Scandinavian Journal of Medicine & Science in Sports

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ORIGINAL ARTICLE OPEN ACCESS

Understanding the Interactions Between Loading, Pain Dynamics, and Imaging Characteristics for Osgood Schlatter: A Cross-Sectional Study

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Received: 24 April 2024 | **Revised:** 29 August 2024 | **Accepted:** 30 August 2024

Funding: This work was supported by the Danish Rheumatism Association (Gigtforeningen grant ID R168-A5697; Holden) and the Independent Research Foundation Denmark (IRFD Grant ID 9039-00238B; Rathleff).

Keywords: apophysis | load | sports injury | youth

ABSTRACT

Osgood Schlatter's disease (OSD) is characterized by pain at the tibial tuberosity provoked during knee-loading activities, and is common in adolescent athletes. The aim of this study was to characterize clinical, pain and ultrasound imaging characteristics in participants with OSD compared to controls. This cross-sectional study included adolescents diagnosed with OSD and matched controls. Following baseline evaluation including ultrasound, participants completed the following aggravating activities in a randomized order: single-leg isometric knee hold, single-leg squat, single-leg vertical jump, hopping, running, cutting, lunges, and walking. Participants rated pain intensity on a numeric rating scale (0–10; no pain to worst pain imaginable) and localization during activities. We included 35 participants with OSD (48.5% females, age 13.0 [SD 1.5]) and 21 controls (47.6% females, age 13.4 [SD1.4]). Doppler signal was more prevalent in OSD participants at the tendon (77% vs. 30%) and tuberosity (29% vs. 10%). Tendon thickness was greater in OSD at distal (mean difference = 4.5 mm 95% CI 1.5–7.5) and proximal sites (mean difference = 4.2 95% CI 0.1–8.3). Aggravating activities induced higher pain in OSD. The greatest differences between OSD and control were the dynamic single-leg squat (mean difference = 4.2 (95% CI 3.22–5.1)). Pain was localized at the tibial tuberosity and patellar tendon during activities. Sex, sports participation, bilateral pain, and Doppler were associated with greater pain during aggravating activities. Single-leg activities loading the tibial tuberosity through the tendon appear to provoke OSD-related pain more than other sports specific movements. This may be useful to guide adolescents on which activities are likely to aggravate pain.

1 | Introduction

Apophyseal injuries are some of the most common gradual onset injuries in sports active adolescents [1–3]. These problems commonly occur at the heel, knee, and the hip with Osgood Schlatter's (OSD; an apophysitis of the tibial tuberosity) being the most common [4]. This affects up to one in ten adolescent athletes [5], and population-based studies show the prevalence is approximately 11.0% of boys and 8.3% of girls [5]. Osgood Schlatter was previously assumed to be a self-limiting condition without any long-term impact, but recent research shows it severely impacts physical activity and quality of life, and lasts several years in some cases [6, 7].

The etiology is unclear, but current theory suggests repetitive overload and inadequate recovery which causes pain, with or without tissue damage [4, 8–10, 11]. This is supported by a high prevalence in high-impact sports such as football which has the highest prevalence of OSD [5, 12]. Cross-sectional studies show an association between self-reported sports participation per week and the prevalence of OSD, and higher odds in single sport versus multi-sport athletes [12].

However, no studies have evaluated potential pain aggravating activities that adolescents with OSD may be exposed to in clinical or sports settings. There is a need to understand potentially aggravating factors to support adolescents, clinicians, and coaches to manage the painful activities, and assessment and progression of exercise based on pain responses. Furthermore, little is known about pain localization [13, 14]. The clinical diagnosis is based on pain localized at the tibial tuberosity [15], and during activities that increase the strain on the tibial tuberosity [16]. However, some studies have shown pain in other locations such as the patellar tendon [13]. It is likely there may be subgroups of OSD, with differing presentations. This is supported by imaging studies that describe OSD classifications based on involvement of different tissues [13, 14].

The aim of this study is to investigate pain responses to knee-loading activities in adolescents with OSD, and to characterize clinical pain and imaging findings compared to controls. A secondary aim was to investigate if clinical, and imaging characteristics were associated with higher pain during aggravating activities.

2 | Methods

2.1 | Study Design

This study was designed as an observational study of adolescents with OSD to investigate the effect of Acute and Cumulative LOADing (ACCULOAD study). The ACCULOAD study consisted of one session including a clinical examination, ultrasound scan, evaluation of pain aggravating activities (in a randomized order), and subsequent prospective activity monitoring. This paper reports cross-sectionally on the aggravating activities and their relation to clinical and ultrasound characteristics.

The study was approved by the research ethics committee of the Northern Denmark Region (N-20200001). Parental/guardian informed written consent was provided by the appropriate custody holder, as well as participant consent, prior to any study-related procedures being undertaken. Data were stored and processed in alignment with the General Data Protection Regulation (GDPR) guidelines.

2.2 | Recruitment

Both youth with OSD and pain free controls were recruited for this project. Participants were recruited from local sports clubs in sports such as football and handball, which have a high prevalence of OSD. This recruitment was supplemented by advertisements online through social media and local clinics. Controls were recruited from the same sports, sex, and age range.

2.3 | Inclusion and Exclusion

Inclusion criteria for OSD were aged 8–18 years old, playing sport and diagnosed with OSD as follows: activity-related pain with an insidious onset localized at the tibial tuberosity, provoked by palpation of the tibial tuberosity and resisted isometric knee extension. All diagnoses were made by a qualified physiotherapist or rheumatologist, who were both members of the author team.

Exclusion criteria for OSD were patellar instability, other reasons for pain such as patellofemoral pain or Sinding Larsen Johansen, previous knee surgery, and patellofemoral instability. The inclusion criteria for the pain-free controls were: aged 8–18 years old; no current self-reported lower extremity pain; no self-reported prior surgery in the lower extremity; no other chronic illness (e.g., neurological, diabetes, autoimmune diseases).

2.4 | Procedures

2.4.1 | Clinical Examination

The clinical examination included comprehensive history, and a diagnosis of OSD as described above including standard physical examination including pain on palpation of the tibial tuberosity, and during resisted contraction of the knee extensor mechanism. In addition, pain during a functional activity was evaluated by asking participants to squat to 60° of knee flexion on their most symptomatic knee holding this position for 45 s, at which point pain was recorded. For each of these assessments, participants rated their pain on an 11-point numeric rating scale (NRS) ranging from 0 (no pain) to 10 (worst pain imaginable). In addition, the examiner noted the presence of localized swelling at the tibial tuberosity (yes/no), and whether the participant reported pain on kneeling (yes/no). All clinical examinations were conducted by the same experienced healthcare practitioner, with an experienced rheumatologist specializing in sports medicine available for consultation.

2.4.2 | Baseline Assessment

Height and weight were measured using a measuring tape and weighing scales respectively, with participants in bare feet and outer clothing removed (i.e., shorts and t-shirt). Sitting height was measured with the participant sitting on a box, to allow for biological maturity to be estimated using time from peak height velocity equations developed by Mirwald and colleagues [17]. Participants completed an electronic questionnaire (REDCap) including participant demographics, self-reported symptoms (including pain intensity, duration, and frequency), and sports participation. Self-reported knee function was captured using the Knee injury and Osteoarthritis Outcomes Score (KOOS) Child version [18, 19], and health-related quality of life using the youth version of the EuroQol five dimensions, with three levels (EQ 5D 3L Youth) [20].

2.4.3 | Ultrasound

Ultrasonography was performed using a Hi Vision Preirus machine (Hitachi Medical Systems UK) with a 18–5 MHz linear array transducer. The ultrasound measurements were carried out with the patients in a supine position with either the knee extended when assessing the color Doppler activity or flexed 45° when measuring the thickness of the tendon and evaluating the area of the apophysis. The color Doppler flow in the tendon and bone was estimated from a longitudinal scan and recorded from 1 to 4 according to Newman's grading scale [21], with one indicating no Doppler activity. To determine proximal thickness, a transversal scan taken 1 cm from the apex of the patella (marked by marker to ensure it was repeated at the same point post-exercise) and distal (1 cm from TT) attachment in the transverse plane. The average of three measurements was used for analysis. Ultrasound was completed by a trained researcher with previous experience in musculoskeletal ultrasonography, who was supervised by a rheumatologist with >18 years' experience in musculoskeletal ultrasonography who checked US assessments.

2.4.4 | Experimental Knee Joint-Loading Activities

Eight pain provoking knee-loading activities [22–25] (listed below) were performed, based on our pilot studies and questionnaires asking adolescents with OSD which activities were most painful. Each participant performed these in a randomized order. The randomized order was generated for each participant by the tester prior to the session using the RAND function in Microsoft Excel to generate a random number for each activity, which was then used to allocate the exercise order by ascending numbers.

2.4.5 | Knee Joint-Loading Activities

1. Single-leg isometric knee hold.
2. Single-leg squat.
3. Single-leg vertical jump.
4. Repeated hopping (plyometric).
5. Jogging (medium pace) 30 m.
6. Cutting.
7. Lunges (on both legs).
8. Walking 30 m.

Participants with OSD performed the tests on their affected limb, or the self-reported most painful limb in case of bilateral pain. The test limb for controls was the dominant limb determined as the leg used to kick a ball as far as possible. Participants performed five repetitions for each test, except for the isometric hold which was held for 15 s. Following this, they reported pain intensity using the 0–10 NRS. Participants were also shown a diagram of the knee from which they could choose their pain localization—at the tibial tuberosity, the patellar tendon, the patella, the quadriceps/quadriceps tendon or "other." Localization was only captured if the participant reported pain during that specific activity, and participants could choose more than one location for each exercise. A wash-out period of 5–10 min was given between activities, where participants were instructed for passive rest. During this period, participants also received instruction on the next activity.

2.5 | Statistics

2.5.1 | Sample Size

In order to detect a clinically relevant difference in pain between groups of 3 points on the NRS (assuming a common standard deviation of 2), with an alpha level of 0.00625 to control the family-wise error rate at 0.05 (across eight activity comparisons), and a power of 95%, we would require at least 20 participants per group (OSD and control), and 40 participants overall.

2.5.2 | Aggravating Activities for OSD Compared to Controls

A 2×8 mixed between (OSD vs. control) within (activity) subjects analysis of variance (ANOVA) was used to evaluate pain across groups and tasks. The dependent variable was pain intensity recording on the NRS. Post hoc pairwise comparisons were done using Bonferroni adjustment. For pain localization during activities, we calculated the proportion (95% CI) of OSD participants reporting pain for each location to identify the most common pain localization.

2.5.3 | Differences in Imaging Characteristics Between OSD and Controls

We examined the difference between groups in proportions with Doppler at the tendon, and bone on the affected side using Chi-squared test/Fisher's exact test (as relevant). The difference between tendon thicknesses distally, proximally, and at midpoint of tendon using an independent samples *t*-test.

2.5.4 | Association Between Clinical and Imaging Characteristics and Pain Aggravations

A general linear mixed model was used to examine the effect of clinical and imaging characteristics on pain during aggravation. The dependent variable was pain intensity (0–10) during aggravating activities. Subjects were included as a random effect and activity was included as a repeated measures factor to account for the within-subject nature of the aggravating activities, with a variance components covariance structure. Fixed effects were sex, swelling at the tibial tuberosity, hours of sport per week, and presence of Doppler signal at the tibial tuberosity.

3 | Results

3.1 | Participants

We included 35 participants with OSD (48.5% females), and 21 controls (47.6% females). Participants were similar in terms of age, BMI, and maturity (Table 1). Seventy-seven percent of participants with OSD reported reducing sport due to OSD. Median sports participation in adolescents with OSD was 2 h/week lower compared to controls.

3.1.1 | Clinical and Imaging Characteristics

On clinical examination, 60% ($n = 21$) of participants with OSD had swelling localized at the tibial tuberosity. Mean pain on palpation of the TT was 3.2 (SD 2.1) for participants with OSD, compared to 0 (SD 0) for controls. Pain on isometric extension was median 3 (IQR 1.3–5) for those with OSD (0 (SD 0) for controls). Pain during the functional pain provocation (AKPP) was 5.8 (SD 2.5) for OSD and 1.1 (SD 1.6) for controls. Sixty-nine percent of participants with OSD ($n = 24$) reported pain on kneeling. Figure 1 demonstrates the KOOS scores, health-related quality of life. Overall, 77% of OSD compared to 30% of controls presented with positive Doppler US in the tendon. Twenty-nine percent of OSD and 10% of controls presented with positive Doppler US at the tibial tuberosity. Full details of ratings are presented in Table 2.

There was evidence of greater tendon thickness in OSD compared to controls at the distal (mean difference = 4.5 mm 95% CI 1.5–7.5; $t = 3.0$, $p < 0.005$), and proximal (mean difference = 4.2 95% CI 0.1–8.3; $t = 2.1$, $p < 0.05$) sites. There was no difference at the mid-portion site (mean difference = 2.3 95% CI −0.6 to 5.3; $t = 1.6$, $p > 0.05$).

TABLE 1 | Demographics (mean [SD]) and weekly sports participation (median [inter-quartile range]) for control and Osgood Schlatter (OSD). Pain frequency and bilateral pain (% [*N*]) for OSD only.

	Control	OSD
BMI	18.9 (2.4)	18.7 (3.1)
Age	13.4 (1.4)	13.0 (1.5)
Maturity offset	−0.2 (1.9)	−0.4 (1.2)
Sport (times per week)	3 (2–4)	2 (1.5–3)
Sports (hours per week)	5 (4–5)	3 (2–4)
Pain frequency		% (*N*)
Never	NA	0.0 (0)
Rarely	NA	8.5 (3)
Monthly	NA	5.7 (2)
Weekly	NA	17.2 (6)
Bilateral pain		% (*N*)
Bilateral	NA	47.2 (17)
Right knee only	NA	25.0 (9)
Left knee only	NA	27.8 (10)

3.1.2 | Pain Aggravating Activities

The mixed ANOVA demonstrated a significant interaction between activity and group ($F = 6.89$ [5.34, 256.45]; $p < 0.001$). Post hoc analysis revealed significant differences between the OSD and control groups on all activities except walking. The activities with the greatest differences between OSD and control (Figure 2) were the dynamic single-leg squat (mean difference = 4.2 [95% CI 3.22–5.1]) followed by the isometric single-leg squat (mean difference = 3.4 [95% CI 2.5–4.4]). There was no difference in pain between different activities in controls. However, there were significant differences between pain during aggravating activities for OSD ($F(5.27, 164.0) = 12.3$; $p < 0.001$). Again, dynamic single-leg squat was the most painful activity (with a median pain intensity of 5), followed by the isometric single-leg squat hold.

3.1.3 | Pain Location During Aggravating Activities

The median number of pain locations OSD participants reported in the SLS (the most painful activity) was 1 (range 0–3). Pain provoked by the activities was most commonly at the TT, followed by the PT (Figure 3). The isometric SLS and SLS jump aggravated pain at the TT, while the dynamic SLS were the activities most commonly associated with pain at the PT (in addition to the TT).

Only one participant reported pain at the patella (during lunges), and also reported pain at the TT. Few participants (one to two per activity) reported pain in the quadriceps/quadriceps tendon.

3.1.4 | Association Between Clinical and Imaging Characteristics and Pain Aggravations

Sex, bilateral pain, hours sport per week, and Doppler at the tibial tuberosity were significant and retained in the final multivariable model (Table 3 below for estimates). Swelling at the tibial tuberosity was significantly associated with higher pain in the univariable model (0.60 points higher for those with swelling 95% CI 0.04–1.16, $p < 0.05$), but not in the multivariable model so were not retained in the final model.

4 | Discussion

Osgood Schlatter is one of the most common sports-related injuries in adolescent athletes active in sports. Prior to this study, there was a gap in understanding which sports specific and other activities aggravate pain in this group. This study provides evidence to support an association between knee loading activities and pain presentation (intensity and localization). Additionally, it was identified that specific demographic (female) and clinical findings (bilateral pain and neovascularization on ultrasound) as well as higher weekly sports participation were associated

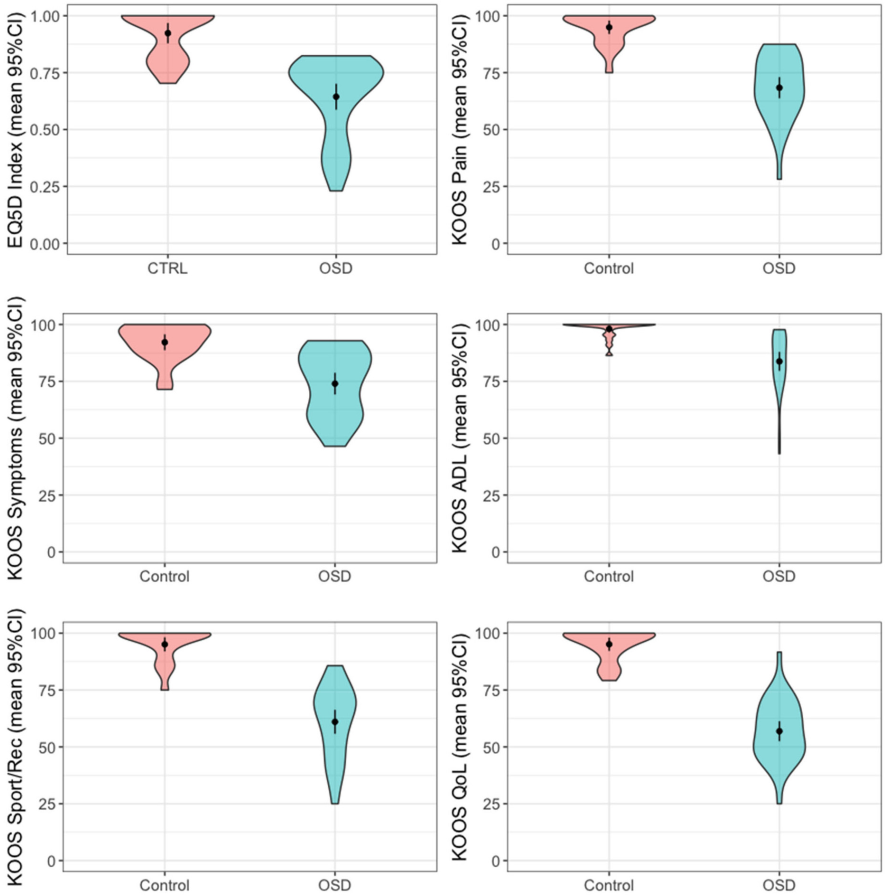

FIGURE 1 | Health-related quality of life (EQ5D), Knee Osteoarthritis Outcome Score (KOOS) subscales (Sport/Rec: Sport and recreation, QoL: Quality of life, ADL: Activities of daily living) in participants with OSD and controls.

TABLE 2 | Degree of vascularity as measured on power Doppler ultrasonography.

	Tendon		Bone	
	Control (%)	**OSD (%)**	**Control (%)**	**OSD (%)**
None	65.0	22.9	90.0	71.4
Mild	30.0	45.7	5.0	25.7
Moderate	5.0	25.7	5.0	2.9
Marked	0.0	5.7	0.0	0.0

with higher amounts of pain during aggravating activities. This highlights loading and structure driven pain as a key determinant of this common problem in adolescent athletes and provides both clinically relevant insights and a deeper understanding of this condition. The use of Doppler US in clinical examinations may provide relevant clinical information that can alter management of OSD patients.

4.1 | Understanding the Link Between OSD Knee Loading and Pain Aggravation

We included both sports specific (running, cutting, hopping) and rehabilitative exercises (such as squat and lunges) used to strengthen the lower extremity and load the knee extensor musculoskeletal system. Interestingly, the activities thought to be associated with the development of OSD (running, jumping, and cutting) were associated with a lower degree of pain. It seems like dynamic hoping exercise of short bouts of loading is associated with low levels of self-report pain but slower dynamic exercises (e.g., isometric and dynamic single-leg squat) with a longer time under tension is associated with higher amounts of pain.

Scattone Silva et al. [22] recently developed patellar tendon loading profiles and a "loading index" combined of loading peak, loading impulse, and loading rate for different rehabilitation exercises. The single-leg decline squat showed the highest loading index, based on these characteristics for patellar tendon loading.

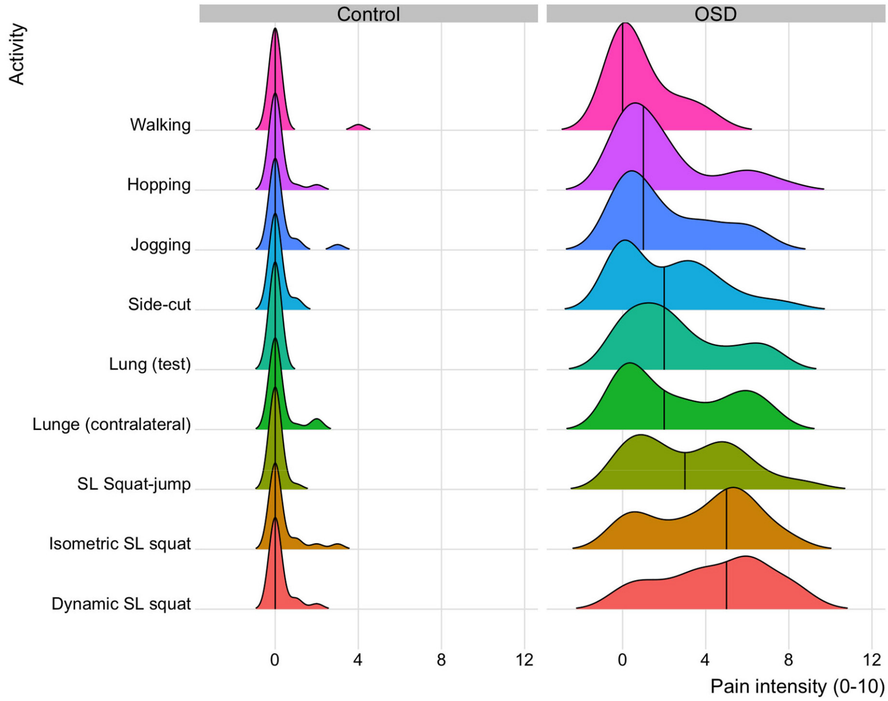

FIGURE 2 | Ridgeline plot demonstrating distribution of pain intensity during activities for the control and OSD (Osgood Schlatter) groups, respectively. Black line indicates the median value. SL = single leg.

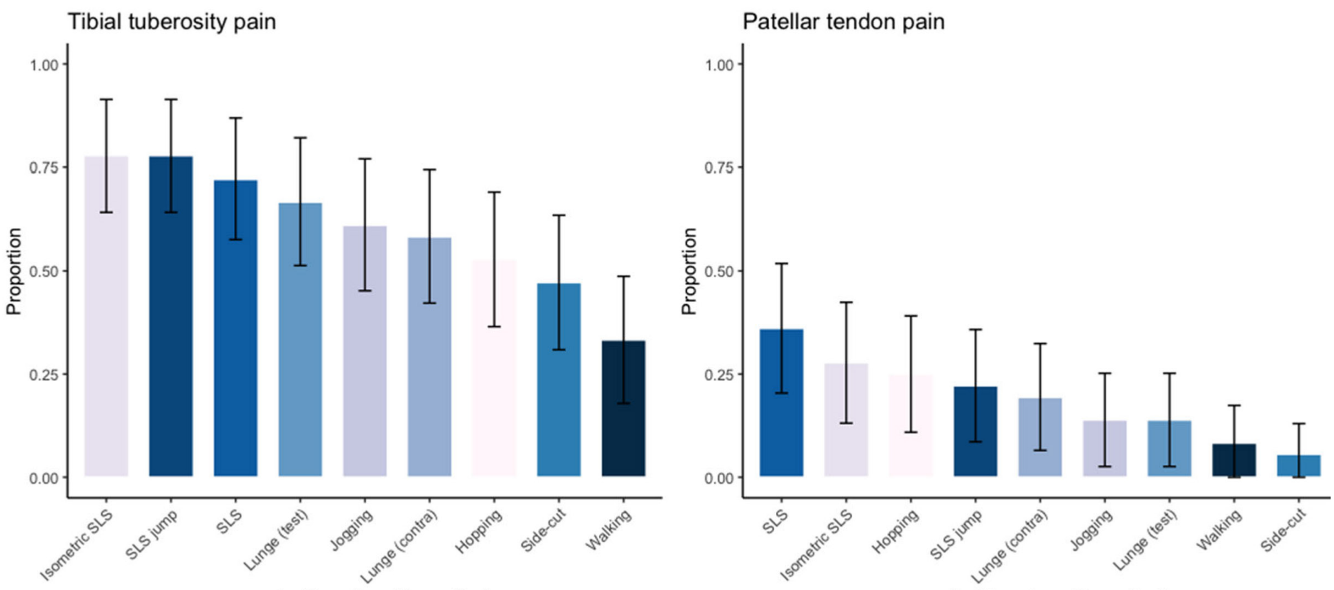

FIGURE 3 | Proportion of participants reporting pain at the tibial tuberosity (left panel) and the patellar tendon (right panel) during each of the activities. SLS = single-leg squat.

This may provide an explanation for the high pain during single-leg squat exercises for this population. In contrast to this, a study by Itoh et al. [26] aimed to identify the load on the tibial tubercle using 3D biomechanics to quantify kinetics during various activities. They found that the peak knee extension moment and angular impulse were highest in a single-leg jump-land, and higher than both squats and sports specific activities.

While loading rate appears to be important for mechanical properties [27], it may be that cumulative stresses from repetitive jumping and landing are needed to elicit a greater pain response due to the short nature of these activities. Five repetitions of hopping may have a high loading rate over a shorter duration, but requires less sustained contraction compared to the five repetitions of squatting. The sustained contraction of the quadriceps during squats may lead to cumulative stresses on the tibial tuberosity which may explain why we found lower pain intensity during hopping despite studies showing higher peak loading.

The multivariable model provided further insights into the nociceptive component of pain. Increased Doppler activity

TABLE 3 | Results of the multivariable regression.

	Estimate	95% confidence interval lower	95% confidence interval	p
Female (relative to male)	0.84	0.26	1.42	0.01
Doppler at the tibial tuberosity (per point increase in rating)	0.81	0.28	1.35	0.00
Bilateral pain (relative to unilateral)	0.78	0.17	1.39	0.01
Hours sport per week (per hour increase)	0.36	0.10	0.61	0.01

(indicative of neovascularization, and higher blood flow) was associated with higher self-report pain. This aligns with the finding of Sailly [10] who also showed that the presence of positive Doppler was associated with higher amounts of pain during palpation and resisted extension. We extend these by showing not only the presence but the degree of signal intensity (and neovascularization) were associated with higher pain during aggravating activities. However, a key difference is that Sailly et al. [10] did not find any differences in pain between those with Doppler positive findings during the single-leg squat, while our analysis was primarily based on pain during loading activities. Sailly et al. [10] hypothesized that greater pain in those with positive Doppler during palpation and resisted contraction may be due to greater compressive forces in these activities. Higher weekly sport participation was also associated with higher pain aggravations. This may be because increased activity sustains and exacerbates the stress on the tuberosity, thereby maintaining or worsening pain in symptomatic patients with OSD. This highlights the need to balance training participation to help manage pain effectively. We also found that demographic and clinical characteristics were associated with higher pain. This may be more relevant even in females, and those with bilateral pain, as we found these characteristics were associated with higher pain aggravations.

The primary pain localization during aggravations was reported to be the tibial tuberosity, which is unsurprising given this is the cardinal symptom of OSD. Interestingly, a small proportion of participants reported pain at the tendon as well. Pain at the tendon almost exclusively was reported in combination with pain at the tibial tuberosity. However certain activities (particularly the squatting activities) were more likely to provoke tendon pain in addition to the tuberosity. OSD was once thought to only be related to changes at TT, but recent studies have shown how some experience pain and have imaging findings in the patellar tendon as well [8]. It must be acknowledged that self-reported pain localization means it may be difficult for participants to distinguish between the different pain locations' particularly in sites that are so close to each other such as the patellar tendon and the tibial tuberosity. Additionally, the assessor was not blinded to status (control vs. participants with OSD) which must be acknowledged as a limitation.

4.2 | Perspectives

To prevent aggravations of OSD, practitioners may use this information to control the load and pain on the tibial tubercle in symptomatic cases to prevent worsening during sports and rehabilitation. The findings of this research can be incorporated into informative leaflets for children and their parents [28]. Activities that load the extensor mechanism transfer force through the tendon onto the attachment at the tuberosity, and may have the propensity to aggravate pain at the tibial tuberosity. This cross-sectional study only tested the immediate effects of different activities on self-report pain and location of pain. It is unclear how the accumulation of loading parameters changes the response over time as in everyday activities such as soccer or handball. Future work should explore the response to accumulated loads as this may have relevant implications for rehabilitation and advising adolescents.

5 | Conclusions

Single-leg activities loading the tibial tuberosity through the tendon appear to provoke OSD-related pain more than other sports specific movements. This may be useful to guide adolescents on which activities are likely to aggravate pain. In addition, it appears clinical and imaging predictors, such as sex, higher sports participation, bilateral pain, and Doppler ultrasound are associated with heightened pain during aggravating activities. Such information would be useful for keeping adolescents active while avoiding pain flare up which is often a barrier for being physically active.

Ethics Statement

The study was approved by the research ethics committee of the Northern Denmark Region (N-20200001).

Consent

Parental/guardian informed written consent was provided by the appropriate custody holder, as well as participant consent, prior to any study-related procedures being undertaken. Data were stored and processed in alignment with the General Data Protection Regulation (GDPR) guidelines.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Researchers interested in the data from this study may contact the principal investigator, Sinéad Holden, siho@hst.aau.dk.

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