire previously used by Ng et al. ^[10] was handed out to the participants obtaining basic anthropometric data, type, duration and intensity (low/mid/high) of training, competition level, rowing technique, duration of other sports activities per week and passed time since joining the elite rowing team. Next, LBP was assessed with questions about prevalence (12 months / 7 days), localization and activity relation. Pain intensity and disability were assessed through the German adaptation of the chronic pain grade (CPG) ^[22]. The CPG combines Numerical Rating Scales ranging from 0 to 10 to define short-term pain intensity in the last 24 hours, characteristic pain intensity in

the last 3 months and disability points to form a grading score from 0 (no pain) to IV (high disability severely limiting). In the following, NRS scores of the last 24 hours were defined as short-term pain intensity and characteristic pain intensity scores in the last 3 months were defined as long-term pain intensity.

Magnetic Resonance Imaging

Images were acquired on a 3 Tesla MR scanner (MAGNETOM Skyra; Siemens Healthineers, Erlangen, Germany) using the built-in whole body coil of the patient table of the scanner. Participants were scanned in supine position (head first) with a clinical protocol for lumbar spine investigation. The clinical protocol consists of transversal native T1 weighted sequence, a T1-map and a T2-map with the following parameters:

T1 weighted images measured with the 3D volumetric interpolated breath-hold examination (VIBE) sequence using Dixon fat suppression: transversal field of view (FOV) 400×324 mm measured with a 3D acquisition block containing 96 slices, image size 320×240 voxel with voxel size of $1.3 \times 1.3 \times 3$ mm, slice gap 0.6 mm, TE (echo time) = 1.26 ms, TR (repetition time) = 4.06 ms, flip angle 9° , Cartesian k-space trajectory and bandwidth of 1040 Hz per pixel. No GRAPPA or other readout acceleration method were used.

T1 Mapping with a 3D Fast Low-Angle Shot (FLAIR) sequence and variable flip angle method^[23]: transversal FOV 400×324 mm measured with a 3D acquisition block containing 48 slices, image size 384×311 voxel with measured voxel size of $1.0 \times 1.0 \times 5$ mm interpolated to 0.5×0.5 mm in-plane resolution, slice gap 1.0 mm, TE = 2.0 ms, TR = 15 ms, flip angles 5° and 26° , Cartesian k-space trajectory with 6/8 partial Fourier, bandwidth of 280 Hz per pixel and GRAPPA acceleration factor of two. Quantitative T1-Maps were generated by the built in MapIt module of the sequence.

T2 Mapping with a 2D Spin-Echo (SE) sequence: transversal FOV 350×350 mm, 20 slices, image size 256×230 voxel with measured voxel size of $1.36 \times 1.52 \times 5$ mm interpolated to 0.7×0.7 mm in-plane resolution, slice gap 1.0 mm, six TE values (10.5 ms, 21 ms, 31.5 ms, 42 ms, 52.5 ms, 63 ms), TR = 2750 ms, flip angle 180° , Cartesian k-space trajectory with 7/8 partial Fourier, bandwidth of 201 Hz per pixel and GRAPPA acceleration factor of two. Quantitative T2-Maps were generated by the built in MapIt module of the sequence.

Data Analysis

The muscle volume (MV), muscle fat fraction (MFF) as well as T1 and T2 relaxation times were evaluated using Visage Imaging Client (Software Release v7.1, Visage Imaging, Berlin, Germany). MR image segmentation was performed manually seeding bilateral regions-of-interest (ROIs) in the erector spinae muscle (ES) and multifidus muscle (MF) at the upper vertebral endplate level of L4 to the postero-inferior border level of the vertebral L5 endplate. Segmentation was based on fascial plane separation considering the transverse process, spinous process and thoracolumbar fascia as muscle borders and using the facet joint as anatomical landmark between ES and MF (Fig. 1). Quantitative MFF (%) was

calculated in axial 3D gradient echo-modified two-point Dixon-based MRI with a chemical shift-encoded reconstruction of the water and fat signal using the formula $\frac{SI(FAT)}{SI(FAT)+SI(WATER)} \times 100$. The MV was determined using axial T2-weighted imaging.

Statistical analysis

Statistical Analysis was undertaken using SPSS Statistics (Software release v27, IBM, Armonk, USA). Patient characteristics were expressed as mean and standard deviation (SD). Normal distribution was evaluated using the Kolmogorov-Smirnov-Test. Pearson correlation and linear regression analysis were conducted with characteristic pain intensity in the last 3 months as long-term outcome for LBP. For the correlation of short-term pain, we chose the NRS pain value of the last 24 hours as dependent variable and performed a Poisson regression analysis due to non-normal distribution of the data. Both long- and short-term pain outcome were correlated to training characteristics and quantitative MRI parameters. Paired sample t-test was performed for the assessment of a possible imbalance of muscle volume and fat fraction between the left and right side. Statistical significance was defined as $p \leq 0.05$.

Results

Anthropometric data and training characteristics

Table 1 delivers an overview of anthropometric data and reported training characteristics. All participants ($n = 20$) were male and had a mean age of 15.75 years (SD 1.22), with the majority being scull rowers ($n = 14$). Mean training volume per week was 15.55 hours (SD 3.05). Five main exercise types were specified. Ergometer and strength training were the most frequent training forms in the week before and in the last 24 hours before examination (see Table 2).

LBP prevalence, location and related activities

The majority of participants reported episodes of LBP either in the last year ($n = 17$; 85.0%) or in the last week ($n = 11$; 55.0%). Pain was mostly multilocular ($n = 9$; 52.9%) and the lower back, especially the lumbal and sacral area was affected in all patients (Table 3). Different exercises in rowing training routine, most frequently ergometer and strength training, as well as prolonged sitting were reported as being linked to former LBP episodes (Table 4).

Assessment of pain intensity and disability

CPG results are summarized in Table 3. Three participants (15%) did not report about pain in the last three months (CPG 0). The large majority ($n = 14$, 70%) was classified as CPG I (low disability, low intensity) and CPG II ($n = 3$, 15%, low disability, high intensity). None of the patients reported pain of CPG grade III and IV (moderate and severe limitation, high intensity).

Muscle volumetry and fat fraction

The mean muscle volume was 227.82 (31.79) cm³ for ES muscles and 151.60 (25.08) cm³ for MF muscles (see Table 5). There was no difference in muscle volume between left and right side for both ES ($p = 0.998$) and MF muscle ($p = 0.885$). The average muscle fat fraction means was 12.43 (SD 3.45) % in the ES and 11.42 (SD 3.18) % in the MF muscle. Here again, no difference was found between both sides (ES $p = 0.755$ and MF $p = 0.570$).

LBP, qMRI parameters and training characteristics

Mean relaxation times calculated in T1 and T2 mapping sequences were 1502.2 ± 88.0 ms / 1539.0 ± 72.7 ms (T1 Mapping) and 42.26 ± 2.77 ms / 42.43 ± 2.66 ms (T2 Mapping) for ES and MF muscle, respectively. Evaluation of anatomic T1 and T2 imaging sequences did not show any detectable findings.

Short-term pain intensity (last 24 hours) was significantly associated with shorter T1 relaxation in the ES and MF muscle ($B = -0.004$, $p = 0.025$ and $B = -0.005$, $p = 0.022$, respectively) and longer T2 relaxation times ($B = 0.144$, $p < 0.001$ and $B = 0.163$, $p < 0.001$, respectively) (Fig. 2). Characteristic pain intensity in the last 3 months was associated with longer T2 relaxation times for ES and MF muscle ($r = 0.727$, $p < 0.001$ and $r = 0.615$, $p = 0.004$, respectively), but was not related to T1 relaxation times ($r = -0.363$, $p = 0.116$ and $r = -0.314$, $p = 0.178$, respectively) (Fig. 3). Training intensity and rowing technique were not significantly associated with short-term pain ($B = 0.036$, $p = .927$ and $B = .398$, $p = .696$, respectively).

Discussion

This prospective cohort study evaluated the prevalence of lower back pain and associated structural changes in the skeletal muscles of adolescent elite rowers with quantitative MR imaging.

The following main findings were provided: (1) Prevalence of LBP is high in adolescent elite rowers; (2) T1 and T2 relaxation times are significantly related to short-term pain outcome; (3) T2 relaxation times are significantly related to long-term pain outcome.

Our findings regarding the 7-day point prevalence (55.0%) are in line with current literature, where prevalence ranged from 25 to 65%, whereas pain rates for the last 12 months (85.0%) were significantly higher (ranges from 26–55%) [24–28]. First, this could be due to a small sample size and influenced by the time point of examination. Moreover, median age was higher in most studies focusing on 1-year prevalence (ranges from 19 to 23 years) than in the present study (15.75 years). Similar findings are reported in a study by Ng et al. [10], where reported lifetime LBP rates decreased with increasing age. Increased long-term LBP prevalence rates in rowers could also be explained by sports kinematics such as bending and twisting motions as well as heavy loading of the lumbar spine [2, 5].

No relation was found between rowing technique (scull/sweep) and short-term (7-day) LBP intensity. This is in contrary to the current literature [25, 29], where findings are explained through rowing kinematics such as lumbar flexion or asymmetrical movement and lateral bend in sweep rowing [30]. Additionally, CSA

measurements of the lumbar spine muscles did not show a significant difference from left to right side indicating that rowing technique does not lead to a muscular imbalance.

On the other hand, training routine seems to play a role in the aggravation of LBP. Strength training (n = 14) and ergometer training (n = 10) were the most frequently reported exercises directly related to LBP episodes, which is in with other studies ^[10, 31].

T2 relaxation times in the skeletal muscle are highly dependent on various intrinsic and extrinsic factors, such as muscular protein concentration, exercise level and the ratio of concentric to eccentric muscle action ^[32–34]. Different pathophysiological mechanisms have been identified to contribute to changes in relaxation time. For a long time period, increase in T2 relaxation times was thought to be related merely to an increase in extracellular fluid due to increased muscle perfusion ^[32]. Meyer et al. also describe an activity-induced increase in T2 relaxation as a result of osmotically driven shift of water into the myofibrillar space ^[18].

Moreover, the blood oxygen dependent (BOLD) effect, which is already known from functional neuroimaging also seems to play a role in imaging of the skeletal muscle. Due to its paramagnetic features, desoxyhemoglobine leads to distortions in the local magnetic field and ultimately leads to a decrease in T2 relaxation. On the other hand, increased muscle perfusion due to activation leads to a shift towards oxyhemoglobine, which has no paramagnetic features and therefore indirectly increases T2 relaxation ^[32, 35].

Studies focusing on the lumbar paraspinal muscles could already detect an activity-related increase in T2 relaxation, most likely due to changes of intracellular osmotic pressure and therefore higher concentration of lactic acid concentration, degree of fatty infiltration and the number of capillaries ^[36–38].

In our study, longer T2 relaxation was significantly related to reported higher long- and short-term pain intensity. These findings and the fact that the majority of participants described pain being related specifically to several training activities (ergometer, strength training) support our thesis that pain is induced by muscular strains rather than more severe structural spine injuries.

An interesting finding was a significant influence of shorter T1 relaxation times on short-term pain intensity. Decreased T1 relaxation correlates with a higher fatty infiltration of the skeletal muscle ^[39], possibly reflecting lower fitness level due to lower training volume. This is supported by findings of Trompeter et al. ^[29] and Newlands et al. ^[27], in which training volume was significantly associated with higher rates of LBP.

This study is not without limitations. A major factor is a decreased internal validity due to a small study sample size (n = 20) and missing control group. Moreover, our study group consisted of adolescent rowers which were merely of male sex, so that findings might not be generalizable to athletes of other gender or age.

Conclusion

The prevalence of LBP in adolescent elite rowers is high and frequently associated with structural changes of the autochthonous back muscles, which are detectable with quantitative T1 and T2 mapping. Imaging findings imply that LBP is associated to muscular injury and that training volume plays a role in developing LBP at an adolescent age. Therefore, quantitative MRI might serve as a non-invasive tool for early detection and grading of muscular overuse for athletes performing extensive training.

Declarations

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Author contributions:

A.A.M., T.A.A. and S.K. conceived of the presented idea

A.A.M. and S.K. designed the study

A.A.M. wrote the manuscript

G.B. worked out the technical details and helped with examinations

P.G. performed the analytic calculations and designed the figures

D.G. and B.H. supervised the project

All authors provided critical feedback and helped shape the research, analysis and manuscript

Data availability statement:

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

Competing Interests Statement:

The author(s) declare no competing interests.

Declaration of Informed Consent:

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Tables

Tables are available in the Supplementary Files section.

Figures

Figure 1

ROI selection of ES and MF from the upper vertebral endplate level of L4 to the postero-inferior border level of the vertebral L5 endplate. Segmentation was based on fascial plane separation considering the transverse process, spinous process and thoracolumbar fascia as muscle borders and using the facet joint as anatomical landmark between ES and MF

Figure 2

Association between T1 and T2 relaxation times and NRS at 24 hours of the ES and MF muscle. A) T1 relaxation showed a significant association with NRS pain score ($B = -0.004$, $p < 0.001$ and $B = -0.005$, $p = 0.001$, respectively) B) Significant association of T2 relaxation times with 24-hour NRS score ($B = 0.144$, $p < 0.001$ and $B = 0.163$, $p < 0.001$, respectively).

Figure 3

Association between T1 and T2 relaxation times and CPI score of the MF and ES muscles. A) T1 relaxation showed no significant association with NRS pain score in both muscle groups (ES: $r = -0.363$, $p = 0.116$; MF: $r = -0.314$, $p = 0.178$) B) Significant association of T2 relaxation times with 24-hour NRS score (ES: $r = 0.727$, $p < 0.001$; MF: $r = 0.615$, $p = 0.004$).

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