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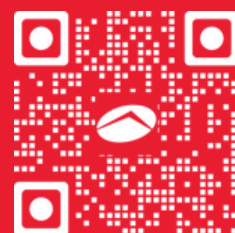


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1. Gerdemeyer L, Mittermayr R, Fuerst M, et al. Current evidence of extracorporeal shock wave therapy in chronic Achilles tendinopathy. *Int J Surg*. 2015;24(Pt B):154-159. doi:10.1016/j.ijsu.2015.07.718
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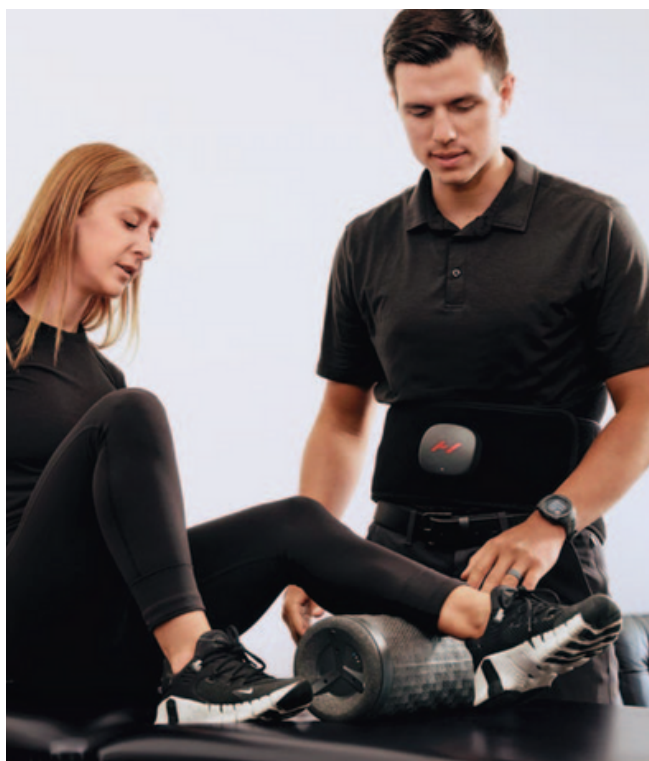
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Gauthier ML, Unverzagt CA, Davies GJ. Evaluation and Treatment of Baseball Pitchers: There's More to Assess than the Arm. IJSPT. 2025;20(1):113-126. doi:10.26603/001c.127461. PMID:39758696

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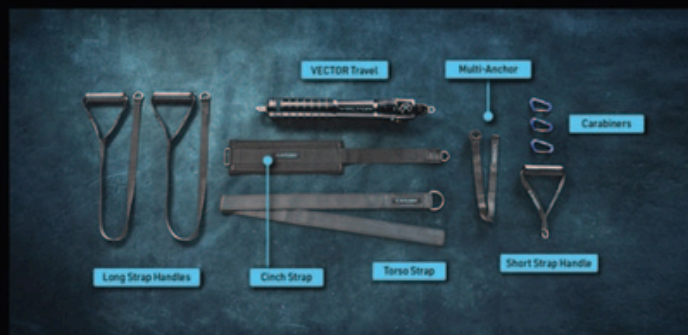


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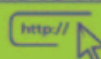
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Original Research

The Influence of Coronal Strike Stance Angle on Kicking Mechanics in Adolescent Female Soccer Players

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Background

Anterior cruciate ligament (ACL) tears are one of the leading injuries in soccer players, especially among female athletes. Prior research has investigated risk factors associated with the swing limb during a soccer kick, but limited research has focused on biomechanical risk factors of the stance limb that may contribute to elevated injury risk when kicking.

Hypothesis/Purpose

The purpose of this study was to quantify the relationship between strike stance angle (SSA) and lower extremity kinematics and kinetics during a soccer kick. SSA is the coronal angle created by the hip joint center to the ankle joint center of the stance limb from vertical. It was hypothesized that a greater SSA would be correlated to greater biomechanical risk factors and that correlated findings would differ by dominance.

Study Design

Cross-sectional study.

Methods

Nineteen healthy female soccer players (15.2±0.9 years) were tested performing a soccer kick on each limb in a motion capture laboratory. Kinematics and kinetics from the stance limb were captured at ball contact. Spearman correlations were performed to identify significant associations with SSA.

Results

During the stance limb-dominant kick, greater ankle dorsiflexion ($r=0.72$, $p=0.018$) was associated with greater SSA. Non-significant trends towards increased hip adduction and knee flexion were also observed. For the stance-limb-non-dominant kick, knee valgus moment ($r=-0.81$, $p=0.002$) and external knee rotation moment ($r=-0.66$, $p=0.038$) were also associated with greater SSA. A non-significant correlation was also observed between increased knee flexion and greater SSA.

Conclusions

Altered hip mechanics and knee loading risk factors were associated with greater SSA, and associations differed by limb dominance. Additional research is needed to better

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define the relationship between SSA and lower extremity injury risk of healthy youth soccer players and to explore the potential impact on injury prevention.

Level of Evidence

Level 3

INTRODUCTION

Soccer has steadily risen in popularity, attracting active males and females worldwide. Specifically, soccer participation among adolescent females has experienced exponential growth, attributable in part to increased media coverage, greater investment in women's sports, and the rising visibility of professional female athletes.¹ However, as sport participation rises, so does exposure to injury.^{2,3} Female soccer players are two to nine times more likely to experience an anterior cruciate ligament (ACL) injury compared to males, with approximately 18% of high-level women's soccer players having a history of ACL injury.⁴ Therefore, a strong understanding of the biomechanical risk factors associated with ACL injury,⁵ particularly those specific to soccer movements, is important for developing effective strategies to reduce injury risk in female athletes.

Soccer athletes perform highly dynamic movement patterns that require speed, strength, and agility, such as sprinting, changing direction, jumping, and kicking. While these movements are an important aspect of high-level performance, poor technique can quickly increase the risk of injury. Notably, female athletes have been found to have high-risk knee mechanics, such as increased dynamic knee valgus, specifically during cutting, pivoting and landing movements that have been shown to increase load on the ACL and thus heighten the rate of injury compared to males.⁶⁻⁹ During a soccer kick specifically, prior research has primarily investigated varying positions of the swing limb,¹⁰ angle of the stance foot,¹¹ and approach angle when kicking to increase movement efficiency.^{12,13} However, limited investigations have focused on the mechanical contributions to potential risk factors associated with the stance limb during kicking, despite the stance limb bearing substantial load throughout kicking.

In the current study, strike stance angle (SSA) was used to assess the orientation of the stance limb in relation to vertical when kicking, which can be useful in identifying potential biomechanical risk factors associated with the loaded limb. The stance limb of a soccer player is loaded multiple times during a game. While a direct causal link between SSA and ACL injury risk has yet to be established, coronal plane deviations of the lower limb have been associated with altered joint loading and injury risk factors.¹⁴ Therefore, assessing coronal SSA may provide insight into how improper loading mechanics during kicking may relate to potential risk factors of injury. Specifically, the purpose of this study was to quantify the relationship between SSA and lower extremity kinematics and kinetics during a soccer kick. It was hypothesized that a greater SSA would be correlated to greater biomechanical risk factors and that correlated findings would differ by dominance. Understanding the role of SSA in kicking mechanics can contribute to more

effective training protocols for female athletes, optimizing stance position to reduce risk factors potentially leading to injury. Findings from this study may lead to evidence-based recommendations for improving soccer kick mechanics and reducing lower extremity injury risk in female soccer athletes.

MATERIALS AND METHODS

PARTICIPANTS

Participants tested for this study consisted of healthy female youth athletes who reported soccer as their primary sport. Participants were excluded if they reported a lower extremity injury six months prior to testing, or any musculoskeletal or neuromuscular conditions that would prevent their abilities to complete the soccer kick task. All participants wore their preferred athletic footwear and attire during testing in the motion capture laboratory. This study was approved by the local Institutional Review Board, and informed consent/assent was obtained from all parents and participants prior to participation.

TOOLS AND EQUIPMENT

A 14-camera motion capture system (Vicon Motion Systems Ltd, Denver, CO, USA) was utilized to collect kinematic data at 240 Hz. Retroreflective markers were placed on anatomical landmarks on the trunk, pelvis, thigh, shank, and foot derived from the Modified Helen Hayes marker set.^{15,16} Specifically, trunk markers were placed on the first and tenth thoracic vertebrae, jugular notch, mid-sternum, xyphoid process, and sacrum. Additionally, markers were placed bilaterally on the anterior superior iliac spines, medial and lateral femoral epicondyles, patella, anterior shank, medial and lateral malleoli, heel, first metatarsal, and fifth metatarsal. Fixed marker clusters were placed bilaterally on the anterior shank and lateral thigh to aid in overall lower extremity tracking. Six embedded force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to collect kinetic data at a sampling rate of 2,880 Hz.

TASK PROCEDURES

Participants completed four trials of soccer kicks, two kicks per leg. The athlete's typical kicking leg was recorded as their dominant limb and used for comparison to the non-dominant limb. However, to provide context for interpretation, when referring to findings for the "dominant kick", kinematics and kinetics were presented for the stance limb. The kicking task was completed in a 15-foot stretch of space on the floor of the laboratory, including a large net to replicate a soccer setting. There was sufficient space leading up

to the force plates where participants could approach the ball as they typically would when performing a penalty kick. Participants were instructed to kick as they normally would, and their starting position was adjusted, as to not alter their natural kicking mechanics, such that their stance/plant limb landed on the force plate while performing the soccer kick. Trials in which the participant did not plant solely in the force plate were deemed unsuccessful and discarded.

DATA PROCESSING AND ANALYSIS

Kinematic data were processed in Vicon Nexus software and were filtered using a Woltring filter (predicted mean square error of 10 mm²). Kinetic data from the force plates were also processed in Vicon Nexus software and filtered using a fourth-order low-pass Butterworth filter with a cutoff of 16 Hz. A custom MATLAB (MATLAB 2022a, Natick, Massachusetts, USA) code was used to determine joint and segment angles and (external) moments in the sagittal, coronal, and transverse planes. The hip joint centers were estimated using the Harrington method, while the knee and ankle joint centers were calculated as the midpoint between the respective medial and lateral joint markers.¹⁷ Segmental angles and moments were subsequently extracted at the time of ball contact during each kicking trial. Ball contact was defined as the timepoint where the swing and stance limbs were adjacent using the difference between the toe markers, tracking where the ball would be impacted. Entry velocity was also calculated using a custom MATLAB code, taking the maximum velocity from the sacrum marker between the previous contralateral step and initial contact of the stance limb.

Lastly, SSA was calculated at the time of ball contact to assess the alignment of the stance limb in the coronal plane of the global coordinate system (Figure 1). SSA was defined as the two-dimensional angle between the vector connecting the stance limb's hip joint center and ankle joint center and the vertical axis of the global coordinate system, projected into the coronal plane of the of the global coordinate system. To ensure consistent interpretation across kicking sides, the SSA was sign-adjusted such that a positive angle represented medial inclination of the stance limb, regardless of whether the left or right limb was used for stance. Additionally, swing limb speed was calculated using the three-dimensional position of the ankle joint center in the global coordinate system. The linear displacement vector was measured by subtracting the ankle joint center position at ball contact from that at initial contact. The magnitude of this displacement was divided by the elapsed time between the two events to compute swing limb speed (m/s). Of the successful trials, the trial with the fastest entry velocity was chosen for each kicking limb and used for subsequent analysis.

Given significant tests for normality (Shapiro-Wilk), nonparametric analyses were conducted using the Wilcoxon signed-rank test. Spearman correlations were performed to identify significant relationships between SSA and kinematic and kinetic measures for both stance limb-dominant kick and stance limb-non-dominant kicks at ball

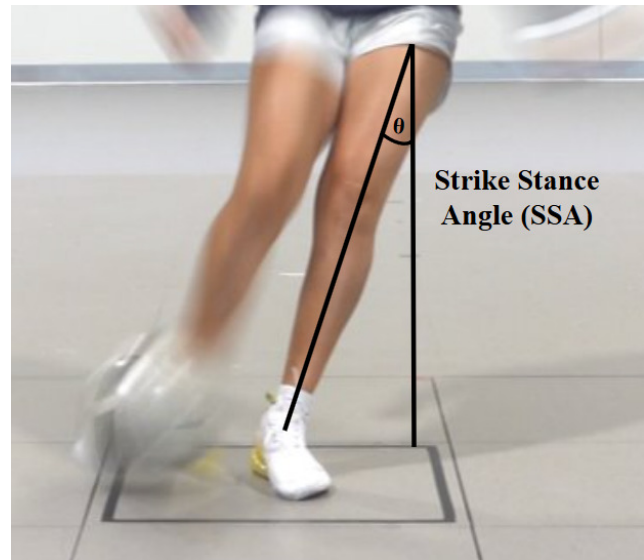


Figure 1. Coronal strike stance angle (SSA) at ball contact.

contact. To address multiplicity, the false discovery rate was controlled using the Benjamini–Hochberg procedure with $Q = 0.10$. Corrections were applied within families of tests that addressed distinct questions: (a) limb-to-limb comparisons and (b) correlations between SSA and kinematic and kinetic variables. Only FDR-adjusted p -values are reported, and inferences are based on these adjusted values. For transparency, rank-based effect sizes (r) with 95% confidence intervals are also reported for paired comparisons. Lastly, correlation strengths were defined as weak ($r \leq 0.35$), moderate ($r = 0.36$ – 0.67), or strong ($r \geq 0.68$).¹⁸

RESULTS

Nineteen healthy female soccer players (15.2 ± 0.9 years, 168.2 ± 5.8 cm, 61.3 ± 7.8 kg) were tested from October 2023 to August 2024 in which they performed soccer kicks bilaterally. All participants reported their right leg as their dominant limb that they preferred to kick with. A total of 37 soccer kicks were included for correlation analysis, as one kick was removed from the dataset due to an incorrect execution of the task. No significant differences between stance limb-non-dominant and stance limb-dominant kicks were observed for kinematic and kinetics at ball contact. Spearman correlation results between SSA and dominant and non-dominant kick kinematics and kinetics are presented in Table 1. Detailed descriptive data and statistical results, including effect sizes, are presented in Appendix A.

PERFORMANCE METRICS

For both the dominant and non-dominant kicks, there were no significant correlations between entry velocity and SSA. On the non-dominant kick, greater swing limb speed was moderately correlated with SSA ($r = 0.55$ $p = 0.038$). There were no significant correlations between SSA and swing limb speed during the dominant kick.

Table 1. Correlations between SSA and kinematic and kinetic measures for stance limb-dominant and stance limb-non-dominant kicks at ball contact.

Measure	Stance Limb Non-Dominant Kick		Stance Limb Dominant Kick	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Performance Metrics				
Swing Limb Speed (m/s)	0.55	0.038	0.01	0.288
Entry Velocity (m/s)	0.32	0.432	0.13	0.795
Kinematics (°)	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Trunk				
(Forward) Flexion	0.02	0.977	0.40	0.368
(Lateral) Lean	0.26	0.588	0.42	0.368
Internal Rotation	0.33	0.432	0.35	0.383
Pelvis				
Anterior Tilt	0.01	0.977	0.25	0.550
Pelvic Rise	-0.16	0.718	-0.37	0.368
Internal Rotation	0.19	0.666	-0.01	0.977
Hip				
Flexion	0.21	0.666	0.32	0.424
Adduction	0.42	0.296	0.51	0.261
Internal Rotation	-0.41	0.296	-0.02	0.977
Knee				
Flexion	0.48	0.264	0.50	0.261
Varus	-0.19	0.666	0.32	0.424
Internal Rotation	-0.42	0.296	-0.01	0.977
Ankle				
Dorsiflexion	0.21	0.666	0.72	0.018
Foot				
Internal Rotation	-0.35	0.432	0.08	0.881
Kinetics (Nm/kg)	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
Hip				
Flexion Moment	0.10	0.814	0.18	0.733
Adduction Moment	-0.12	0.807	0.24	0.552
Internal Rotation Moment	0.04	0.974	-0.38	0.368
Knee				
Flexion Moment	0.27	0.588	0.13	0.795
Varus Moment	-0.81	0.002	0.16	0.740
Internal Rotation Moment	-0.66	0.038	-0.09	0.881
Ankle				
Dorsiflexion Moment	-0.11	0.807	-0.30	0.433

Note: Significant correlations (FDR-adjusted $p < 0.05$) denoted in bold. Correlation strengths were defined as weak ($r \leq 0.35$), moderate ($r = 0.36-0.67$), or strong ($r \geq 0.68$).¹⁷ All measure labels reflect the movement direction associated with a positive value.

TRUNK AND PELVIS

There were no significant correlations between trunk and pelvis measures and SSA at ball contact during the stance limb-dominant and stance limb-non-dominant kicks.

HIP

There were no significant findings between hip kinematics and kinetics and SSA during the stance limb-non-dominant

kick. On the stance limb-dominant kick, greater hip adduction was moderately correlated with a greater SSA ($r = 0.51$, $p = 0.261$). Thus, as the stance limb plants at a greater angle, the ipsilateral hip becomes more adducted. While there was a relatively moderate correlation, it was not statistically significant.

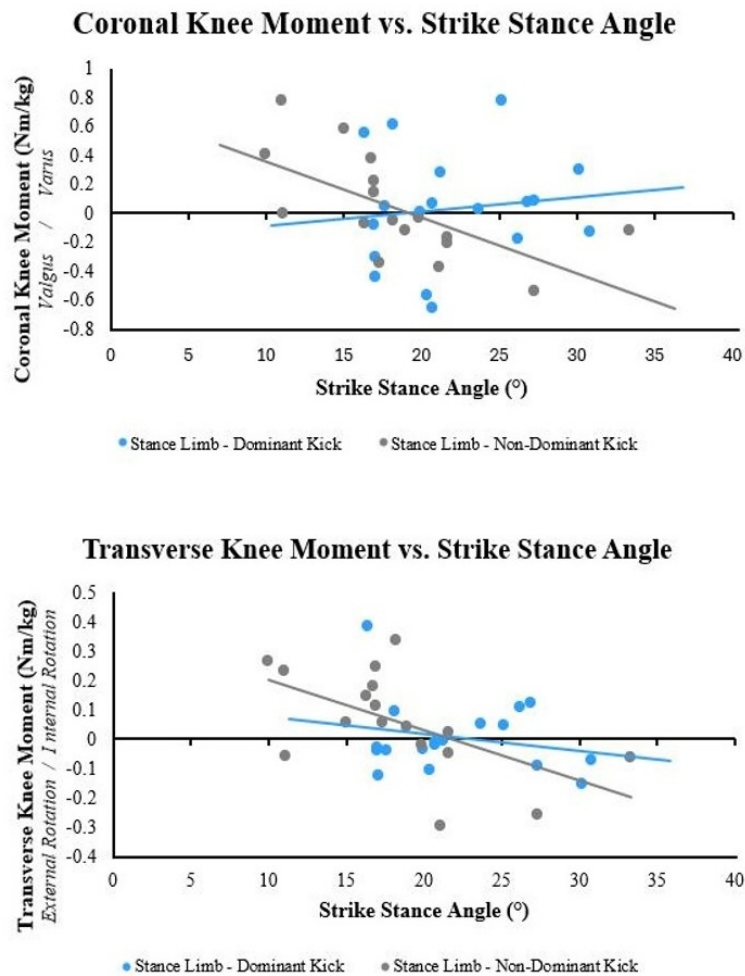


Figure 2. Correlations between SSA and knee kinetics at ball contact for stance limb-dominant and stance limb-non-dominant kicks.

KNEE

On the stance limb-non-dominant kick, increased knee flexion correlated with a greater SSA ($r = 0.48$, $p = 0.264$). While this is a relatively moderate correlation, it was not statistically significant. SSA was found to have a strong negative correlation with coronal knee moment (varus moment) ($r = -0.81$, $p = 0.002$), such that a greater SSA was associated with a reduced knee varus moment, or in some cases a greater knee valgus moment, on the stance limb during the non-dominant kick at ball contact (Figure 2). The transverse moment at the knee exhibited a moderate negative correlation to SSA ($r = -0.66$, $p = 0.038$), which indicates that a greater SSA is associated with a reduced internal rotation moment, or in some cases an increased external rotation moment, at the stance limb knee during the non-dominant kick (Figure 2). Similarly, knee flexion during the stance limb-dominant kick was moderately correlated with SSA ($r = 0.50$, $p = 0.261$). This indicates that as the SSA increases, there is more flexion on the stance limb at ball contact. Although the correlation was moderate, it was not statistically significant.

ANKLE AND FOOT

A strong positive correlation was found between SSA and sagittal ankle angle ($r = 0.72$, $p = 0.018$) during the stance limb-dominant kick, indicating that as SSA increased, ankle dorsiflexion also increased at ball contact. There were no significant correlations between SSA and foot rotation during both the stance limb-dominant and stance limb-non-dominant kicks.

DISCUSSION

The results of the current study defined the relationship between SSA and lower extremity kinematics and kinetics at ball contact during a soccer kick in adolescent females. The hypothesis, that a greater SSA would be correlated to greater biomechanical risk factors differing by dominance, was supported. Biomechanical measures with the strongest associations to greater SSA for the stance limb-non-dominant kick were increased knee valgus moment and knee external rotation moment. For the stance limb-dominant kick, the strongest association to greater SSA was increased ankle dorsiflexion, and non-significant trends existed to-

ward associations with increased hip adduction and knee flexion at ball contact.

Although not statistically significant, the observed trend of increased hip adduction with greater SSA likely reflects compensatory mechanics arising from limited dynamic stability and coronal plane control at the hip. The observed trends approaching statistical significance may be attributable to the limited sample size and could reach significance in studies with a larger cohort. One study similarly found that soccer players exhibited greater hip adduction angles due to muscle shortening of the hip flexors as a result of habitual recruitment during a single-leg squat task, a common imbalance leading to altered hip mechanics.^{19, 20} Hip adductor and abductor strength in both the swing and stance limb help stabilize the orientation of the body throughout the entire soccer kick, emphasizing the importance of maintaining hip strength to prevent imbalances that pose a risk for injury.²¹ Numerous reports have shown that females tend to have less hip abductor strength compared to males, indicating a potential association to dynamic knee valgus which may increase risk of ACL injury.²²⁻²⁴ Specifically, weak hip abductors may lead to an inability to prevent knee collapse into valgus. Similarly, in the current study, the association between greater SSA and hip adduction during the stance limb-dominant kick may indicate a deficit in hip abductor strength to control the entire movement. Previous research has identified that decreased muscle activation at the hip ultimately decreases quadriceps and hamstring activation in the stance limb.²⁵ This reduction in activation limits the dynamic stability of the knee joint, putting the lower extremity at risk for injury. Additionally, it has been reported that females typically land from a jump in a more upright hip position, resulting in an altered knee angle upon landing that poses biomechanical risk factors.²⁵ The results of the current study indicated that altered mechanics of the stance limb hip, and an upright position when establishing the stance limb at ball contact may improperly distribute the load throughout the kick. Incorporating hip abductor strength exercises into female soccer athlete's training protocol to aid in dynamic stability may benefit players from both an injury prevention and performance standpoint.

In the present study, the significant increase in knee valgus moment with greater SSA suggests elevated mechanical loading at the knee, which may have implications for joint stability and injury risk during the soccer kick. Although not statistically significant, the observed trend toward increased knee flexion may also have potential relevance for altered joint loading and stability under these conditions and should be studied further. On average, the stance limb of a soccer player is loaded at least 20-25 times during a 90-minute game,¹³ and improper loading at the knee joint can predispose athletes to the risk of injury.²⁶⁻²⁸ Interestingly, a previous study investigated ground reaction forces of the stance limb during a soccer kick, suggesting that the soccer kick resulted in significant loading of hip, knee, and ankle joints.²⁹ Repetitive loading on the stance limb with a greater SSA, alongside other biomechanical risk factors, may be putting the lower extremity in a vulnera-

ble position at risk for injury. The current study identified several contributors to dynamic knee valgus – greater knee valgus moment, hip adduction, and external tibial torsion (via external knee rotation moment) – relating to greater SSA during a soccer kick. Therefore, a greater SSA may be associated with valgus loading, a biomechanical risk factor for ACL injury.^{5,30} Likewise, during a single leg squat task, investigation of the musculoskeletal profile of elite female soccer players revealed that many demonstrated a combination of hip adduction, hip internal rotation, knee valgus, and reduced knee flexion.¹⁹ Previous studies have investigated sex differences regarding knee valgus loading during dynamic tasks, suggesting that females land in greater knee valgus than males, a factor that contributes to the sex disparity in ACL injuries.³¹ Having a greater SSA in addition to predisposed knee valgus during a soccer kick may further increase the likelihood of injury in female soccer players due to the increased load on the stance limb knee joint.

Regarding limb dominance, the stance limb is the main contributor to stability and balance throughout the kick. When kicking with the non-dominant limb, this stability is often compromised due to less strength and control, which can put increased stress on the hip and knee joints.³² Additionally, less experienced athletes will typically only kick with their dominant limb, whereas high-level soccer players tend to be more symmetrical in strength and skillset. Due to the unfamiliarity of kicking with their non-dominant limb, they may have altered stance and kicking mechanics that are suboptimal to offset for the lack of strength and balanced force distribution. It has been reported that female athletes playing asymmetric sports exhibited greater dynamic balance in their dominant limbs compared to their non-dominant limbs.³³ Greater emphasis on strength and balance training for the non-dominant limb in asymmetric sports is necessary to mitigate risk and further improve performance variables. Future studies with larger sample sizes may be able to identify greater biomechanical deficits between dominant and non-dominant limbs when kicking, however, limited research has been conducted on both limbs during a soccer kick.

Female athletes have also been shown to perform dynamic athletic maneuvers with decreased hip and knee flexion (i.e., stiffer landing strategies) as well as greater knee valgus moments.^{25,34,35} However, this trend was not fully supported in the current study given the association between increased ankle dorsiflexion and greater SSA in addition to observed trends toward increased knee flexion. These moderate to strong associations may be the result of compensating for weakness of the hip stabilizers, creating a greater range of motion in the hips to follow through, or for shock absorption to maintain balance throughout the kick. From a performance aspect, prior research has investigated how support limb kinematics were related to kicking performance in which a stiffer, more extended stance limb throughout each phase of the soccer kick was related to faster foot speeds at ball contact, which resulted in a higher contralateral hip position creating greater stance limb stability.³⁶ The current study found that faster swing limb speeds during kicking were associated with a greater

SSA in the non-dominant kick. This may reflect a compensatory strategy in high performance players to promote increased toe clearance and to accommodate for the demands of faster swing limb velocities. The increased SSA could be necessary to aid in maintaining balance and generate more power as the swing limb speed impacts the entire body. However, this biomechanical adaptation may also be linked to elevated injury risk as greater SSA can increase joint loading and compromise overall stability during the kick. As the current study did not investigate in-depth measures of performance but rather focused on biomechanical risk factors, future directions should focus on how SSA can influence performance variables, such as ball speed and kick accuracy, coinciding with stance limb kinematics.

LIMITATIONS

The current study has some limitations that should be noted. Given the current study was conducted on healthy, young female athletes, the results presented here may not be generalizable to older female or male participants. Adolescent females exhibit an increased risk for ACL injury, due in part to differences in lower extremity biomechanics, which has been well documented in prior works investigating dynamic athletic maneuvers.^{26,35-38} Thus, future work is needed to determine how sex or age may influence SSA associations as tested in the current study. Additionally, the laboratory setting and surface was not a typical representation of a game-like environment (i.e., field or turf). However, there was an ample amount of space for dynamic, free movements and a large goal to mimic the competition environment with the intention of having no variation in their natural kicking technique. Future studies examining associations between SSA and kinematic and kinetic measures should include different skill level athletes, uncontrolled conditions, such as kicking a moving ball, and more realistic surfaces such as turf or grass.

The current analysis was isolated to ball contact because SSA was defined at this event. While this event-focused approach preserved construct validity and limited multiplicity in a modest sample, it did not capture how pre- and post-contact mechanics may relate to SSA or performance. In addition, the authors were unable to quantify kicking accuracy as there was no ability to track the position of the ball as it reached the net. Future work will extend this initial analysis by investigating the relationship between SSA and both performance metrics and biomechanical risk fac-

tors observed across different phases of the kick to enhance applicability and clinical relevance.

Lastly, the sample size of the current study was modest ($n = 19$) relative to the number of variables analyzed, which increases uncertainty in estimates and raises the risk of both false positives and false negatives, particularly for correlation-based analyses. Although false discovery rate was controlled for at $Q = 0.10$ within families of tests and emphasized effect sizes with confidence intervals, the findings should be interpreted as exploratory and require replication in a larger cohort.

CONCLUSION

The findings of the present study highlight kinematic and kinetic associations with greater SSA, which included biomechanical risk factors differing between dominant and non-dominant limbs. Specifically on the stance limb-non-dominant kick, increased knee valgus and external knee rotation moments were found to be significantly associated with greater SSA. Conversely, a greater SSA on the stance limb-dominant kick showed a significant association with ankle dorsiflexion. Understanding the influence that SSA has on movement patterns when kicking should inform training protocols, allowing for a greater focus on both dominant and non-dominant limbs and optimizing kicking stance to promote injury prevention. Further research is needed to better define the relationships between SSA and lower extremity biomechanics of healthy youth soccer players during kicking, and to investigate its impact on injury prevention. Additionally, future work should identify how SSA can impact performance metrics, such as ball speed and accuracy, to provide a well-rounded training protocol that incorporates both injury prevention and performance aspects of soccer kicks.

CONFLICT OF INTEREST STATEMENT

The authors have nothing relevant to disclose.

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SUPPLEMENTARY MATERIALS

Appendix

Download: https://ijspt.scholasticahq.com/article/145881-the-influence-of-coronal-strike-stance-angle-on-kicking-mechanics-in-adolescent-female-soccer-players/attachment/306064.docx?auth_token=x4QIbEPIDONqfF9vjUFd

Original Research

Changes in the Medial Elbow Joint During Repetitive Pitching and Related Factors in High School Baseball Players: An Analysis of Physical Characteristics Including Maximum Elbow Valgus Torque

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Background and Purpose

The medial elbow joint undergoes changes after repeated pitching; however, the relationship with elbow valgus torque remains unclear. This study aimed to investigate the relationship between the rate of change in medial elbow conditions and the factors related to physical characteristics, including the maximum elbow valgus torque (MEVT) after 100 repetitive pitches.

Study design

Descriptive laboratory study.

Methods

This controlled laboratory study included 26 male high school baseball players from a baseball team. Participants were instructed to throw 100 pitches (20 pitches × five sets). After pitching, the rate of change in the medial elbow joint width, ulnar collateral ligament (UCL), and stiffness of the forearm flexor pronator muscles (FPMs) were examined using ultrasound imaging. The primary outcome was the post-to-pre pitching change ratio of medial elbow tissue; associated factors were evaluated using stepwise multiple regression analysis.

Results

Immediately after pitching, the medial elbow joint width significantly increased, whereas the UCL and FPMs stiffness significantly decreased. The change rate in the medial elbow joint width was associated with the pre-pitch medial elbow joint width. The change rate in UCL stiffness correlated with the nMEVT and shoulder abduction strength. In addition, the change rate in FPM stiffness was associated with the thoracic kyphosis angle at maximum shoulder flexion and change in thoracic kyphosis angle.

Conclusion

Completion of 100 pitches resulted in changes in the medial elbow. Only the rate of change in UCL stiffness after repetitive pitching was related to nMEVT. These findings

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support monitoring ultrasound-based medial elbow changes after pitching and warrant prospective evaluation of whether their magnitude and the IMU-derived metric relate to later symptoms or injury.

Levels of Evidence

3

INTRODUCTION

Shoulder and elbow pain are common issues during pitching in baseball. Lyman et al.¹ reported a 26% incidence of elbow pain, with 68% of the cases occurring on the medial side. In a systematic review, Bullock et al.² reported that elbow valgus torque (EVT) was positively associated with the occurrence of elbow injuries. Regarding factors that increase EVT, Khalil et al.³ reported a relationship between increased shoulder external rotation range of motion (glenohumeral external rotation gain) and glenohumeral internal rotation deficit. In addition, Sakata et al.⁴ reported that the thoracic kyphosis angle is a risk factor for elbow joint disorders; therefore, the spinal angle, especially the thoracic angle, may be related to EVT.

Recent advancements in technology have enabled the measurement of maximum EVT (MEVT) using inertial measurement units (IMUs) alongside smartphone applications.^{5,6} This innovation has allowed the convenient measurement of MEVT during repetitive pitching on the field, instead of under controlled laboratory conditions.

Hattori et al.^{7,8} reported an increase in the medial elbow joint width after over 60 pitches and a decrease in ulnar collateral ligament (UCL) stiffness after 100 pitches. Okoroha et al.⁹ reported that increased EVT was associated with increasing number of innings in a game format. This suggests that EVT increases with increasing number of pitches, leading to a greater load on medial elbow tissues, especially the UCL. Although a relationship between the condition of the medial elbow joint and physical characteristics after repeated pitching has been reported,¹⁰ no studies have investigated this relationship while incorporating mechanical factors such as EVT. Therefore, in addition to the results of previous studies,¹⁰ the relationship between changes in the elbow joint and repeated pitching can be clarified by examining multiple factors, including spinal curvature and MEVT, which are associated with elbow joint disorders.

The present study aimed to investigate the relationship between the rate of change in medial elbow conditions and the factors related to physical characteristics, including the maximum elbow valgus torque (MEVT) after 100 repetitive pitches. The authors hypothesized that the greater the measured MEVT, the greater the medial elbow gap distance and the lower the stiffness of the UCL and forearm flexor pronator muscles (FPMs) would be after repeated pitches.

METHODS

STUDY PARTICIPANTS

Twenty-six male high school students were recruited and enrolled between January 2023 and February 2024. The in-



Figure 1. Throwing conditions: the official throwing distance was 18.44 m.

clusion criteria were 1) membership on a baseball club and participation in at least five practices or games per week and 2) experience as a pitcher or presently playing as a pitcher. Participant characteristics are presented in [Table 1](#). The exclusion criteria were 1) history of surgery on the pitching arm and 2) pitching in a game or practice within the last 24 h.

This study was approved by the Research Ethics Review Committee of Bunkyo Gakuin University Health and Medical Sciences (approval number 2022-08) and performed in accordance with the Declaration of Helsinki. In addition, the purpose and content of the study were explained to the participants, and their consent was obtained before measurements were taken.

PITCHING TASK

The pitching conditions were based on a study by Hattori et al.^{7,8,10} The throwing distance was 18.44 m. Participants made a full pitch from the pitcher's mound toward the catcher ([Figure 1](#)). The participants started pitching from a set position and performed five sets of 20 pitches each, totaling 100 pitches. The pitch interval was 30 s, and the rest between sets was 5 min. Ball velocity was measured using a pitching analysis device (PITCHING 2.0; Rapsodo LLC, Kanagawa, Japan). The device was positioned 4.75 m from the front edge of the home plate, as recommended in the user manual.



Figure 2. Pulse Throw installation location, attached 5 cm distal to the medial epicondyle of the humerus.

MEASUREMENT OF MEVT DURING PITCHING

MEVT, the main outcome, was measured using an IMU (Pulse Throw, Driveline Baseball, WA, USA) device. The device was placed 5 cm distal to the medial epicondyle of the humerus (Figure 2).¹¹ The average value of the MEVT in each participant when 100 balls were thrown was calculated. In addition, according to the method described by Aguinaldo et al.¹² the measured MEVT was divided by height (m) and body mass (kg) to exclude the effect of body size, and the result was termed normalized MEVT (nMEVT).

ULTRASOUND IMAGE MEASUREMENT

Ultrasound images were captured using an ultrasound 18-5 Hz linear array transducer (L64; Hitachi Aloka Medical, Tokyo, Japan), with the B-mode setting and real-time sonoelastography technique. The ultrasound transducer was installed as previously described^{10,13} and in accordance with the guidelines of the American Society of Ultrasound in Medicine to ensure image consistency. The test position was confirmed using a goniometer, with the participant in the supine position, the shoulder joint 90° abducted, the elbow joint 90° flexed, and the forearm in the mid-position (test position). The medial elbow gap distance and strain rate of the UCL and FPMs were measured, as previously described.¹⁰ The average value of the three measurements was used for data analysis.

All ultrasound measurements were performed by a single physical therapist (H.H.) with over 12 years of experience in ultrasound imaging.

OTHER MEASUREMENTS

Passive range of motion (PROM) was measured for shoulder flexion, shoulder external and internal rotation at 90° ab-

duction, shoulder internal rotation at 90° flexion, and elbow flexion and extension.¹⁰ PROM was measured by passively moving the joint to the point of first end feel, where initial resistance was detected without overpressure. Measurements were taken using a goniometer in 5° increments, and all PROM assessments were performed in the supine position. When measuring the internal and external rotation angles of the shoulder joint in 90° abduction, a towel was placed under the distal humerus and adjusted to the same height as the scapular plane. For internal rotation measurements, the coracoid process was stabilized by applying posterior pressure.^{14,15} Elbow joint PROM was determined by measuring the flexion angle and extension PROM, with the forearm in a supinated position.

Hip joint PROM was evaluated following the method described by Saito et al.¹⁶ Hip joint internal rotation and external rotation PROM were measured in the supine position, with the hip flexed to 90°, the knee flexed to 90°, and the lower leg positioned at midline (0°) as the starting point, verified with a goniometer. The straight leg raise angle was measured by raising the lower leg with the knee joint fully extended, and the angle between the long axis and the thigh from the side of the trunk was measured. The straight leg raise angle was measured by passively moving the joint to the point of first end feel, where initial resistance was detected without overpressure. Muscle strength was measured using a handheld dynamometer (microFET2; Hoggan Industries Inc., West Jordan, Utah, United States). Shoulder abduction strength was measured in the standing position, with the shoulder at 90° abduction in the scapular plane. Shoulder external and internal rotation strength were both measured in the supine position, with the shoulder at 90° abduction and the elbow at 90° flexion. Participants were verbally instructed to exert maximal muscle force for 2 s.¹⁷ The results obtained (N) were normalized by dividing them by body mass (kg), yielding a weight ratio (N/kg). Each movement direction was measured three times, and the average value was used as the representative value.

Spinal curvature angles were measured using a spinal shape measuring device (Spinal Mouse; Index Ltd., Tokyo, Japan). The reliability of this device is good within and between examiners.^{18,19} Measurements of spinal curvature angles were performed in two conditions: resting standing and maximum shoulder flexion positions. The sensor was placed on the spinous processes from C7 to S3 and moved from the head to the caudal side. The thoracic kyphosis angle (Th1-12) and lumbar lordosis angle (L1-5) were measured at each measurement position. A change in an angle was determined by subtracting the result of the resting standing position from that of the maximum shoulder flexion position. An increase in the thoracic kyphosis angle was considered positive, whereas an increase in the lumbar lordosis angle was considered negative.

STATISTICAL ANALYSIS

A priori power analysis was conducted to determine the sample size needed to achieve statistical significance with a power of 80% ($1 - \beta$). This analysis was performed using G*Power 3.1.9.4 (<http://www.gpower.hhu.de/>). To compare

Table 1. Characteristics of the participants

Parameters	Mean (range)
Age, years	16.0 ± 0.5 (15.0–17.0)
Height, cm	174.3 ± 5.6 (168.0–192.0)
Body mass, kg	70.1 ± 7.1 (57.5–86.0)
Body mass index, kg/m ²	23.1 ± 1.9 (20.1–26.3)
Years of baseball experience, years	8.9 ± 1.6 (6.0–11.0)

SD, standard deviation.

^aData are expressed as means (range) ± SD.

the condition of medial elbow tissues before and after pitching, the sample size was calculated using the following settings: *t*-test; effect size, 0.5; α , 0.05; power ($1 - \beta$), 0.8. A total of 26 participants were required for this study. The sample size for multiple regression analysis was calculated with the following settings: *f* test; effect size, 0.35, α , 0.05; power ($1 - \beta$), 0.8. As a result, a total of 31 participants were required for this study.

Data are reported as mean ± standard deviation. For statistical processing, the normality of each measurement item was confirmed using the Shapiro–Wilk test, and a paired *t*-test was used to compare the medial elbow joint width and UCL and FPMs stiffness before and immediately after pitching. In addition, Cohen's *d* was calculated as an effect size (ES) for items with significant differences.

Factors related to the level of change in medial elbow tissue due to repeated pitching (post-pitching/pre-pitching) were examined using stepwise multiple regression analysis. The rate of change in the medial tissue of the elbow joint due to repeated pitching was used as the dependent variable. Meanwhile, the independent variables were participant characteristics such as obesity level, height, weight, years of baseball experience, medical history of the medial elbow joint, measurements of the medial elbow joint before pitching, immediately after pitching, PROM, muscle strength, average pitch speed, MEVT, nMEVT, and spinal curvature angle. The significance level was set as <5%.

RESULTS

[Table 1](#) presents the descriptive information regarding the 26 male high school baseball players included in the study.

The average maximum ball speed was 121.6 ± 7.4 km/h. The mean value of MEVT was 40.2 ± 8.7 Nm, and the mean value of nMEVT was 0.33 ± 0.06 Nm/(m*kg).

[Table 2](#) shows the ultrasound measurement results before and after pitching. Medial elbow joint width (mm) significantly increased after pitching compared the before pitching value (3.93 ± 0.76 before pitching; 4.77 ± 0.86 after pitching; *p* = 0.001, ES: 1.04). UCL stiffness (arbitrary units) significantly decreased immediately after pitching compared with the stiffness before pitching (before pitching 5.06 ± 2.04; after pitching 3.42 ± 1.23; *p* = 0.001, ES: 0.97). The stiffness of FPMs significantly decreased immediately after pitching compared with the stiffness before

pitching (before pitching 0.49 ± 0.21; after pitching 0.4 ± 0.15; *p* = 0.001, ES: 0.49).

[Table 3](#) shows the post-throwing change rate of the medial elbow joint and the results of multiple regression analysis. The pre-medial elbow joint width was extracted as a factor independently related to the change rate of medial elbow joint width (β = -0.46, *p* = 0.02). The UCL stiffness change rate was extracted as a dependent variable; multiple regression analysis showed that the nMEVT (β = 0.82, *p* < 0.001) and shoulder abduction muscle strength (β = -0.4, *p* = 0.008) were independently related factors. The FPMs stiffness change rate was extracted as a dependent variable; multiple regression analysis showed that the level of thoracic kyphosis angle variation (flexion – rest position) (β = -0.53, *p* = 0.004) and thoracic kyphosis angle in shoulder flexion (β = 0.36, *p* = 0.04) were independently related factors.

DISCUSSION

This study clarified the relationship between the condition of the medial elbow following 100 repetitive pitches and other objective measures, including the MEVT measured using an IMU. The results showed that after 100 pitches, the medial elbow gap distance increased significantly and the stiffness of the UCL and FPMs decreased.

The analysis identified nMEVT and shoulder abductor muscle strength as predictors of change in the UCL. The UCL and FPMs provide stability that resists EVT. EVT applies an extensional load to the UCL, and excessive EVT can cause damage.²⁰ Regarding the relationship between the condition of the UCL and EVT, Hurd et al.²¹ reported that the elbow valgus torque was significantly greater in patients with magnetic resonance imaging-based abnormalities compared to those without. Although the author did not diagnose UCL pathology in the same cohort as the current study, prior work has linked greater elbow valgus moment to indicators of medial elbow compromise. In the current study the data suggests that the MEVT measured using an IMU reflects the condition and changes in the medial elbow tissue of baseball players. Furthermore, in the present study, the findings were normalized by height and weight, to minimize the effects of bone structure and muscle mass between subjects. Therefore, the authors believe that only the rate of change in UCL stiffness, a tissue within the elbow joint not affected by muscle mass, is relevant.

Table 2. Comparison of medial elbow condition before and after pitching. Data are presented as mean $\pm$ standard deviation.

	Before pitching	After pitching	Effect size
Medial elbow joint distance [mm]	3.93 $\pm$ 0.76**	4.77 $\pm$ 0.86	1.04
UCL strain ratio	5.06 $\pm$ 2.04**	3.42 $\pm$ 1.23	0.97
FPMs strain ratio	0.49 $\pm$ 0.21**	0.40 $\pm$ 0.15	0.49

**p < 0.01 in paired t-test

UCL= ulnar collateral ligament, FPMs= forearm flexor pronator muscles

Table 3. Factors related to the rate of change after pitching by multiple analysis

Dependent variable and related factors	B	(95% CI)	β	P value
Ratio of change in medial elbow joint width before and after pitching				
Elbow joint medial distance before pitching	-0.07	-0.14 to -0.01	-0.46	0.02 ^b
Ratio of change in UCL before and after pitching				
nMEVT	2.85	1.86–3.85	0.82	0.001 ^b
Shoulder joint abductor muscle strength	-0.60	-1.02 to -0.17	-0.40	0.008 ^b
Ratio of change in FPMs before and after pitching				
Thoracic kyphosis angle variation (flexion – rest position)	-0.026	-0.042 to -0.009	-0.53	0.004 ^b
Thoracic kyphosis angle in shoulder flexion	0.007	0–0.014	0.36	0.04 ^b

UCL= ulnar collateral ligament, FPMs= forearm flexor-pronator muscles, B= partial regression coefficient, β = standardized partial regression coefficient, nMEVT= normalized maximum elbow valgus torque^a Model of the rate of change of the medial elbow joint gap distance after pitching: F value, 5.96; P = 0.02; R², 0.213^b Stepwise multiple regression analysis^c Model of UCL rate of change after pitching: F value, 18.4; P < 0.001; R², 0.638^d Model of the rate of change in FPMs after pitching: F value, 8.5; P = 0.002; R², 0.449

Regarding the finding that shoulder abductor strength was extracted as a significant factor, the shoulder abductor muscles function to maintain shoulder joint stability and act as prime movers for humeral elevation during pitching. When shoulder abductor strength is reduced, shoulder stability may not be sufficiently maintained during repetitive pitching, increasing susceptibility to fatigue and leading to changes in arm position. Aso et al.²² reported that the shoulder joint horizontal adduction angle during maximum external rotation decreased in the latter inning compared to the first inning. Such fatigue-related positional changes may increase the load on the elbow joint, particularly on the UCL. Therefore, this may explain the observed association with changes in UCL stiffness.

The increase in the medial elbow gap distance after repeated pitching was similar to that which has been described in previous studies.^{7,8} In multiple regression analysis using the post-throwing change rate of the medial elbow gap distance as the dependent variable, the medial elbow gap distance before pitching was extracted. A possible explanation may be that the rate of change in medial elbow gap distance due to pitching may be greater in athletes with a shorter medial elbow gap distance before pitching. However, if the medial fissure distance of the elbow joint is larger, ligament loosening may occur. Therefore, it is unclear whether this increase in the rate of change in the medial elbow gap distance is a negative factor.

Regarding the FPMs, Hodgins et al.²³ reported that among patients with FPM strain, 19.4% underwent UCL re-

construction within one year. This highlights the importance of preventing damage to the FPMs. In the current study, a correlation was identified between FPMs and changes in the thoracic angle, as well as the thoracic kyphosis angle in the shoulder flexion position. Specifically, the current findings indicate that the amount of change in thoracic kyphosis angle variation (flexion – rest position) and the maximum thoracic kyphosis angle in shoulder flexion were important variables associated with the change in FPMs stiffness. This relationship is clinically significant because the thoracic spine contributes to scapulothoracic posterior tilt and upward rotation, which facilitate glenohumeral external rotation during pitching. When thoracic mobility or posture is limited, kinetic demand can shift distally, increasing valgus loading at the elbow and dependence on the flexor-pronator mass to maintain medial stability. Indeed, previous studies have highlighted the importance of thoracic spine mobility in overhead athletes. For instance, Gonno et al.²⁴ reported that athletes with medial elbow disorders had a smaller thoracic spine extension angle during standing trunk extension than did athletes without such disorders. This thoracic kyphosis angle is related to the scapular and humeral angles during arm elevation.^{25,26} Miyashita et al.²⁷ reported that maximum external rotation during pitching involves not only the external rotation angle of the glenohumeral joint but also scapular retroversion and thoracic spine extension. A decrease in thoracic kyphosis angle (extension motion) may

reduce glenohumeral external rotation, thereby decreasing the valgus torque applied to the elbow joint.

Regarding the measurement accuracy of the IMU used to measure nMEVT, Camp et al.⁵ reported that IMU-derived measurements were lower than those obtained from motion capture (MC), a finding that should be considered when interpreting the accuracy of IMU measurements in the present study. Nevertheless, the measurement accuracy of IMUs during repetitive fastball pitching range from 96.9%²⁸ to 100%,²⁹ and IMUs are more practical to use than MC systems under repetitive pitching conditions such as those in the present study. Therefore, although IMU measurements are not identical to those obtained with MC, their use is considered appropriate when evaluating elbow valgus torque in a repetitive pitching protocol. However, the authors believe that dividing the value by weight and height and using the nMEVT as an index,¹² instead of the actual IMU value, can prove useful in the management of the UCL condition.

A limitation of this study is that the muscle activity of the FPMs, which protects the UCL from nMEVT, was not measured. Regarding the activity of the forearm muscles during pitching, the activity of the flexor carpi ulnaris muscle during the early cocking phase has been reported to be low in athletes with UCL injuries.³⁰ In the future, the authors believe that it will be necessary to examine the relationship between nMEVT and FPMs muscular activity and to consider this relationship together with UCL stiffness. Another limitation of this study is that the participants were limited to male high school baseball players. Compared with professional players, high school athletes generally demonstrate lower ball velocity.¹² In addition, pitching mechanics differ depending on the competitive level.³¹,³² Therefore, it remains unclear whether the present find-

ings can be generalized to other age groups. Future studies including athletes of different age groups are warranted.

Finally, the sample size did not reach the initially targeted number of participants. Therefore, a post hoc power analysis was conducted for the multiple regression analysis. Based on the model with the lowest coefficient of determination ($R^2 = 0.213$), one predictor, a sample size of 26, and $\alpha = 0.05$, the effect size was calculated as $f^2 = 0.27$. The achieved statistical power ($1 - \beta$) was 0.72. Because this value is below the generally recommended threshold of 0.80, the possibility of insufficient power should be considered, and the interpretation of the present findings should be made with caution.

CONCLUSION

The results of this study indicate that repetitive pitching of 100 throws induced changes in the medial structures of the elbow joint, specifically, the UCL. Future studies examining how these changes relate to injuries are warranted. In addition, a relationship only between nMEVT measured using an IMU and the rate of change in UCL stiffness after repetitive pitching was observed. These findings support monitoring ultrasound-based medial elbow changes after pitching and warrant prospective evaluation of whether their magnitude and the IMU-derived metric relate to later symptoms or injury.

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Original Research

Does Pain Self-efficacy influence Initial Forward Bending in Adults with Chronic Low Back Pain following Exercise? A Cohort Study

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Background/Purpose

Chronic low back pain affects how individuals bend. Whether pain self-efficacy, a term describing one's confidence in their ability to perform activities despite experiencing pain, affects how much people with chronic low back pain bend their lumbar spine and hips in response to exercise is unknown. The aim of this study was to investigate whether baseline pain self-efficacy influenced either lumbar or hip flexion range of motion over the first quarter of forward bending post-exercise intervention.

Study design

Cohort study.

Methods

New patients (aged 18-65 years old) presenting to a physiotherapy clinic with moderate-severe chronic low back pain-related disability who had not undergone spinal or lower limb surgery underwent assessment of pain self-efficacy (using the Pain Self-Efficacy Questionnaire; range 0-60 points; higher indicates better), pain intensity and kinesiophobia prior to 12-weeks of an exercise rehabilitation program. Two outcome measures (lumbar and hip flexion range of motion over the first quarter of forward bending from stance) were assessed at baseline, 6 and 12-weeks. Multivariable linear mixed-effects modelling was performed for each outcome.

Results

Sixty-nine participants were recruited. At baseline, mean pain self-efficacy score was 44.0 (SD=10.0; range 22 to 60) points. For every 10-point increase in baseline pain self-efficacy, lumbar flexion range of motion during initial forward bending decreased by a mean 1.47 (95% CI: -2.68, -0.27), 0.51 (95% CI: -1.41, 0.39) and 0.94 (95% CI: -1.75, -0.13) degrees, while hip flexion range of motion decreased by a mean 1.74 (95% CI: -3.68, 0.21), 1.64 (95% CI: -3.70, 0.41) and 1.43 (95% CI: -3.34, 0.48) degrees at baseline, 6 and 12-weeks, respectively.

Conclusions

At baseline, higher pain self-efficacy was associated with reduced lumbar flexion during initial forward bending. However, pain self-efficacy did not influence initial forward bending following a 12-week exercise intervention.

Level of evidence

2

INTRODUCTION

Low back pain is a major global health problem, responsible for substantial disability with many cases progressing to a

chronic state.¹ Impairments in range of motion and movement are commonly associated with chronic low back pain (CLBP)-related functional tasks, such as forward bending from stance.²⁻⁹ Given that impairments in forward bending

are associated with increased disability or pain, improving forward bending may play an indirect role in helping to alleviate the burden of CLBP.^{4,6,7,10-12} In particular, improving initial bending may be beneficial since this phase coincides with reversal of lumbar lordosis and the steepest rise in intradiscal pressure,^{13,14} a loading phase that may be provocative in some individuals with low back pain, even if not the sole cause of pain.¹⁵

Exercise, particularly strengthening, coordination or stabilization exercises, can improve pain, function and disability in CLBP populations.¹⁶⁻¹⁸ However, whether exercise improves forward bending is unclear.¹⁹⁻²¹ Individual responses to exercise vary and the mechanisms behind how certain people with CLBP improve with exercise are poorly understood.^{18,22,23}

To enhance understanding, a biopsychosocial model is recommended.²⁴ Under this model, the underlying mechanisms of response to exercise in individuals with CLBP are considered an interplay of biological, psychological and social factors.²⁴ One important psychological factor to consider in people experiencing pain is pain self-efficacy.²⁵⁻³⁰ Pain self-efficacy is the belief that certain activities can be carried out despite pain.²⁶ People with CLBP who demonstrated poorer pain self-efficacy also demonstrate greater disability.^{31,32} Aside from this association with poorer CLBP outcomes, lower (i.e., worse) pain self-efficacy has also been associated with altered lifting mechanics, including a stiffer trunk and reduced lumbar contribution.³³ However, little is known about which phase of the forward-bend movement is most sensitive to these psychological influences. In particular, reversal of lumbar lordosis occurs within ~20-25 % of trunk flexion, marking the point of steepest rise in intradiscal pressure and posterior nucleus migration.¹³ This initial phase is also characterized by the slowest lumbar and hip angular velocities,⁹ which may prolong the period of increased disc loading in people with CLBP. Therefore, the first quarter of forward bending is a critical phase during which the susceptibility of lumbar and hip movements to influence from pain self-efficacy is unknown.

There are also other elements aside from pain self-efficacy that may impact lumbar and hip flexion range of motion during bending. Kinesiophobia, a psychological factor distinct from pain self-efficacy, measures the fear of being active and of moving due to the possibility of injury or exacerbating pain.^{26,31,34,35} Someone holding such beliefs may avoid or limit movement.³⁴ The intensity of pain experienced in the lower back may also explain the degree of movement achieved.^{18,29} This subjective pain rating, along with kinesiophobia, are important to consider when investigating the relationship between pain self-efficacy and lumbar and hip flexion range of motion.

Using secondary data derived from a recently published randomized controlled trial,³⁶ the aim of this study was to investigate whether baseline pain self-efficacy influenced either lumbar or hip flexion range of motion (ROM) over the first quarter of forward bending post-exercise intervention. It was hypothesized that adults with lower baseline pain self-efficacy may respond better to exercise than

those with higher baseline pain self-efficacy, demonstrated by increased lumbar flexion ROM and/or reduced hip flexion ROM during initial forward bending when assessed at 6 and 12-weeks.

METHODS

STUDY DESIGN AND SETTING

The design was a cohort study, utilizing data originally collected for a randomized-controlled trial (RCT) of two exercise interventions conducted at a single primary care physiotherapy clinic in Melbourne, Australia over approximately 21 months (between July 2018 and March 2020).³⁶ The present study was approved by an institutional review board or similar committee (reference number 1749845). There was no patient or public involvement in the design, conduct, interpretation or translation of this study. New patients with CLBP presenting to the clinic were screened by a physiotherapist for eligibility into the study. Eligible participants ([Table 1](#)) gave informed consent to participate in the study then underwent baseline assessment followed by 12-weeks of global and isolated machine-based strengthening exercises with or without a neuromuscular control retraining exercise.³⁶ In summary, all participants attended two 30-minute exercise sessions per week, supervised in a one-to-one setting by qualified physiotherapists.³⁶ Data were collected again at 6 and 12-weeks post baseline assessment. The research question for the present cohort study was developed following the completion of data collection.

PARTICIPANTS

Participants with CLBP aged 18 to 65 years who were new patients of a physiotherapy clinic in Melbourne, Australia were recruited in this study. Participants were included if they presented with at least three months of low back pain and at least moderate disability (ie, 21% or higher) on the Oswestry Disability Index (ODI).³⁷ Further details of inclusion and exclusion criteria are outlined in [Table 1](#). A physiotherapist individually screened participants who presented to the clinic. Participants who met the eligibility criteria were presented with written information about the study, including its procedures. Those interested in participating provided written informed consent prior to randomization and the rights of participants were protected.

VARIABLES

EXPOSURE

The exposure (pain self-efficacy) was measured at baseline using the Pain Self-Efficacy Questionnaire (PSEQ), which comprises 10 questions and ranges in score from 0-60 points, where higher scores indicate stronger beliefs or more confidence in performing certain activities despite pain.^{25,26,35} A score of 41 or more on the PSEQ indicates minimal impairment, while a score of 31 to 40 indicates mild impairment, a score of 21 to 30 indicates moderate impairment and a score below 21 indicates severe impair-

Table 1. Study inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
1. Aged between 18 and 65 years	1. Medication managed
2. Report chronic low back pain with or without pain radiating into the lower limbs for at least 3 months	2. psychological illness
3. Demonstrate moderate or greater disability on the ODI (i.e., 21% or greater)	3. Previous spinal and lower limb surgery
	4. Diagnosed spinal osteoporosis/ osteopenia
	5. Diagnosed unstable spondylolisthesis/ spondylolysis
	6. Diagnosed active systemic/inflammatory joint disease
	7. Diagnosed neurological and developmental disorders
	8. Overt neurological sign (absence of lower limb reflex or motor paralysis)
	9. Diagnosed significant medical conditions such as cancer or major cardiac diseases
	10. History of abdo-pelvic organ prolapse
	11. Use of medications that may influence balance
	12. Patients funded by a compensable body
	13. Inability to understand written/spoken English
	14. Pregnant
	15. <6 months postpartum

ODI= Oswestry Disability Index.

ment.^{34,38} The PSEQ, with a Minimal Clinically Important Difference of 9 or 11,³⁹ has demonstrated responsiveness (minimal important change of 5.5⁴⁰) as well as high criterion validity ($r>0.88$) and reliability ($ICC>0.70$) in CLBP populations.^{35,38,40,41}

OUTCOMES

The two biomechanical outcomes were i) lumbar flexion ROM and ii) hip flexion ROM over the first quarter of forward bending assessed at baseline, 6 and 12-weeks post-randomization. For kinematic analyses, participants were assessed barefoot while wearing shorts. Non-reflective markers were placed on the skin overlying specific vertebrae, as well as the head, pelvis, upper and lower limbs. Three-dimensional mapping of anatomical landmarks was performed using a 12-camera optoelectric motion analysis system (Optitrack Flex 13, NaturalPoint, Corvallis, OR, USA) sampling at 120 Hz.

Participants started the task standing upright with arms by their sides. Participants were given standardized instructions to bend down and lift an 8-kg object with both hands from the ground to the level of their abdomen using a self-selected technique. They then placed this object on their right side four times then on their left side four times. Bending ([Figure 1](#)) was conducted a maximum of eight

times, the first and fifth (first time bending to lift the object to the other side) serving as practice.

The marker trajectories were labelled, cleaned and gap-filled using Optitrack Motive software (NaturalPoint, Corvallis, OR, USA). The joint angle data were filtered using a fourth order zero-phase shift low-pass Butterworth filter. Filtering is required to remove noise from kinematic data.⁴² A frequency of 6 Hz was used as a standard cut-off Butterworth filter frequency for joint angle.⁴³ The marker trajectories were then passed to OpenSim (v4.0) software to calculate the lumbar and hip joint angles using the inverse kinematics tool.⁴⁴ Joint angles were calculated using an XYZ Cardan rotation sequence corresponding to flexion/extension, abduction/adduction, and internal/external rotation. The hip joint center was estimated using the regression method described by Bell et al.,⁴⁵ which uses pelvic marker positions to estimate joint center location and is widely applied in lower limb kinematic modelling. Time (from upright stance until the object on the floor was grasped: the forward bending phase of the lift) was standardized to 0%-100%. Lumbar and hip flexion ROM over the first quarter of forward bending was measured in degrees using Matlab (2020a) software. Negative flexion ROM indicated the individual extended their hip or lumbar spine. Mean lumbar flexion ROM and mean hip flexion ROM over the first quarter of forward bending from up to six lifts (excluding the two practice lifts) were used in the data analysis.

POTENTIAL CONFOUNDERS

A causal diagram was developed prior to commencing analysis ([Figure S1](#)). The causal diagram made explicit the authors' understanding of the current evidence for the important influences on pain self-efficacy and initial forward bending and identified potential confounding variables. As depression, anxiety and stress were unmeasured, the present study used data collected at baseline on the participant's age (in years), sex (male or female), kinesiophobia, and pain intensity. Kinesiophobia was measured using the Tampa Scale for Kinesiophobia (TSK-17), which comprises 17 questions regarding pain-related fear beliefs about movement and re-injury.^{34,46} Scores range from 17 to 68 with higher scores indicating greater fear of movement. Pain intensity of the lower back over the past week was measured using the Visual Analogue Scale (VAS) with a range of 0 to 10.

STUDY SIZE

The present cohort study was a secondary analysis of data collected for a RCT,³⁶ and, as such, the convenience sample of 69 participants was obtained due to COVID-19 restrictions preventing the continuation of the supervised exercise programs and data collection.

STATISTICAL METHODS

A descriptive table for pain self-efficacy (the exposure), lumbar and hip flexion ROM (the outcomes), and age, sex,



Figure 1. Bending task from left to right: starting stance position to initial bending, bending and end bent position.

pain intensity and kinesiophobia (the potential confounders) was generated for the total cohort with participants grouped by whether they completed only the baseline assessment, the baseline and 6-week assessment, or all three assessments to explore whether there was differential loss to follow-up.

Multivariable linear mixed-effects models were fitted per outcome with an interaction term between baseline pain self-efficacy and time, and adjustment for the confounders age, sex, and baseline kinesiophobia and pain intensity (identified as the confounder set in the causal diagram, Figure S1). These models were fitted using restricted maximum likelihood with an unstructured residual covariance, and all available outcome observations were analyzed (i.e., an available case analysis) where missing outcome data were assumed to be missing at random.⁴⁷ Scatter plots at each timepoint with LOWESS (locally weighted scatterplot smoothing) curves were used to check the model assumption of linearity between the outcomes and baseline pain self-efficacy and continuous potential confounders, age, baseline kinesiophobia and pain intensity.

Sensitivity analyses of the model results for each outcome were conducted with potential outliers (residuals ≥ 3 standard deviations [SD]) removed. The model for each outcome was also refitted using all the individual observations from each of up to 6 lifts per participant as the outcome (instead of the average from up to six lifts) by nesting the individual observations within each participant. All statistical analyses were performed using Stata Version 15 (StataCorp, College Station, TX, USA).

RESULTS

Sixty-nine participants completed the assessments and their data were analyzed. Figure 2 shows the number of individuals at each stage of the study and the reasons for

non-participation. The primary reason for ineligibility was a score of 'minimal disability' (less than 21%) on the ODI. While 69 participants completed baseline assessment, 53 completed the baseline and the 6-week assessment, and 43 completed assessments at all three timepoints. Of the 26 participants who did not complete the 12-week assessment (38% of the total sample), 16 (23% of the total sample) also did not complete the 6-week assessment. The primary reason for non-participation was due to COVID-19 restrictions (N = 12).

At baseline, all 69 participants recorded measures of pain self-efficacy, age, sex, pain intensity, kinesiophobia and initial bending outcomes for six lifts except for one participant with recorded outcomes for five lifts and one participant with recorded outcomes for two lifts. Of the 53 participants who completed the 6-week assessment, all participants recorded outcomes for six lifts except for three participants with recorded outcomes for five lifts each. All 43 participants who completed the 12-week assessment recorded outcomes for six lifts.

Table 2 indicates that some characteristics and summary measures of study participants differed according to which assessments were completed. In particular, the 16 participants who only completed the baseline assessment were more likely to be male (75% vs 49%) and flexed at the hip (11.9° vs 8.8°) slightly more at baseline than those 43 who completed all three assessments. The 10 participants who completed only the baseline and 6-week assessments flexed at the lumbar spine (8.5° vs 5.9°) and hip (11.2° vs 8.8°) more at baseline than participants who completed all three assessments.

At baseline, 45 out of 69 participants (65.2% of the sample) were classified as minimally impaired in pain self-efficacy (a PSEQ score greater than 40). There was a similar proportion of participants with minimal impairment in baseline pain self-efficacy remaining at six weeks (66.0% or

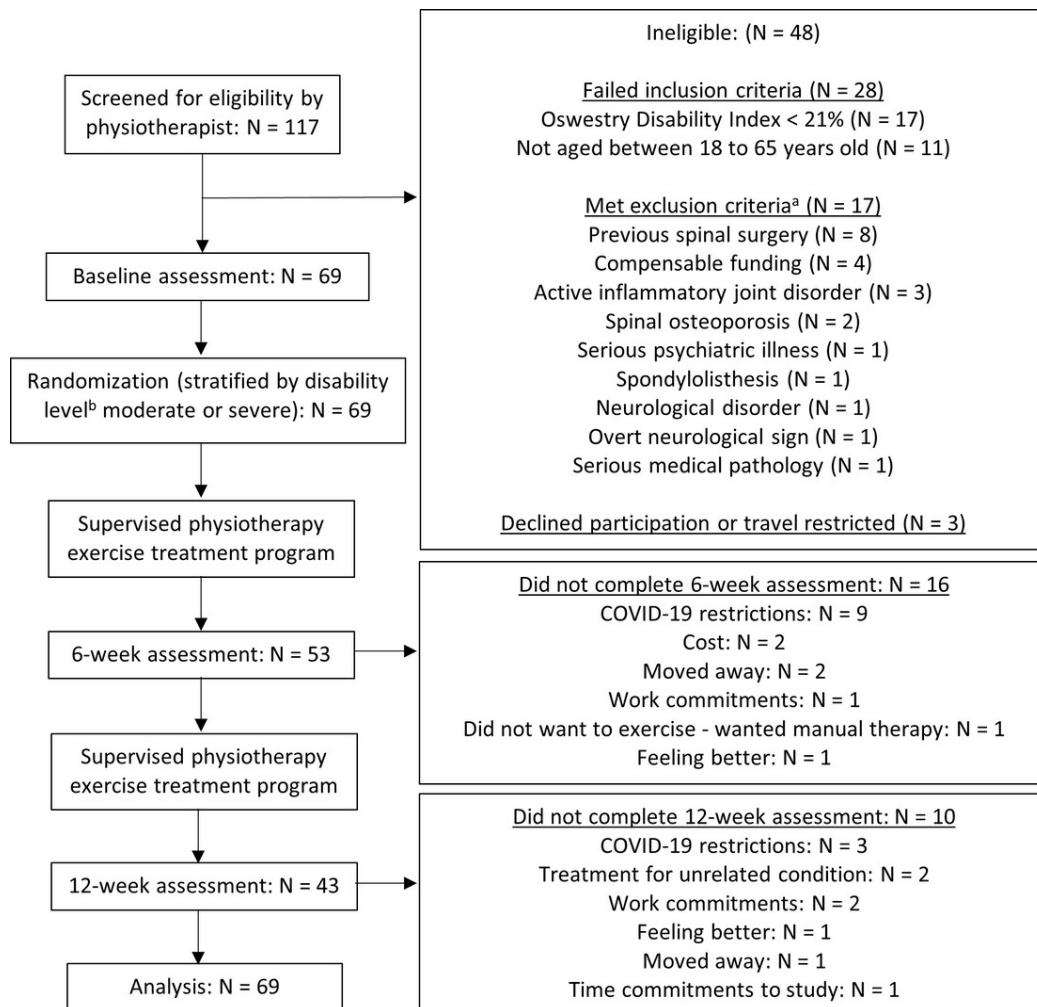


Figure 2. Study flow chart with the numbers of individuals remaining or no longer participating at each stage and reasons for non-participation.

^aSome individuals met multiple exclusion criteria. ^bDisability is measured using the Oswestry Disability Index; scores between 21% and 40% indicate moderate disability and scores ≥41% are classified as severe disability.

35 out of 53 participants) and 12 weeks (67.4% or 29 out of 43 participants). No participants recorded PSEQ scores in the severe impairment band (a score less than 21).

Table 3 shows the estimated mean change in each outcome at each timepoint with a 10-point increase in baseline PSEQ score, adjusted for age, sex, and baseline kinesiophobia and pain intensity. A 10-point change in baseline PSEQ was chosen because the standard deviation (SD) of the PSEQ measure in this study was 9.96 and the minimal important change in PSEQ has been reported as nine.³⁵ At baseline, there was an estimated mean decrease of 1.47 degrees (95% CI: -2.68, -0.27) in lumbar flexion ROM and 1.74 degrees (95% CI: -3.68, 0.21) in hip flexion ROM over the first quarter of forward bending per 10-point increase in baseline pain self-efficacy, adjusted for age, sex, and baseline kinesiophobia and pain intensity. At 6- and 12-weeks, there were, respectively, estimated mean decreases of 0.51 (95%CI: -1.41, 0.39) and 0.94 degrees (95%CI: -1.75, -0.13) in lumbar and 1.64 (95%CI: -3.70, 0.41) and 1.43 degrees (95%CI: -3.34, 0.48) in hip flexion ROM over the first quarter of forward bending per 10-point increase in baseline

pain self-efficacy, adjusted for age, sex, and baseline kinesiophobia and pain intensity.

Figure 3 shows that the association between baseline pain self-efficacy and each outcome did not change substantially over time, and this was confirmed with the interaction terms for baseline pain self-efficacy and follow-up time (interaction p-values ranged from 0.086 to 0.931).

The main analysis was robust to removal of outliers (observations more than 3 SD from the mean residual) and to using the individual lift scores instead of an average of up to six lifts per participant (Table S1 and Table S2, respectively).

DISCUSSION

KEY RESULTS

Adults with CLBP often demonstrate altered forward bending mechanics, yet it remains unclear why some individuals show greater changes in movement patterns following exercise interventions than others. Pain self-efficacy has been linked to disability and lifting strategies in CLBP popula-

Table 2. Study participant characteristics and summary measures^a grouped by which assessments were completed.

	Completed baseline assessment only	Completed baseline and 6-week assessments	Completed baseline, 6 and 12-week assessments	Total
	N=16	N=10	N=43	N=69
Sex				
Female	4 (25)	7 (70)	22 (51)	33 (48)
Male	12 (75)	3 (30)	21 (49)	36 (52)
Age (Years)	46 (37-53)	47 (33-53)	50 (40-57)	48 (39-55)
PSEQ	43.5 (7.6)	40.8 (12.4)	44.9 (10.3)	44.0 (10.0)
TSK-17	37.8 (5.7)	38.7 (9.5)	37.5 (7.3)	37.7 (7.2)
Pain intensity (VAS)	48.0 (17.8)	64.2 (19.1)	51.5 (16.7)	52.5 (17.8)
Lumbar flexion ROM				
Baseline	6.27 (7.60)	8.48 (5.18)	5.87 (3.47)	6.34 (4.95)
Week 6		4.85 (2.86)	4.86 (3.01)	4.86 (2.96)
Week 12			3.78 (2.51)	3.78 (2.51)
Hip flexion ROM				
Baseline	11.85 (9.25)	11.20 (7.30)	8.82 (6.24)	9.86 (7.20)
Week 6		10.09 (8.01)	8.35 (7.04)	8.68 (7.18)
Week 12			6.66 (5.84)	6.66 (5.84)

Abbreviations: VAS, Visual Analogue Scale; PSEQ, Pain Self-Efficacy Questionnaire; TSK-17, Tampa Scale for Kinesiophobia (17 item); ROM, Range of Motion.

^aData are presented as mean (SD) or median (25th-75th percentile) for continuous measures, and n (%) for categorical measures.**Table 3. Estimated mean change in each outcome at each timepoint per 10-point increase in baseline PSEQ score^a.**

Outcome	Timepoint	Mean (95% CI)	p value
Lumbar flexion ROM	Baseline	-1.47 (-2.68, -0.27)	0.017
	Week 6	-0.51 (-1.41, 0.39)	0.265
	Week 12	-0.94 (-1.75, -0.13)	0.023
Hip flexion ROM	Baseline	-1.74 (-3.68, 0.21)	0.080
	Week 6	-1.64 (-3.70, 0.41)	0.117
	Week 12	-1.43 (-3.34, 0.48)	0.143

Abbreviations: PSEQ, Pain Self-Efficacy Questionnaire; CI, Confidence interval; ROM, Range of motion.

^aAdjusted for age, sex, and baseline kinesiophobia and pain intensity using a multivariable linear mixed-effects model with unstructured residual covariance for each outcome.

tions and may be one factor influencing this variability. Understanding whether baseline pain self-efficacy influences changes in lumbar and hip movement during forward bending could inform personalized rehabilitation strategies. Therefore, the aim of the present study was to determine whether baseline pain self-efficacy was associated with lumbar and/or hip flexion ROM in the initial phase of forward bending following a 12-week exercise program. The present study found no evidence that baseline pain self-efficacy influenced lumbar flexion ROM or hip flexion ROM during initial forward bending post-exercise in adults with CLBP. This is the first study that has investigated the potential influence of baseline pain self-efficacy on this movement post-exercise intervention. The present study also found that, at baseline, participants with higher pain self-

efficacy flexed their lumbar spine less than those with lower pain self-efficacy during initial forward bending. The difference, however, was less than 2 degrees for every 10-point change in pain self-efficacy, which may be clinically negligible. This initial phase of forward bending in people with CLBP was of interest as it may be associated with pain provocation given lumbar disc degeneration.¹⁵ In a degenerated lumbar disc, intra-discal pressure is not uniform and often accompanied by annular fissuring and ingrowth of nerve endings into the nucleus.¹⁵ Movement of the nucleus during initial lumbar flexion may compress these nerve endings, resulting in irritation and pain.¹⁵ A strategy to minimize the risk of pain provocation during the initial stage of bending movement could be to flex less through the lumbar spine and/or more through the hip (i.e., lower

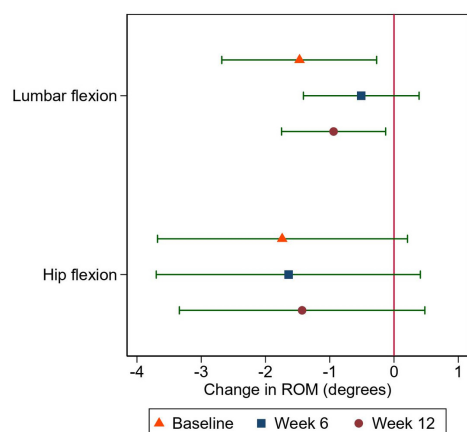


Figure 3. Estimated mean changes (and 95% confidence interval) in each outcome at baseline, 6-weeks, and 12-weeks per 10-point increase in baseline PSEQ score.

PSEQ, Pain Self-Efficacy Questionnaire; ROM, Range of motion.

lumbar-hip ratio).¹⁵ This is consistent with previous research identifying that, during forward bending, those with CLBP flexed their lumbar spine less or their hips more than those without CLBP.^{4,8} While prior studies have analyzed either total range of motion⁴ or later quartiles,⁸ the present study extends this work by examining the initial quartile of motion, when mechanical loading on spinal structures rises most steeply. However, whilst we hypothesized that pain self-efficacy may influence the adoption of a movement strategy post exercise intervention similar to those without CLBP, the current findings failed to support this notion.

Higher levels of pain self-efficacy, which indicate greater confidence in one's ability to perform activities despite experiencing pain, are associated with better outcomes in terms of pain management, disability reduction, and functional ability.^{29,33,48} Previous research suggests CLBP sufferers with lower pain self-efficacy lift light loads (of approximately 10% body weight) using a different technique (i.e., stiffer back, knees more bent) compared to those with higher pain self-efficacy.³³ This is somewhat in contrast to the current results of higher pain self-efficacy being associated with less lumbar spine flexion during initial bending. Lifting a light load with an extended lumbar spine could be detrimental to spinal health as this posture is associated with a higher amount of loading.⁴⁹ Consequently, investigating how pain self-efficacy influences bending and lifting kinematics following interventions such as exercise is important.

Changes of lumbopelvic movement coordination are thought likely to be a result of specific motor control training of the lumbopelvic region.⁵⁰ Tsang et al.⁵⁰ (2021) reported changes in lumbar spine and hip angular velocity during repeated forward bending movement following a 6-week training program. The participants in this study also reported improvement in pain self-efficacy (assessed using the PSEQ) following the program. Tsang et al. exam-

ined deep abdominal (transversus abdominis) muscle activation, while the present study concentrated on isolated lumbar extensor muscle strengthening using a lumbar extensor dynamometer with pelvic stabilisation.⁵¹ Additionally, Tsang et al.⁵⁰ progressed their exercises from activating deep muscles to performing controlled movements of the lumbopelvic area. In contrast, the exercise progression in the present study involved increasing resistance to the same movement. The lack of targeted training may explain why the results of the present study did not show associated changes in lumbopelvic motor control.

A strength of the present study was the utilization of longitudinal data from the robustly designed prior RCT. The causal diagram also made explicit the investigator's evidence-based assumptions of what influences pain self-efficacy and initial forward bending post-exercise in this CLBP population and identified potential confounding variables that were adjusted for in the analyses.

LIMITATIONS

As a secondary analysis of data originally collected as part of an RCT investigating the effect of two exercise interventions on disability, the (general strengthening) exercises were not targeted to improve initial forward bending. Hence, a lack of change in this movement, regardless of pain self-efficacy score, may explain the null result.^{2,8,22,28,48,52} As most participants were minimally impaired in pain self-efficacy, and no one severely impaired, the generalizability of the results are also reduced. The present study sampled participants seeking treatment, which may explain why most had high pain self-efficacy. Though the hypothesis related specifically to the initial 25% of the forward bending movement (as this is where it was theorized a change in response to exercise may occur),¹⁵ the biomechanics of lifting may not be adequately reflected in lumbar and hip kinematic data in the initial 25% of forward bending alone and may need to be combined with knee and ankle kinematic data, data on the remaining 75% of the forward bending motion or kinetic data. It is a limitation of the present study, however, that this other data was not analyzed. Additionally, the magnitude of change that was observed (<2° for both lumbar and hip flexion) is smaller than the typical measurement error reported for marker-based optical motion capture of the spine and hip. Specifically, typical soft tissue artifact-related angular errors (5-10° lumbar; 6-8° hip) and published minimal detectable change values (≥6-15°) exceed the <2° changes observed in the current study, indicating these differences may lie within measurement noise.⁵³⁻⁵⁵ Hence, the small angular differences detected in this study should be interpreted with caution, as they may fall within the error of the measurement system. Finally, there was substantial missing outcome data, largely due to COVID-19 restrictions, with indications of differential loss to follow-up. Consequently, the results may be biased since mixed-effects modelling assumes data are missing at random, after controlling for the measured confounders.

INTERPRETATION

Given these limitations, a lack of evidence that pain self-efficacy influences initial forward bending post-exercise is not conclusive. Further studies are needed to corroborate these findings. Such studies may consider analyzing other lifting-related kinematic and kinetic data. These studies may also consider alternate methods of recruitment aside from sampling only those seeking treatment. Targeting exercise to improve certain kinematic and kinetic outcomes, such as by training lifting techniques for tasks such as lifting groceries, would also maximize the chance of detecting an effect of pain self-efficacy on these outcomes, if one existed.

CONCLUSION

In the present study, baseline pain self-efficacy did not influence initial forward bending at 6- and 12-weeks following exercise but was associated with less lumbar flexion during initial bending at baseline. Further research on other modifiable variables that may affect exercise outcomes is required.

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DISCLOSURE OF INTEREST

The authors report there are no competing interests to declare.

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SUPPLEMENTARY MATERIALS

Supplementary material

Download: https://ijspt.scholasticahq.com/article/146051-does-pain-self-efficacy-influence-initial-forward-bending-in-adults-with-chronic-low-back-pain-following-exercise-a-cohort-study/attachment/306554.docx?auth_token=YVfDdjM_e2CzH6T1Oca

Original Research

Association between Body Composition Characteristics and Chronic Low Back Pain in High-School Baseball Players: A Retrospective Study

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Keywords: chronic lower back pain, baseball, percentage bod fat, body composition, adolescent athletes

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Background

Chronic low back pain (CLBP) is common among adolescent athletes, particularly baseball players; however, its association with body composition remains unclear.

Purpose

To investigate the relationship between body composition parameters and the presence of CLBP in high-school baseball players.

Study Design

Retrospective cohort study

Methods

Male high-school baseball players were recruited and divided into the CLBP and non-CLBP groups. CLBP was defined as low back pain rated ≥ 3 on the numerical rating scale (NRS) and lasting >12 weeks. Body composition was measured using bioelectrical impedance analysis in the first year of high school. Logistic regression was used to identify the factors associated with CLBP.

Results

Ninety male baseball players participated (mean age: 16.8 ± 0.4 years, during second year). The CLBP group ($n=31$) showed significantly higher percentage body fat (PBF), body fat mass (BFM), BFM index, and trunk fat mass compared with the non-LBP group ($n=59$). Logistic regression analysis identified first-year NRS scores (odds ratio [OR]: 2.10; 95% confidence interval [CI]: 1.46–3.21) and PBF (OR: 1.26; 95% CI: 1.05–1.51) as significant predictors of CLBP.

Conclusion

Elevated body fat percentage and elevated pain intensity in early high-school years were associated with the development of CLBP among high-school baseball players. Regular monitoring of body composition and early intervention based on pain levels may effectively prevent CLBP in adolescent baseball players, thereby supporting better long-term athletic performance and health outcomes

Level of Evidence

3b

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INTRODUCTION

Baseball is a widely played popular sport in Japan, with a large number of participants at the youth level. Upper limb injuries, such as those affecting the shoulder and elbow, are common in baseball, and low back injuries are frequent.^{1, 2} Recent systematic reviews and meta-analyses have reported a high prevalence of low back pain (LBP) in adolescent athletes (1-year prevalence: 29–55%), and identified risk factors, such as overweight/high body mass index (BMI), sport participation, and training volume/intensity.³

A survey of university athletes found that baseball players had the second highest prevalence of LBP after volleyball players, with an odds ratio (OR) 3.2 times higher than that of non-athletes for lumbar disc degeneration.⁴ A cross-sectional study of high-school baseball players revealed that 49.1% experienced LBP, with 20.3% classified as having chronic LBP (CLBP).⁵ Similarly, more than 30% of university baseball players reported experiencing LBP.⁶ These findings indicate that LBP is highly prevalent among Japanese baseball players.

Previous systematic reviews and meta-analyses have shown a correlation between an elevated BMI and the severity of LBP in the general adult population.^{7,8} This suggests that body composition may be an important factor for evaluating the risk of LBP, even among athletes. In cases of CLBP, specific physical or body composition characteristics, such as high body fat or low muscle mass levels, may increase the load on the lumbar spine and serve as contributing factors. Additionally, baseball players are exposed to repetitive and asymmetrical trunk movements during pitching and hitting, which generate substantial torsional and compressive forces on the lumbar spine.⁹ These biomechanical stresses may elevate the risk of spinal injury, particularly in the presence of physical factors, such as inadequate muscular support or excess adiposity.

Body composition is typically categorized into fat, fat-free, and bone mass. In athletic populations, assessments usually emphasize fat mass and lean mass, often expressed as relative measures, such as percentage body fat (PBF) and fat-free mass (FFM) index (FFMI), to account for differences in body size and height.

Studies of ice hockey and rugby players have reported associations between body composition and LBP, particularly in relation to the size and fat content of the multifidus muscles.^{10,11} In ice hockey players, higher PBF has been significantly correlated with smaller multifidus muscle size, suggesting that increased fat mass may hinder muscle development and elevate mechanical stress on the lumbar region.¹⁰ Similar associations between muscle characteristics and LBP have been observed in rugby players.¹¹

In contrast, few studies have examined the relationship between body composition and LBP in baseball players.⁵ Given that CLBP may be influenced by specific physical characteristics, including body fat distribution, a more detailed evaluation of body composition in this population is warranted. Therefore, the purpose of this study was to investigate the relationship between body composition para-

meters and the presence of chronic low back pain (CLBP) in high-school baseball players.

MATERIALS AND METHODS

This retrospective cohort study was conducted in accordance with the Declaration of Helsinki and approved by the Research Ethics Review Board of Osaka Kawasaki Rehabilitation University (Approval No. OKRU-RA0003). Written informed consent was obtained from all the participants and their guardians, and additional consent was obtained from the team manager.

PARTICIPANTS

All participants were male high school baseball players from a school in Japan. All players trained six days per week, averaging approximately four hours per day. During the winter off-season (December to February), training emphasized running, strength training, and batting practice, with reduced pitching activity.

Players were recruited during their team's annual medical assessments. Inclusion criteria were participation in regular team training, and completion of both first-year and second-year assessments. Players who reported low back pain lasting for more than three months in their second year, and meeting the clinical definition of chronic low back pain (CLBP; pain intensity ≥ 3 on the numerical rating scale persisting for at least 12 weeks) were assigned to a CLBP group.¹² Players who reported no low back pain during either year were assigned to a non-low back pain group.

Exclusion criteria were (1) a history of low back pain not meeting the definition of CLBP, and (2) incomplete survey data. All participants and their guardians provided written informed consent, and additional permission was obtained from the team manager.

QUESTIONNAIRE

A self-administered questionnaire was used to assess the presence and intensity of LBP and gather baseball-related information. The questionnaire collected information on baseball experience (years) and primary playing positions (pitcher, catcher, infielder, and outfielder).

Players were informed in advance that their responses would not be shared with the coaches or team staff.

Pain intensity was measured using a visual NRS, ranging from 0 ("no pain") to 10 ("worst imaginable pain"). LBP history and current symptoms were assessed separately to distinguish past and ongoing pain. The questionnaire used in this study is shown in Appendix 1.

BODY COMPOSITION

Body composition data collected during the first year of high school were analyzed retrospectively. A bioelectrical impedance analyzer (InBody 270; InBody Co., Ltd., Seoul, Republic of Korea) operating at frequencies of 20 and 1000 kHz was used. The following parameters were recorded:

Anthropometrics included: Height (measured using a portable stadiometer), weight, and BMI; Lean and fat mass metrics: Soft lean mass, FFM, skeletal muscle mass (SMM), and body fat mass (BFM). Segmental analysis included: Lean and fat masses of the right and left arms, trunk, and right and left legs. Indices including PBF, SMM index, FFMI ($\text{FFMI} = \text{FFM}/\text{height}^2$), and BFM index ($\text{BFMI} = \text{BFM}/\text{height}^2$) were measured using the InBody 270. The InBody 270 has been previously validated for reliability and accuracy in estimating body composition across diverse populations, demonstrating high agreement with reference methods, such as dual-energy X-ray absorptiometry.^{13,14}

STATISTICAL ANALYSIS

Statistical analyses were performed using the IBM SPSS Statistics version 27.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$. Normality of distribution was assessed using the Shapiro–Wilk test. Between-group comparisons were performed using the chi-square test for categorical variables, Student t-test for continuous variables, and the Mann–Whitney U test for ordinal variables. Effect sizes for parametric comparisons were calculated using Cohen’s d to quantify the magnitude of between-group differences, interpreted as small (≥ 0.2), medium (≥ 0.5), and large (≥ 0.8) according to conventional benchmarks. Effect sizes were not calculated for variables analyzed with non-parametric tests due to distributional assumptions. Multivariate logistic regression was performed for variables that demonstrated significant differences in the univariate analysis. The dependent variable was the presence of CLBP, and body composition parameters were selected as independent variables. A forward stepwise model selection method was used. Model significance was evaluated using the model chi-square test, and model fit was assessed using the Hosmer–Lemeshow test, with $p \geq 0.05$ indicating a good fit.

RESULTS

Of the 122 players initially surveyed, 27 were excluded because they reported LBP in the first year but no symptoms in the second year, while five were excluded due to incomplete questionnaire responses. The final analysis included 90 players: 31 (34.4%) and 59 (65.6%) in the CLBP and non-LBP groups, respectively. The mean (SD) age of all participants was 16.8 (0.4) years, with no significant difference between groups. [Figure 1](#) presents the flowchart of participant inclusion and analysis.

QUESTIONNAIRE RESULTS

[Table 1](#) summarizes the questionnaire results including age, years of baseball experience, playing position, and NRS score. Age, baseball experience, and position distribution did not differ between the two groups. However, the NRS scores in the CLBP group in both the first and second years were significantly higher compared to those in the non-LBP group ($p < 0.001$).

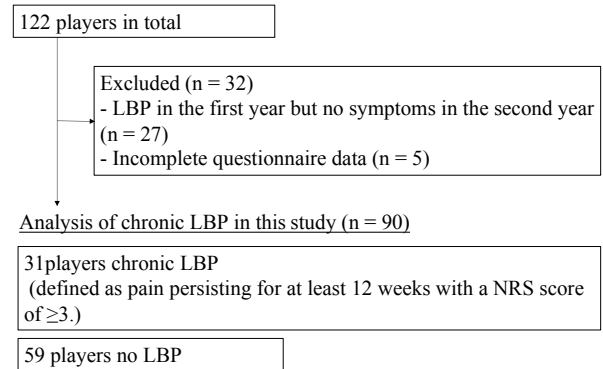


Figure 1. Flow diagram of participant inclusion and exclusion.

CLBP = chronic low back pain; NRS = numerical rating scale.

BODY COMPOSITION RESULTS

[Table 2](#) shows a comparison of body composition between the CLBP and non-LBP groups. The CLBP group had significantly higher values of PBF, BFM, BFMI, and trunk fat mass. The effect sizes for these differences were large for PBF ($d=3.24$) and BFM ($d=2.81$), and moderate for trunk fat mass ($d=1.68$) and BFMI ($d=0.93$), indicating substantial between-group differences in fat-related measures.

LOGISTIC REGRESSION ANALYSIS

[Table 3](#) presents the results of logistic regression analysis for CLBP. The analysis identified the first-year NRS score and PBF as significant independent risk factors for CLBP (NRS score [first year]: $B=0.773$, standard error [SE]=0.201, Wald=14.766, OR, 2.16; 95% confidence interval [CI]: 1.46–3.21, PBF: $B=0.235$, SE=0.093, Wald=6.384, $p < 0.001$, OR=1.26; 95% CI: 1.05–1.51). The model showed a good fit based on the Hosmer–Lemeshow test ($p < 0.05$), and the overall classification accuracy was 78.2%.

DISCUSSION

This study retrospectively examined risk factors for CLBP in high-school baseball players, focusing on body composition and pain intensity. The results identified PBF and first-year NRS scores as significant predictors of CLBP.

Several fat-related parameters—including PBF, BFM, and BFMI—were significantly higher in the CLBP group than in the non-LBP group. Notably, effect sizes for PBF (Cohen’s $d=3.24$) and BFM (Cohen’s $d=2.81$) were large, indicating that these differences were not only statistically significant but also of substantial practical relevance. These findings suggest that excessive fat accumulation may contribute to the development or persistence of CLBP in adolescent athletes by increasing mechanical load on the lumbar spine or altering spinal biomechanics. Increased abdominal fat may elevate anterior shear forces on the lumbar spine, shift the

Table 1. Questionnaire results

	Non-LBP group (n=59)	CLBP group (n=31)	p-value
	Mean (SD)	Mean (SD)	
Age (years)	16.8 (0.4)	16.8 (0.3)	0.63*
Baseball experience (years)	8.4 (1.2)	8.3 (1.3)	0.93†
NRS (first year)(points)	0.3 (1.0)	3.4 (2.7)	<0.001†
NRS (second year) (points)	0.4 (1.0)	3.3 (1.5)	<0.001†
Pitcher n (%)	11 (19.0)	6 (19.4)	0.785‡
Catcher n (%)	6 (10.3)	5 (16.1)	
Infielder n (%)	21 (36.2)	12 (38.7)	
Outfielder n (%)	20 (34.5)	8 (25.8)	

NRS, numerical rating scale

*: Independent t-test; †: Mann-Whitney U test; ‡: Chi-square test.

Table 2. Comparison of body composition between groups. Values are mean (SD)

	Total (n= 90)	non-LBP (n= 59)	CLBP (n=31)	p-value	Cohen's d
Height (cm)	170.7 (5.6)	170.7 (5.7)	170.5 (5.5)	0.63 ^a	—
Weight (kg)	65.2 (8.0)	64.8 (8.0)	65.9 (8.0)	0.68 ^a	—
SLM (kg)	53.3 (5.9)	53.4 (6.1)	53.1 (5.6)	0.56 ^a	—
SMM (kg)	31.9 (3.8)	32.1 (4.0)	31.8 (3.5)	0.57 ^a	—
BMI (kg/m ²)	22.3 (2.0)	22.1 (2.0)	22.6 (2.0)	0.44 ^a	—
PBF (%)	13.1 (3.3)	12.4 (3.0)	14.5 (3.6)	0.01 ^b	3.24
FFM (kg)	56.5 (6.3)	56.6(6.5)	56.2 (6.1)	0.56 ^a	—
BFM (kg)	8.6 (2.8)	8.1 (2.5)	9.8 (3.5)	<0.05 ^b	2.81
Segment Lean Analysis					
Right arm (kg)	3.0 (0.4)	3.0 (0.4)	3.0 (0.4)	0.56 ^a	—
Left arm (kg)	2.9 (0.4)	3.0 (0.4)	2.9 (0.3)	0.41 ^a	—
Trunk (kg)	24.3 (2.5)	24.4 (2.6)	24.1 (2.1)	0.48 ^a	—
Right leg (kg)	8.9 (1.0)	8.9 (1.0)	8.9 (1.0)	0.52 ^a	—
Left leg (kg)	8.8 (1.0)	8.8 (1.0)	8.8 (1.0)	0.51 ^a	—
Segment Fat Analysis					
Right arm	0.3 (0.1)	0.3 (0.1)	0.4 (0.2)	0.01 ^b	0.18
Left arm	0.4(0.1)	0.3(0.1)	0.4 (0.2)	<0.01 ^b	0.18
Trunk	3.9 (1.7)	3.6(1.5)	4.5 (1.9)	0.02 ^b	1.68
Right leg	1.4 (0.4)	1.4 (0.3)	1.6 (0.4)	0.01 ^b	0.38
Left leg	1.4 (0.4)	1.3 (0.4)	1.6 (0.4)	<0.01 ^b	0.38
SMI (kg/m ²)	8.1 (0.6)	8.1 (0.5)	8.0 (0.6)	0.45 ^a	—
FFM index (kg/m ²)	19.3 (1.4)	19.3 (1.5)	19.3 (1.3)	0.75 ^a	—
BFM index (kg/m ²)	2.9 (0.9)	2.7 (0.8)	3.3 (1.0)	0.01 ^b	0.93

SLM, soft lean mass; BMI, body mass index; PBF, percentage body fat; FFM, fat-free mass; BFM, body fat mass; SMI, skeletal muscle mass index; n.s., not significant

a: Mann-Whitney U test; b: Independent t-test

Effect sizes were calculated using Cohen's *d* for parametric variables only. For non-parametric comparisons (Mann-Whitney U test), effect sizes were not reported due to the lack of distributional assumptions. All p-values are uncorrected and exploratory; no adjustments were made for multiple comparisons.

center of gravity forward, and increase lumbar lordosis.^{15, 16}

The body composition results align with prior studies. Uchida et al. reported an average PBF of 17.6% in experi-

enced high-school baseball players,¹⁷ while Hikiyara et al. reported 15.7%.¹⁸ Although PBF values vary slightly across studies, the present results (CLBP: 14.5%; non-LBP: 12.4%) are consistent with these findings. Elevated PBF in the CLBP

Table 3. Logistic regression analysis for CLBP

		Co-efficient	p-value	OR	95% CI	
					Low	Upper
Step 1	NRS	0.733	<0.001	2.080	1.448	2.989
Step 2	PBF	0.198	0.012	1.265	1.059	1.402
	NRS	0.779	<0.001	2.165	1.460	3.211

CLBP = chronic low back pain; NRS = numerical rating scale, CI= confidence interval, OR= odds ratio, SE= standard error, PBF= percentage body fat, NRS= numerical rating scale

Step 1: Model χ^2 test: $p < 0.01$, Hosmer–Lemeshow test: $p = 0.435$; hit ratio: 78.7

Step 2: Model χ^2 test : $p < 0.01$, Hosmer–Lemeshow test: $p = 0.418$; hit ratio: 78.7

group may be linked to mechanisms proposed in previous research, suggesting that adipose tissue contributes to pain.¹⁹ Excess fat can induce chronic low-grade inflammation, with adipose tissue secreting cytokines, such as tumor necrosis factor- α , adiponectin, and interleukins.²⁰ In obesity, these cytokines may promote chronic inflammation, intervertebral disc degeneration, and muscle catabolism,²¹ all associated with CLBP.

Furthermore, trunk fat mass was significantly higher in the CLBP group. Given that the trunk supports spinal movement and posture, excess fat in this region may contribute to mechanical overload and back pain. Body composition in athletes can fluctuate seasonally and be influenced by training type, duration, and sport-specific demands.^{22,23} As body composition was measured during the off-season after several months of regular training, individual differences in training adaptation may have contributed to the observed variability. Personalized training tailored to body composition profiles may help reduce CLBP risk. According to recent systematic reviews and meta-analyses, resistance training programs lasting 14 weeks or longer are effective in reducing percentage body fat in youth populations. Moderate to high intensity exercise is generally recommended to improve body composition outcomes.²⁴

Additionally, first-year NRS scores were a significant predictor of CLBP. Shafshak et al. reported that an NRS score >3 was associated with moderate functional disability, as measured by the Modified Oswestry Disability Index.¹² In the current study, the average NRS score increased from 3.1 in the first year to 3.3 in the second year among participants with CLBP, suggesting that a score ≥ 3 may indicate a higher risk of developing chronic pain symptoms rather than directly predicting chronicity.

This study has several strengths, including objective measurement of body composition and a homogeneous sample of adolescent baseball players. However, several limitations should be considered. The retrospective design

limits causal inference; body composition was assessed only once; and data on physical maturation, specific training volume, or lumbar structural integrity (e.g., imaging or functional muscle assessment) were not collected.

CONCLUSION

The results of this study indicate that higher percentage body fat and elevated baseline pain intensity may contribute to the development of chronic LBP in adolescent male baseball players. These findings should be interpreted in light of the study's retrospective design and the absence of training and data on physical maturation and imaging.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest relevant to this study.

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APPENDIX 1. QUESTIONNAIRE USED IN THIS STUDY

This questionnaire was developed and administered in Japanese by the authors, based on previous studies.⁵

It assessed basic baseball-related information and the presence and intensity of low back pain (LBP) using a numerical rating scale (NRS).

ID:
Age: _____ years
School grade (academic year):
Throwing / batting side: _____ Throw: [Right / Left] Bat: [Right / Left]
Primary playing position:
Years of baseball experience: _____ years

Low back pain history and characteristics

1. Have you ever experienced low back pain? (Yes / No)
2. Do you currently have low back pain? (Yes / No)
3. If yes, how long has your low back pain lasted? (___ weeks / ___ months)

Pain intensity and perception

Rate the expected pain when bending forward using a numerical rating scale (NRS)

no pain 0 1 2 3 4 5 6 7 8 9 10 worst imaginable pain

Original Research

Baseline Functional Testing in Competitive Youth Swimmers

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Background

Shoulder injuries are very prevalent in youth adolescent swimmers. As a result, there has been increasing focus on testing athletes post injury using functional testing to assess whether the athlete is ready to return to sports activity. Specifically, the closed kinetic chain upper extremity stability test (CKCUEST) and two versions of a prone ball drop test with elbow straight and elbow bent have been suggested. In order for these functional tests to be used for return to activity decision making normative values for different populations must first be established.

Hypothesis/Purpose

The purpose of this study was to establish normative values for the CKCUEST and prone ball drop tests in the elbow extended and elbow bent positions in a population of uninjured competitive youth swimmers

Study Design

Observational Cross-Sectional Study

Methods

Fifty-three swimmers without active shoulder pain were recruited from a single competitive swimming club. The CKCUEST as well as prone ball drop at 90 degrees of abduction with elbow straight and with elbow bent at 90 degrees were performed in a randomized order. All subjects were tested prior to the beginning of competition for the year. Participants were then categorized into subgroups by sex and age(10-14 or 15-18). Descriptive statistics were analyzed for all tests and groups were compared using two sample t-tests.

Results

Among this youth population CKCUEST demonstrated mean of 17.8 ± 3.5 touches with increased ball drop with elbow extended on the dominant vs non-dominant arm (31.8 ± 12.1 vs 28.6 ± 11.0 reps) as well as with elbow bent to 90 degrees (43.7 ± 13.6 vs 39.6 ± 15.4 reps). Additionally, there were differences in repetitions when groups were split by age with the 15-18 year old group demonstrating significant ($p < 0.05$) increase vs the younger group across all testing.

Conclusion

Baseline values in an uninjured competitive youth swimming population are provided for three commonly described upper extremity functional tests.

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Level of Evidence

Level 3

INTRODUCTION

It is estimated that approximately 16 million people under the age of 18 participate in recreational swimming across the United States.¹ Elite swimmers in that group report swimming eleven months out of the year and four to ten miles per day beginning at age 10 to 12.² Non-traumatic injuries are common in these athletes with shoulder injuries reported to be the most common with prevalence between 40% and 91%.³

Several authors have examined risk factors associated with injury in swimmers across a large range of ages. These studies have demonstrated that increased or decreased external rotation range of motion and prior injury were significant factors for developing shoulder injury.^{4,5} Additionally, a positive sulcus sign (indicating shoulder laxity) was correlated with increased incidence of tendinosis in Olympic level swimmers.⁶ It has also been shown that hours of training per week and weekly mileage are both positively correlated with shoulder pain caused by supraspinatus tendinopathy.⁷

These associations are important not only for understanding potential ways to reduce overall injury risk in this population but also for making a decision about when it is safe to return an athlete to participation following an injury and a course of rehabilitation. In addition to the standard strength and range of motion measurements that are used it is common to use functional testing to examine the athlete's readiness.⁸ Functional tests are commonly utilized and well described related to the lower extremity but have not been studied as much in the upper extremity.⁹ There are several tests that have been described in the literature to examine an athlete's readiness to return from an upper extremity injury,¹⁰ the most studied of which is the closed kinetic chain upper extremity stability test (CKCUEST).¹¹ However, as most upper extremity sports do not take place in closed chain positions there is a question about the ecological validity of the CKCUEST. To account for this gap in validity there are a number of newer tests described in the literature designed to mimic the loads seen during sports where the upper extremity is more frequently used in an open kinetic chain (swimming, baseball, tennis, volleyball, etc.). In particular, the current study explored two tests that place the subject into end range positions seen in swimming and throwing in order to examine strength and endurance in those vulnerable positions.¹⁰ It was hypothesized that these tests may have greater validity for assessing the particular population of competitive swimmers. The first step to being able to use these tests to decide on an athlete's safety to return to their sport is to establish normative values for different populations. Therefore, the purpose of this study was to establish normative values for the CKCUEST and prone ball drop tests in the elbow extended and elbow bent positions in a population of uninjured competitive youth swimmers.

METHODS

Participants aged 10-18 were recruited from a single competitive swimming club. Patients with active shoulder pain or shoulder pain limiting participation in the prior three months were excluded from testing. All testing took place within one month of the beginning of the season and prior to any competition in order to reduce any seasonal effects that may be present. Parental consent with subject assent or subject informed consent was obtained for all subjects prior to their participation in the study. The Hospital for Special Surgery Institutional Review Board approved the study.

Data were collected in a single session. Participants were told not to warm up and testing was done prior to practice on the day of enrollment. The order of testing was randomized in order to reduce the effect of fatigue. In addition to physical testing each patient was interviewed regarding history of shoulder injury requiring medical or physical therapy intervention. Following enrollment subgroups were formed by sex as well as by age greater than fifteen or between ten and fourteen. The age cutoff was created to split the enrolled range into approximately equal ranges while also being split to allow comparison between a high school aged cohort and a younger middle school aged cohort.

The prone medicine ball drop was performed with the participant lying prone on a treatment table with the shoulder abducted to 90°, elbow straight, and palm facing the floor.¹⁰ Participants had the head turned toward the arm and the opposite arm supported on the table. Participants were instructed to drop and catch a 1 kg medicine ball as many times as possible in thirty seconds. This testing was previously described using a 2-pound ball and therefore 1kg was chosen as the closest available alternative.¹⁰ Three trials were performed with 30 seconds rest between each trial while alternating sides between each trial. The average was recorded for both the dominant and non-dominant arms. Form was monitored to maintain a level torso and arm at 90 degrees abduction during testing. Verbal cues were provided as needed for correction.

The 90-90 prone medicine ball drop was performed with the participant lying prone on a treatment table with the shoulder abducted to 90°, the elbow flexed to 90°, and the palm facing the floor. Participants were instructed to drop a 1kg medicine ball and catch the ball as many times as possible in thirty seconds. As in the elbow extended testing, a 1kg ball was used as the closest available alternative to the 2-pound ball previously described in the literature.¹⁰ Form was monitored to maintain a level torso and arm at 90 degrees abduction during testing. Participants alternated arms and were given 30 seconds break between each trial. Verbal cues were provided as needed for correction.

The CKCUEST was performed with two marks on the floor placed 36 inches apart. Each participant was instructed to assume a plank position on their feet and tap back and forth with the opposite hand as has previously

Table 1. Participant Demographics and Overall Sample Means

Gender (M/F)	25/28
Age (years, mean $\pm$ SD)	14.19 $\pm$ 1.89
Years Swam Competitively (mean $\pm$ SD)	6.03 $\pm$ 2.42
Breathe on Both Sides (n)	26
Reported History of Shoulder Pain (n(M/F))	16 (6/10)
CKCUEST (repetitions)	17.8 $\pm$ 3.5
Prone Ball Drop dom (repetitions)	31.8 $\pm$ 12.1
Prone Ball Drop non-dom (repetitions)	28.6 $\pm$ 11.0
90-90 Ball Drop dom (repetitions)	43.7 $\pm$ 13.6
90-90 Ball Drop non-dom(repetitions)	39.6 $\pm$ 15.4

Demographics of population as well as overall mean and standard deviations for functional testing for the entire sample. All functional testing is reported as mean and standard deviations of number of repetitions performed during the testing period. Side was separated by dominant arm (dom) and non-dominant arm (non-dom) for unilateral tasks.

been described.¹¹ The number of successful taps in 15 seconds was recorded. Each subject was given one practice trial and then completed two repetitions of the test with a 30 second break between each trial. The average of the two trials was recorded for analysis.

Statistical analysis was conducted using R version 4.2.2. Descriptive statistics were analyzed for all tests. Limb symmetry index was calculated as the ratio of dominant (dom) to non-dominant (non-dom) arm for each unilateral test. Subgroup differences were evaluated using two sample t tests.

RESULTS

Fifty-three participants were recruited for the study including 25 male and 28 female. Demographics of the subjects as well as overall means and standard deviations of the functional tests are presented in [Table 1](#).

There were significant differences between sex as well as between age groups ($p < 0.05$) for all tests with the exception of the CKCUEST. Limb symmetry indices were not significantly different between groups. Descriptive statistics of the tests split by sex and by age group are presented in [Tables 2](#) and [3](#) respectively.

Table 2. Normal Values by Sex

Test	Females (mean $\pm$ SD)	Males (mean $\pm$ SD)	p-Value
CKCUEST (repetitions)	17.2 $\pm$ 3.3	18.4 $\pm$ 3.6	0.20
Prone Ball Drop – dom (repetitions)	27.4 $\pm$ 12.0	36.8 $\pm$ 10.4	<0.01
Prone Ball Drop – non-dom (repetitions)	24.8 $\pm$ 9.7	32.9 $\pm$ 11.1	<0.01
Prone Ball Drop – Limb Symmetry Index (%)	114.1 $\pm$ 39.3	116.4 $\pm$ 25	0.80
90-90 Ball Drop – dom (repetitions)	38.7 $\pm$ 13.5	49.3 $\pm$ 11.5	<0.01
90-90 Ball Drop – non-dom (repetitions)	34.6 $\pm$ 13.6	46.6 $\pm$ 13.3	<0.01
90-90 Ball Drop – Limb Symmetry Index (%)	117.6 $\pm$ 33.9	108.2 $\pm$ 14.4	0.20

All functional testing is reported as mean and standard deviations of number of repetitions performed during the testing period. Side was separated by dominant arm (dom) and non-dominant arm (non-dom) for unilateral tasks.

There were no significant differences between prior shoulder injury and no injury groups when the sample was split by whether the participant had reported prior seeking medical care for a prior shoulder injury ([Table 4](#)).

DISCUSSION

The primary goal of this study was to establish normative values for upper extremity functional performance tests that had not previously been examined in this population. To the author's knowledge there are no prior published normative values for the ball drop tests in this age group or specific population.

Previous studies have examined both the CKCUEST and the ball drop tests in adult populations.^{11,12} The prone ball drop with elbow extended was reported in male and female groups with dominant arm repetitions of 74.7 $\pm$ 9.9 and 64.7 $\pm$ 13.4 respectively.¹² While the bent elbow ball drop had repetitions of 61.5 $\pm$ 9.9 and 50.4 $\pm$ 12.0 in the same groups respectively.¹² These values are much greater than the means reported in this study population. There was a similar trend with the CKCUEST which previously had reported values of 27.728 and 22.758 for male and female athletes respectively.¹¹ This difference is likely related to the decreased strength and motor control associated with this age population as opposed to adult populations that had previously been studied. It is important to ensure that when using normative data for comparisons the subject being examined is similar to the population that was examined to create the data. It would not be recommended to use previously reported values from an adult population when examining this age group of swimmers.

One way to potentially counteract the differences between age group and between sexes would be to use within subject normalization. In this study using limb symmetry ratio demonstrates similar results to previous studies in an adult population where limb symmetry was reported between 106.4 and 119.2 for the different groups during the ball drop tests.¹² Limb symmetry may be a useful metric to control for differences in raw numbers that were noted between age groups and sex. However, swimming is a bilateral sport so it is possible that the normative values for limb symmetry may be altered when looking at a unilateral dominant sport such as baseball/softball, tennis, or volleyball.

Table 3. Results for age groups

Test	Age < 15 (n=33)	Age ≥ 15 (n=20)	p-Value
CKCUEST (repetitions)	16.9±3.1	19.3±3.7	0.02
Prone Ball Drop – dom (repetitions)	26.4±9.7	40.8±10.2	<0.01
Prone Ball Drop – non-dom (repetitions)	23.8±8.4	36.5±10.6	<0.01
Prone Ball Drop – Limb Symmetry Index (%)	115.5±38.7	114.7±21.4	0.94
90-90 Drop – dom (repetitions)	38.9±11.2	51.6±13.7	<0.01
90-90 Drop – non-dom (repetitions)	35.1±12.3	48.8±14.4	<0.01
90-90 Drop – Limb Symmetry Index (%)	116.3±31.3	108.2±16.3	0.29

All functional testing is reported as mean and standard deviations of number of repetitions performed during the testing period. Side was separated by dominant arm (dom) and non-dominant arm (non-dom) for unilateral tasks.

Table 4. Comparisons between prior injury/no injury groups

Test	Prior Shoulder Injury (n=16)	No Injury History (n=37)	P-Value
CKCUEST (repetitions)	18.0±3.2	17.7±3.6	0.78
Prone Ball Drop – dom (repetitions)	36±11.5	30±12	0.10
Prone Ball Drop – non-dom (repetitions)	31.8±11.4	27.2±10.7	0.16
Prone Ball Drop – Limb Symmetry Index (%)	117.8±27.9	114.1±35.3	0.71
90-90 Drop – dom (repetitions)	48±12.8	41.9±13.7	0.13
90-90 Drop – non-dom (repetitions)	43±16.7	39.1±13.7	0.38
90-90 Drop – Limb Symmetry Index (%)	119.2±25.0	110.6±27.4	0.29

All functional testing is reported as mean and standard deviations of number of repetitions performed during the testing period. Side was separated by dominant arm (dom) and non-dominant arm (non-dom) for unilateral tasks.

Of particular interest are the large differences in testing averages when split between high school and middle school athletes. This is especially important when considering the variability that exists and changes that occur in skeletal maturity within the youth and adolescent population. While skeletal age and skeletal maturity were not assessed in this study there are a number of methods for assessing that are clinically feasible without specialized equipment.¹³ As a substitute for skeletal age the authors chose to split the population evenly and group ages 11-14 and 15-18 together respectively. Given the differences associated with this seemingly arbitrary split it warrants further investigation from future studies.

One finding that the authors found particularly interesting was that there were no differences when the groups were split by prior injury. Given that previous injury has frequently been shown to be a predictor of future injury¹⁴ it was hypothesized that there would be some difference. Based on the current study it is unknown if this lack of association is an indication that the functional tests not being discriminatory for future injury or whether this was simply a function of the small sample size or that the inclusion criteria of no active shoulder pain within 3 months eliminated subjects that would have demonstrated a difference. While the current study did not attempt to establish any association w/ future injury hopefully the data can serve as a starting point for comparison.

There are several limitations to this study. Most importantly is that the sample size is limited such that it is difficult to draw any conclusions from subgroup analysis due to the increased possibility of Type 2 error. Additionally, drop tests were performed with a standard weight and CKCUEST was performed in a standard position across all subjects. This is potentially more impactful in the youth populations where there is significant variability in size and skeletal maturity of the participants. It was noted that some of the smallest participants had difficulty reaching the standard distance apart for CKCUEST as well as holding the weighted ball during drop testing due to the size and weight of the ball. In order to reduce the variability of the results it may be beneficial to use anthropometric measurements in order to create a scaled version of the tests individual to each subject. This has been examined in twelve to seventeen year old basketball and volleyball players for the CKCUEST¹⁵ but was not implemented in this study as to the authors knowledge this had not been described in the literature at the time of planning and data collection.

CONCLUSION

The results of the current study provide a baseline of normal values for upper extremity functional measures in a competitive youth swimming population that can potentially be used in return to sport testing in the future. There were significant differences between sex as well as between

age groups for both of the ball drop tests. However, limb symmetry indices and the CKCUEST were not significantly different between the groups.

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CONFLICTS OF INTEREST

The authors affirm that we have no financial affiliation (including research funding) or involvement with any commercial organization that has a direct financial interest in any matter included in this manuscript.

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Original Research

Sports Injuries and Care Provided by the Physiotherapy Service of the Brazilian Olympic Committee (BOC) during the Rio de Janeiro 2016 Olympic Summer Games

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Background

Understanding previous experiences of athletes regarding treatments is important for preparation for major sporting events. However, there is little evidence regarding the description of physiotherapy services provided at Olympic Games. Providing data may assist with better understanding of the physiotherapy services provided during major sporting events such as the Summer Olympics.

Purpose

To describe the injuries, injured body regions, most affected sports, and the procedures performed by the Brazilian Olympic Committee (BOC) physiotherapy department to help injured athletes recover. This study also aims to provide data to better understand the physiotherapy services provided during the Summer Olympic Games.

Study Design

Descriptive Epidemiology Study

Methods

This observational descriptive study, uses information collected during the Olympic Summer Games based in the city of Rio de Janeiro, in August 2016. Reported injuries treated and procedures performed by physiotherapy professionals are detailed. Furthermore, the sports in which athletes competed and anatomical regions of the injuries treated are reported, through evaluation forms completed by the health team during the service provided by the BOC. A quantitative and qualitative analysis of the results obtained was performed. Descriptive variables are reported, and a qualitative analysis of the results obtained was also performed.

Results

A total of 422 athletes (90.7%) from the Brazilian team, competing in 35 sports, were referred by the medical department to the physiotherapy department. These athletes underwent physiotherapy treatment for 1,021 injuries diagnosed by the medical department of the BOC. Most of the injuries occurred in Judo athletes (n=358, 14.3%), followed by Handball athletes (n=153, 6.1%) and Artistic gymnasts (n=149, 6.0%). The most treated anatomical region was the shoulder region (n=167, 16.4%), followed by the

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knee region (n=152, 14.9%) and lumbar spine (n=126, 12.3%). The most frequently observed types of injuries were tendinopathies (n=207, 20.3%), sprains (n=198, 19.4%) and contusions (n=120, 11.7%). There were 3,539 physiotherapeutic treatments performed. The most utilized procedures were manual therapy (n=973, 27.5%), followed by electrotherapy therapeutic resources (n=876, 24.8%) and exercises (n=375, 10.6%).

Conclusion

A large number of athletes who represented Brazil at the Rio 2016 Summer Olympic Games sought medical care at the Brazilian Olympic Committee's physiotherapy department. Athletes from judo, handball, and artistic gymnastics were those who most frequently sought physiotherapy services. The main injuries treated by physiotherapy professionals were tendinopathies, followed by sprains and contusions. The body regions most frequently treated for injuries were the shoulder, knee, and lumbar spine. The most commonly used procedures in the physiotherapy service were manual therapy, electrotherapy, and exercise.

Level of Evidence

3

INTRODUCTION

The Olympic Games are the largest sporting event in the world, with thousands of athletes competing during the Summer Games. The occurrence and nature of injuries in elite athletes, as well as the sports in which they suffer these injuries during major sporting events have been extensively reported.¹⁻⁵ The total injury rates at the recent Summer Olympic Games were reported in Rio de Janeiro 2016 (8%),³ Beijing 2008 (10%),¹ and London 2012 (11%).²

Injury epidemiology is crucial because it provides the scientific base for preventing and mitigating injuries by identifying risk factors, describing patterns of injury, and evaluating treatments effectiveness. For these reasons, several countries have conducted epidemiological studies during major sporting events. Yoon et al.⁶ characterized the injuries suffered by athletes from the Korean delegation who participated in the Rio 2016 Olympic Games. Two hundred and four athletes competed in 24 sports and suffered 150.9 injuries, with boxing being the sport that presented the most injuries. Furthermore, they found that 51.9% of the injuries occurred in the lower limbs and 24.0% occurred in the upper limbs. Another epidemiological study carried out among elite South Korean rowing athletes, who participated in high-level international competitions and were prepared by the Korean National Training group, revealed that more than half of all the injuries were considered minor and severity of injury varied according to the body region, with the lower extremities being the most injured region. In both male and female athletes, injury incidence rates and severity of injury were associated with weight class.⁷ Grim et al.⁸ documented the injuries that occurred in athletes from the German delegation who participated in the Rio 2016 Olympic Games. Lower limb injuries accounted for 56.5% of the total, while upper limb injuries accounted for 14.8% of the total. Lopes et al.⁹ studied the profile of treatments performed at the Physical Therapy Department of the Brazilian Olympic Committee during the 2007 Pan American Games through a study of 434 athletes referred by the Medical Department to the Physical Ther-

apy Department. The majority of athletes in the Brazilian delegation required physical therapy treatment (65.7%). The main complaints observed were spinal injuries (low back pain, back pain, and neck pain) (n=89, 25.3%), tendinopathies (n=79, 22.4%), and muscle tension (n=43, 12.2%). A total of 2,523 physical therapy treatments were performed, and the most commonly used procedures were exercises (n=969, 24.9%), ultrasound (n=757, 19.4%), and cryotherapy (n=670, 17.2%). The comparison of injury rates between Olympic and Paralympic Team USA athletes competing in the Tokyo 2020 Summer Games showed that there were no differences in injury incidence (IRR, 1.18; 95% CI, 0.84-1.68) between Olympic and Paralympic athletes.¹⁰ However, when the team injury incidence at the 2022 Beijing Winter Olympic and Paralympic Games was analyzed, Olympic athletes had significantly lower injury (IRR=0.56 (95% CI 0.37 to 0.87), p=0.009) risks compared with Paralympic athletes.¹¹ These studies reveal specific epidemiological data for the athletes representing their countries and statuses which may facilitate more focused approaches for injury prevention programs and selection of the best techniques for their treatment.

It is interesting to point out that some recently published studies have analyzed the incidence of injuries in elite athletes over several competition seasons and not just at one season. For instance, a total of 111 British Olympic track and field athletes were followed prospectively for three consecutive seasons between 2015-2018²³. Overuse injuries (56.4%) were more frequent than acute injuries (43.6%). The thigh was the body region most frequently injured (0.6 per athlete year), followed by the lower leg (0.4 per athlete year) and foot (0.3 per athlete year). Muscle and tendon were the most commonly injured tissues, while the most commonly detected pathologies were strains and tears. In another study, the incidence of injuries in Summer and Winter Canada Games athletes was analyzed during Canada Games competitions from 2009-2019²⁴. The injury incidence was 362.8 and 389.9 and per 1000 male and female athletes, respectively. Female athletes had 1.12 greater odds of injury compared to male athletes. Overall,

injury (399.31 vs. 360.31; $p < 0.001$) incidences was higher in Winter Games, compared to Summer Games, per 1000 athletes. It was found that there are sex specific differences in the pattern of injuries when comparing male and female athletes participating in similar sports. All these data could be utilized for the development and implantation of injury prevention programs and injury mitigation strategies in elite athletes during major sporting events.

However, few studies have described the use of physical therapy services at major multisport events, those that did highlighted only the type of services provided by the Physiotherapy Department and the reason why athletes seek care.^{9,12-15} The association between athletes' injury types and the choice of physiotherapy treatments applied was studied at the Polyclinic Tokyo 2020. Chronic injuries affecting the lower limb muscles and/or tendons were the most prevalent issues treated by physiotherapists in that study.¹⁶ The treatments preferred by Japanese physiotherapists to treat athletes were manual therapy, taping, exercises and ultrasound therapy.¹⁶ During the 2018 PyeongChang Olympic Winter Games two polyclinics that provided physiotherapy services for injured athletes were described.¹⁷ The mountain-site polyclinic was designated for outdoor sports as alpine skiing, cross-country, bobsled-luge-skeleton, snowboard, biathlon, freestyle-skiing, and ski-jump. The city venue was designated for indoor winter sports: ice-hockey, figure skating, speed-skating, curling, and short-track indoor events. The comparison between the treatments carried out in the one clinics revealed differences in the athletes' recovery and in the frequency and percentage distribution of injuries by anatomical area. Each polyclinic attended to different populations of athletes, providing important information regarding the types of injuries and the different physiotherapy treatments used.¹⁷ Therefore, information on procedures, most commonly utilized conduct, and main injuries still lacks clarity.

Epidemiological data can contribute to planning for athlete care and contribute to the development of measures to prevent or mitigate injury.

Understanding the services provided by physiotherapists and the resources they use, as well as the most frequent sports disciplines and types of injuries, can enable professionals and researchers working in the area of prevention and treatment of sports injuries to develop protocols based on previous experiences with the aim of minimizing the occurrence of these injuries and optimizing the planning and preparation of athletes for events of this size.

Therefore, the objective for this study was to describe the incidence of injuries, the sports disciplines most affected, the body regions most frequently injured, and the procedures performed for athlete recovery by the physiotherapy department of the Brazilian Olympic Committee (COB) during the Rio 2016 Summer Olympic Games. This study also aims to provide data to better understand the physiotherapy services provided during the Summer Olympic Games.

METHODS

This study used a descriptive, observational, and cross-sectional descriptive epidemiological design to assess injuries and to analyze the actions carried out by the physiotherapy department during the Rio 2016 Olympic Games, in 2016. During Brazil's participation, the country's official delegation, under the responsibility of the BOC, had an exclusive team of physiotherapists among its members working together with the Medical Department.

The team of physiotherapists responsible for the Brazilian delegation consisted of 28 professionals. Brazilian physiotherapists have been improving their skills through training courses organized by the Brazilian National Society of Sports Physical Therapy (SONAFE-Brazil).¹⁸ Of these, 14 physiotherapists, accredited by the confederations of their respective sports, were responsible for providing physiotherapy services in eight sports – basketball, football, handball, judo, rugby, volleyball, and beach volleyball. The remaining physiotherapists accredited by the BOC were divided as follows: a main base in the Olympic Village with ten physiotherapists, a second one with two physiotherapists responsible for treating athletes in the handball and sailing sports, and a third one with two physiotherapists responsible for treating athletes in marathon swimming, canoe sprint, triathlon, road cycling, and rowing.

The physiotherapy treatment area in the Olympic Village was approximately 100 m², with eleven treatment stretchers ([Figure 1](#)). Two other bases had a treatment area of approximately 50 m², with three stretchers each. The departments operated from 8:00 a.m. to 10:00 p.m., a period that could sometimes be extended to accommodate the demands of the athletes. The service area was divided into evaluation rooms and areas for individual treatments. Treatments were performed every day at the physiotherapy department in the Olympic Village, at two other bases, and at the training and competition venues between August 5 and 21, 2016, totaling 17 days of uninterrupted care. Athletes were allowed to receive more than one physiotherapy treatment per day.

PARTICIPANTS

Athletes referred by the Brazilian Olympic Committee's Medical Department to the Physical Therapy Department were considered eligible to participate in the study. Athletes who were not referred by the Medical Department to the Physical Therapy Department were not included in the study.

PROCEDURES

The athletes were informed in advance about the project. Data regarding the type of injury, anatomical region examined, sports the athletes participated in, and the physical therapy procedures performed on the athletes during the Rio 2016 Olympic Games were extracted from their medical records. No data that could potentially violate confidentiality or identify the participant was used.



Figure 1. Physiotherapy Department at the Olympic Village during the Rio 2016 Olympic Games.

All athletes underwent a medical evaluation and were evaluated by the Physical Therapy team Brazil before beginning treatment. A clinical examination and, when necessary, an imaging exam were performed to determine the diagnosis. The Brazilian doctors received a standard table, used and developed by the International Olympic Committee, with the numerical code for each diagnosis to facilitate subsequent data accounting.¹⁹ Information for all encounters were manually entered in Portuguese on a paper form, as required by Brazilian law.²⁰

The diagnosis was determined by the physician, who completed a referral form to the Physiotherapy Department using these codes. With this referral, the athlete then underwent a physical therapy evaluation. The Physical Therapy Record, developed specifically for this event, was used for data collection. All treatment approaches and procedures, sports disciplines, and reasons for attendance were recorded in an Electronic Medical Record during the Rio Olympic Games.¹⁴ The data extracted from the database for analysis included: gender, age, sport, type of injury, injured body part, date and time, and physical therapy treatment performed. All this information was stored in the individual file for subsequent analysis. Sports injuries were considered to be any pre-existing or recurrent musculoskeletal complaint originating from competition and/or training that received medical attention, regardless of the possible absence of competition or training.²¹ The injuries considered were those reported by one of the Brazilian Olympic Committee physicians to ensure the validity of the information and a comparable data standard.

All professionals involved in these procedures underwent training sessions to complete the forms to ensure a uniform data recording standard. During these meetings, members were informed about the objectives of this study.

For data analysis, the physiotherapy procedures were grouped into manual therapy, electrophototherapy resources (microcurrent, laser, transcutaneous electrical nerve stimulation [TENS], functional electrical stimulation [FES], and ultrasound), pneumatic compression with ice (Game Ready®), dry needling, taping, and superficial heat.

All procedures were performed by physical therapists. Dry needling was the physiotherapy technique used, performed by a physical therapist trained in the procedure. Exercises is operationally defined for this research as the systematic therapeutic use of movement - through active, passive, or assisted exercise - to rehabilitate athletes, restore motor function, strengthen muscles, improve joint mobility, and prevent injuries, with individualized application according to the sport and athlete's profile.²² Each athlete was evaluated by a physician and referred for physiotherapy treatment, and each physiotherapist adopted the approach they considered most appropriate for that athlete.

STATISTICAL ANALYSIS

A quantitative analysis of the results obtained regarding injuries, sports that athletes participated in and procedures and treatments used for the recovery of athletes was performed. The normality of the data was assessed using the Kolmogorov-Smirnov test and the statistical program used was SPSS 20.0, with continuous variables described as mean $\pm$ standard deviation and categorical variables described as number and percentage.

CONFIDENTIALITY AND ETHICAL APPROVAL

This study was approved by the research ethics committee of Universidade Federal de São Paulo (approval number 3.006.632), and all members consented to participate in the study. This research was approved by the BOC. All the athletes were informed in advance about the project. No data that could potentially violate confidentiality or identify the participant was used.

RESULTS

At the Rio 2016 Olympic Games, approximately 11,238 Brazilian athletes from 39 different sports took part in the following competitions: athletics, badminton, basketball, boxing, canoe slalom, canoe sprint, BMX, road cycling, mountain biking, track cycling, fencing, football, artistic gymnastics, trampoline gymnastics, rhythmic gymnastics, golf, handball, equestrianism, field hockey, judo, weightlifting, wrestling, open water marathons, synchronized swimming, swimming, modern pentathlon, water polo, rowing, rugby, diving, taekwondo, tennis, table tennis, archery, shooting, triathlon, sailing, volleyball and beach volleyball.

Brazil had the largest number of participants in the history of Brazil's participation in the Olympic Games: 465 athletes. Of these, 209 were female (44.95%) and 256 were men (55.05%). The average age was 27.8 ± 5.8 years. The youngest female athlete, aged 16, played table tennis and the youngest male athlete was 18 years old and participated in archery. The oldest woman was 54 years old and the oldest man 53 years old, both competing in shooting sports. Among the 465 athletes who represented Brazil at the Rio 2016 Games, 422 were referred by the Medical Department of the BOC to the Department of Physiotherapy, represent-

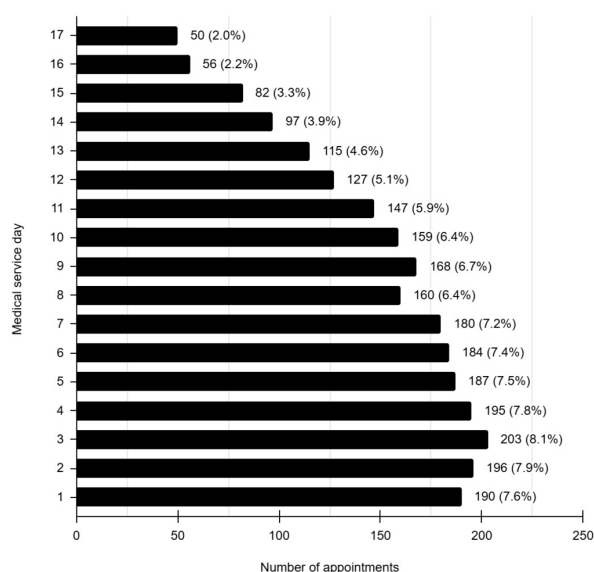


Figure 2. Services carried out in the physiotherapy department of physiotherapy on each day of competition during the Rio 2016 Olympic Games.

ing 90.7% of the total number. Among the athletes treated, 188 were female (44.55%) and 234 were male (55.05%).

Treatments were carried out every day, between August 5 and 21, 2016, totaling 17 days of uninterrupted service, spanning more than 14 hours a day. The third day of the competition marked the peak in care (203 athletes – 8.1%). During the period in which the Brazilian physiotherapist team was working, 2,496 physiotherapy appointments were recorded, distributed throughout the 17 days of competition. The daily distribution of these services can be seen in [Figure 2](#).

[Figure 3](#) shows the total number of Brazilian athletes in each sport who participated in the Rio 2016 Olympic Games. The sport with the largest number of participating athletes was sports disciplines (n=67) and the sport with the smallest number of athletes was trampolines (n=1). These athletes attended at least one appointment at the Department of Physiotherapy. Injured athletes from track cycling (n=1), road cycling (n=4), triathlon (n=2), and football (n=36) were not included in this study since they were attended by physiotherapists who were team-accredited by the confederations of the respective sports.

[Figure 4](#) shows the incidence of injured athletes in each sport. The incidence of injuries was highest in judo athletes, with 358 treatments which corresponded to 14.3% of the physiotherapy team activity, followed by handball (n=153; 6.1%), artistic gymnastics (n=149; 6.0%) and basketball (n=146; 5.8%). The lowest incidence of injuries was observed in BMX cycling (n=6; 0.2%), equestrian (n=7; 0.3%), marathon swimming (n=11; 0.4%), and the modern pentathlon (n=11; 0.4%).

The most frequent types of injuries and the percentage of injury occurrence are presented in [Figure 5](#). The data revealed that tendinopathies were the most common type of

injury (n=207; 20.3%), followed by sprains (n=198; 19.4%), contusions (n=120; 11.8%), and spinal myalgias (n=105; 10.3%).

The most frequently injured anatomical areas recorded were the shoulder (n=167; 16.4%), followed by the knee (n=152; 14.9%) and the lumbar spine (n=126; 12.3%). The numbers and percentages of types of distribution of injuries by anatomical location are shown in [Figure 6](#).

During the period of work of the physiotherapy team of the BOC, the total number of treatment sessions resulted in 3,539 physiotherapy procedures. The distribution of resources used in these procedures is specified in [Figure 7](#). Manual therapy accounted for 27.5% (n=973) of the procedures performed, surpassing any other, followed by the use of electrophysical resources which totaled 24.8% (n=876) of the techniques applied. Other procedures used were kinesiotherapy 10.6% (n=375), bandaging 10.2% (n=360), pneumatic compression with ice 8.8% (n=312), dry needling 7.7% (n=273), cryotherapy 6.1% (n=216), and superficial heat 4.4% (n=154).

DISCUSSION

The aim of this study was to describe the athletic injuries that occurred and the corresponding sport in which they occurred during the Rio 2016 Olympic Summer Games. The physiotherapeutic procedures used to recover from these injuries were also reported.

It was found that 90.7% of the Brazilian delegation suffered some type of injury and were referred to the Physiotherapy Department, demonstrating the importance of this service's availability at major sporting events. Athletes from judo, handball, gymnastics artistic and basketball were the most frequently treated by BOC's physiotherapy services. Lopes et al.⁶ reported that during the 2007 Pan-American Games, 65.7% of Brazilian athletes received physiotherapy care. In contrast, a higher incidence of injuries was observed during the Rio 2016 Olympic Games, possibly due to the greater physical and technical demands of the Olympic competition. Moreover, athletes participating in the Pan-American Games may not have been as well-prepared or conditioned as Olympic athletes, which could also explain the increased need for physiotherapy care. In the Korean delegation at the Rio 2016 Olympic Games, 56.3% of the athletes received health attention,⁶ a considerably lower number than that of Brazilian athletes. Analyzing the data obtained by the International Olympic Committee (IOC), considering athletes treated at the Polyclinic of the Olympic Village or who were received treatment at the competition venues by the Organizing Committee during the 2016 Rio Games, a total of 8% of the athletes were injured.³ Previous works showed comparable values with 10% injured athletes in Beijing 2008¹ and 11% in London 2012.²

The number of injuries that occurred depended on the sport practiced by the athlete. The highest injury incidences were found in judo (14.3%), handball (6.1%) and gymnastics (6.0%). The differences in rate injuries according to the sport can be assigned in part to variations in

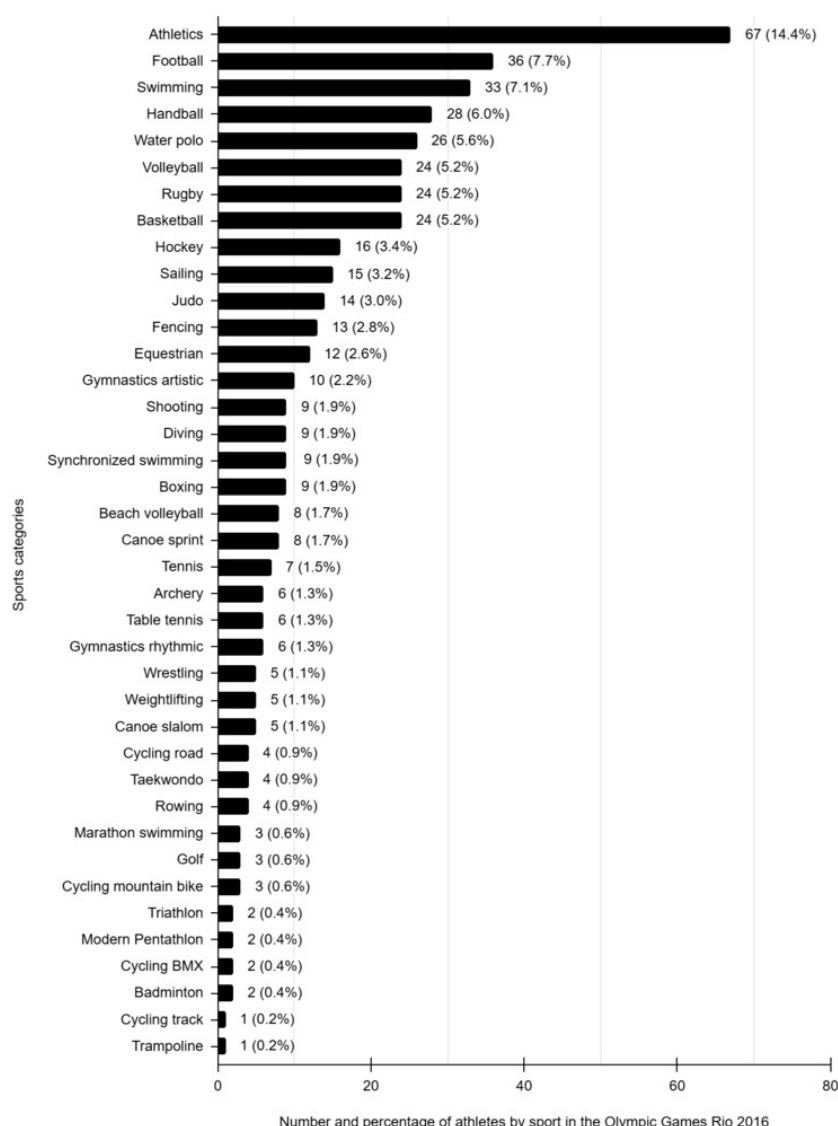


Figure 3. Number and percentage of Brazilian athletes by sport participating in the Rio 2016 Olympic Games.

the number of athletes participating in each sport - in this work, from 67 in athletics to only 1 in trampoline. The number of total days of official competitions by sport can also influence the number of injuries. Some sports competitions last just one day, while others last up to 15 days, influencing the number of injuries per sport. Considering the 11,274 athletes who participated in the Rio 2016, the proportion of injured athletes was highest in BMX bicycling, followed by boxing.³ Data from all physiotherapy services provided at the Olympic polyclinic showed, for this event, that the sports with the most injured athletes were handball (37%), followed by judo (22%), athletics (21%), and taekwondo (19%),¹⁴ data similar to that obtained in the current study. Comparing the injuries that occurred at Rio 2016, London 2012 and Beijing 2008, it was observed that some sports such as football, taekwondo and handball had many injured athletes, while other modalities such as fencing and swimming had few injuries.^{2,3} Most of the injuries suffered by Korean athletes during the Rio 2016 occurred

in boxing (6.0%).⁶ There seems to be a tendency for more severe injuries in contact sports. However, it is difficult to compare different studies, since the results vary according to the group studied, the number of athletes and the sports analyzed in each case.

The most frequent injury among athletes was tendinopathy (20.3%) followed by sprains (19.4%), suggesting that overuse is responsible for the majority of sports injuries. Among all athletes participating in the Rio 2016, the most common types of injuries were sprain/ligament rupture (18.5%), contusion/hematoma/bruise (16.2%), strain/muscle rupture/tear (15.3%), and tendinosis/tendinopathy (10.2%).³ At the 2007 Pan-American Games, tendinopathy was identified as the second most frequent injury among Brazilian athletes (22.4%), followed by muscle strains (12.2%).⁹ At Beijing 2008, the most frequent diagnoses were ankle sprain (7.3%) and thigh strain (6.8%).¹ In general, the type of injuries most commonly attended by physiotherapy

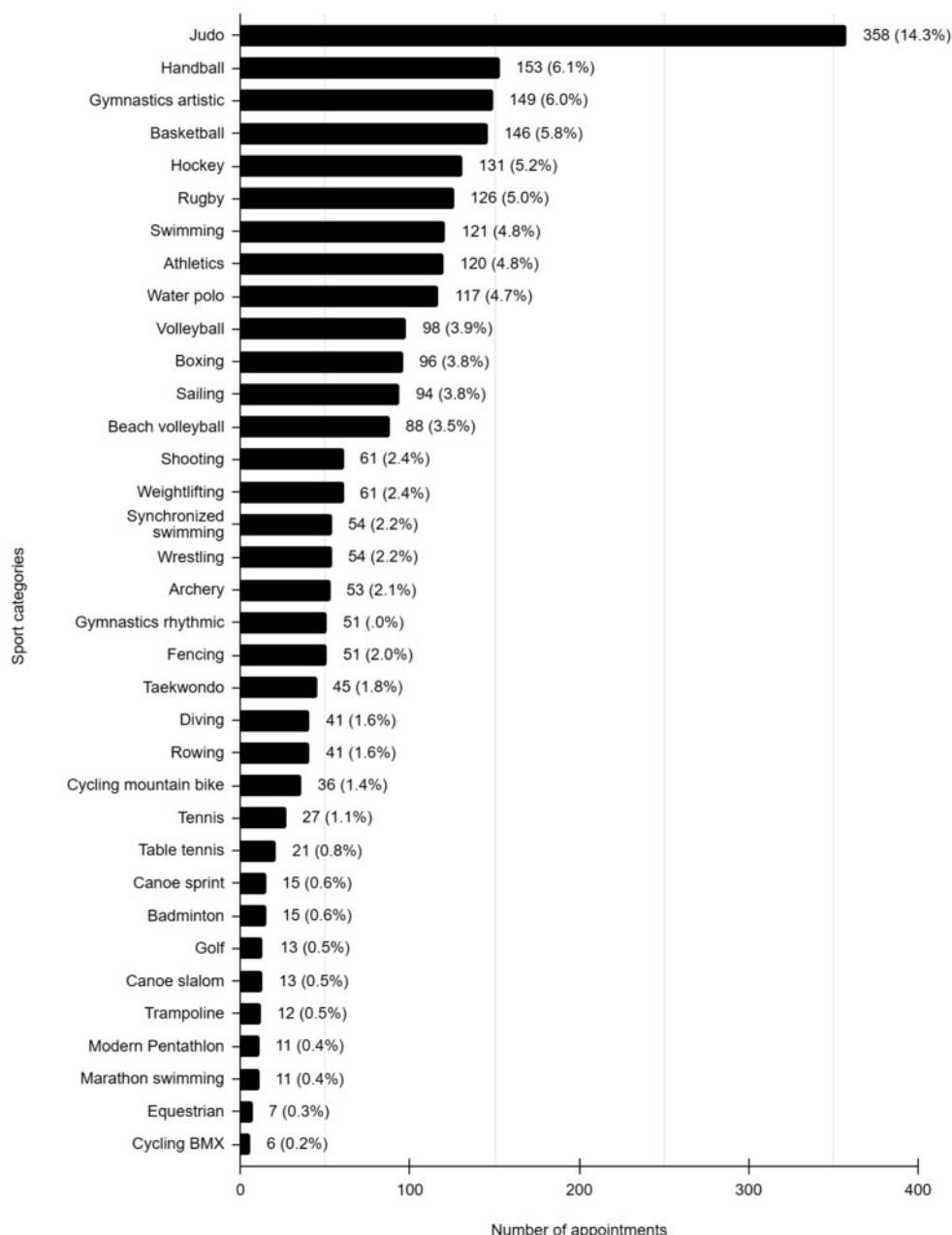


Figure 4. Number of services provided by sport modality during the Rio 2016 Olympic Games.

services in different sporting events are comparable and most involve muscle, tendon, and ligament.

The most frequently injured anatomical regions were the shoulder, followed by the knee, lumbar spine and ankle. When the anatomical regions were grouped by lower extremities (LE) or upper extremities (UE), it was found that LE were responsible for 42.8% of the treatments, while the UE accounted for 30.3% of the treatment. These results are consistent with those observed by Soligard et al.⁸ who, when analyzing the injuries of all athletes participating in Rio 2016, showed that LE injuries were responsible for 39.2% of the care in physiotherapy services. In the Rio Olympic Games LE injuries in German athletes accounted for 56.5% of all injuries and the UE injuries for 14% of the

total.⁸ Similarly, Korean athletes suffered 51.9% LE injuries and 24% UE injuries during the Rio Olympic Games.⁶ In Beijing 2008, the LEs were also the most affected region (54.2%).¹

Therefore, it appears that most injuries consistently occur in the LE.

The most commonly involved tendons in athletes who participated in the Rio 2016 were in the shoulder,²³ which is similar to those results described for London 2012.²⁴ These data are consistent with those obtained regarding Brazilian athletes in this study. Localized elbow injuries reported during London 2012 showed a high percentage of tendinopathies involving the tendons of this region.²⁵ This type of injury occurred mainly in combat sports ath-

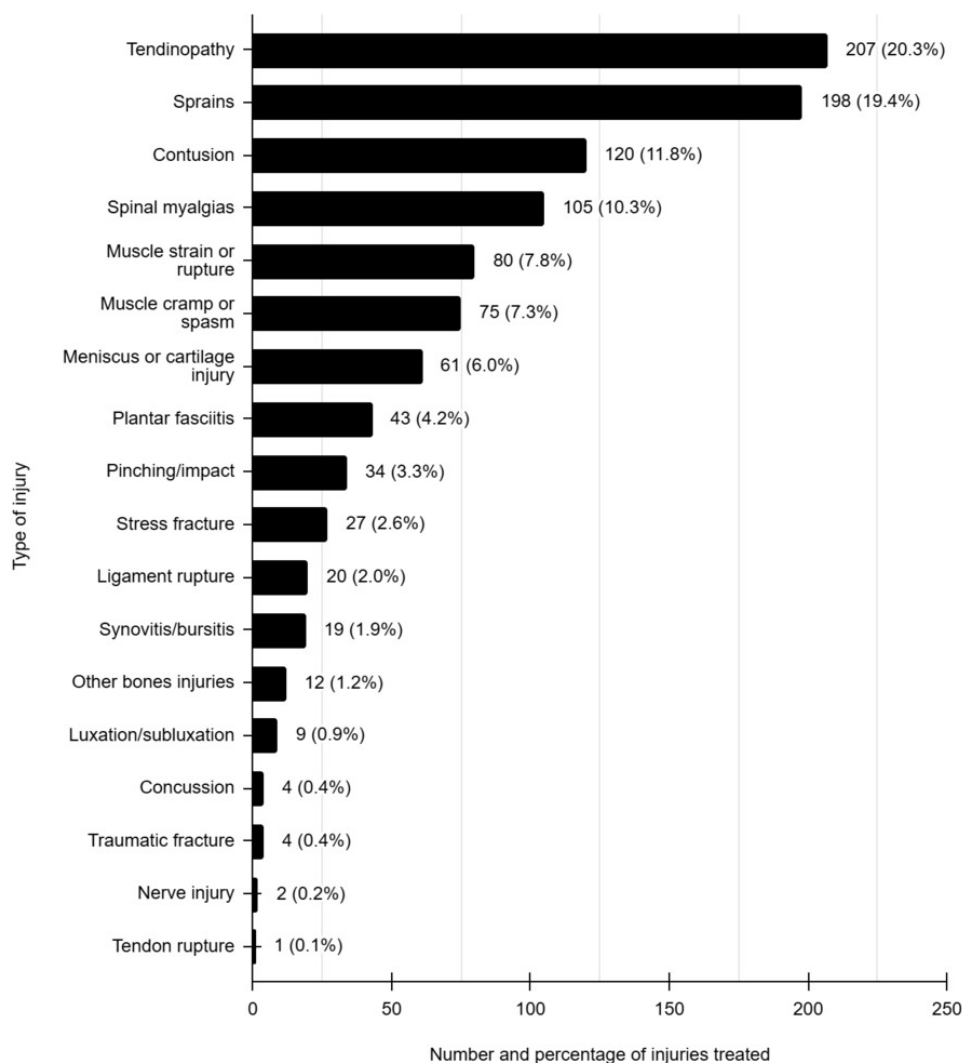


Figure 5. Number and percentage of injuries treated by the Department of Physiotherapy during the Rio 2016 Olympic Games.

letes, such as judo, boxing and wrestling, and in weightlifting athletes. Taken together, these data are quite similar to those obtained in the present study, since tendinopathy was the most frequent injury, with judo athletes being the ones who most sought care at the physiotherapy service, and the shoulder being the most affected anatomical region.

During major sports competitions, there is usually a greater demand for medical care to focus on symptoms and handling of injuries, in order to ensure the athlete's prompt recovery and the return to competition as quickly as possible. The types of treatment most used in the physiotherapy service were manual therapy, electrothermal/phototherapy resources and kinesiotherapy. The physiotherapists who provided care at the BOC had training, qualifications, and professional experience in manual therapy, but it is important to point out that during the 2007 Pan American Games, the most commonly used methods for treatment of Brazilian athletes were exercise (kinesio-

therapy) (24.9%) and ultrasound (19.4%).⁹ In London 2012, the most commonly used resources were massage (23.3%), ultrasound (12.2%) and cryotherapy (10.6%).¹³ A recent study using data from all athletes who participated in Rio 2016 showed that the most commonly used treatments were manual therapy (40%) followed by electrotherapy (36%).¹⁴ The differences in the therapeutic resources used reflect the changes that have been made over time, seeking to use more modern and less invasive recovery techniques. It's important to note that the physical therapists in the Brazilian delegation had different backgrounds and skills, so no specific type of manual therapy was used. Each professional used the technique they deemed most appropriate for each treatment.

Isometric exercises are indicated for the treatment of all athletes who presented tendinopathy as a pathology but are considered a long-term intervention. However, during the Olympic Games, athletes typically do not remain at the competition venue for the entire duration of the event. In

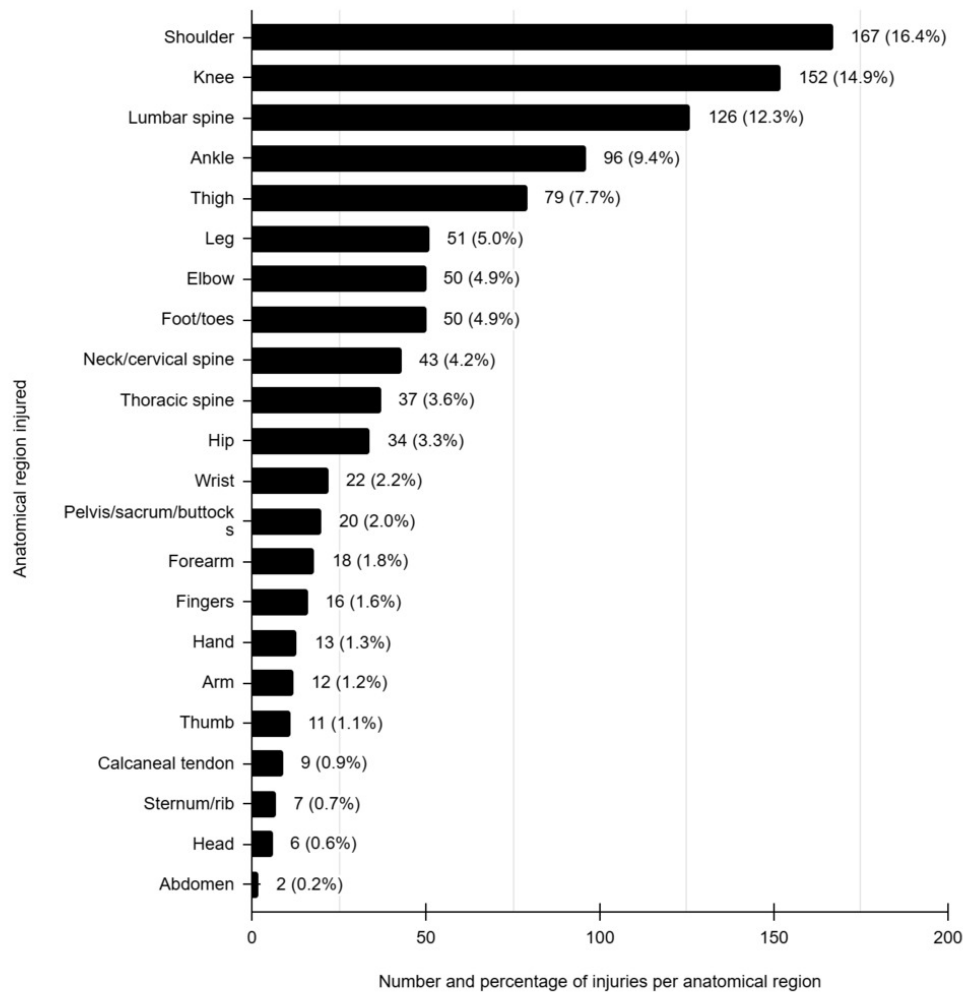


Figure 6. Number and percentage distribution of injuries by anatomical area.

practice, athletes remain at the venue according to the calendar of the sport in which they will compete, that is, they arrive at the start of the event and when their participation comes to an end, they return to their home country of origin. Thus, athletes are guided to perform isometric exercises and undergo long-term treatment to conform with best practices. However, short-term measures are utilized to minimize the athlete's pain so that they can compete in the Olympic Games. Long-term treatment is expected to be undertaken by the athlete upon return to their home institution. Isometric exercises were counted as part of kinesiotherapy.

A methodological limitation of this study may be related to the assessment form. This form was filled out by medical professionals who, despite the training received, may have made mistakes during completion, presenting inaccuracies. In the future, studies should present an independent evaluator who records the procedures performed in order to have an impartial opinion in order to eliminate possible distortions.

Physiotherapy care is rarely the main focus of articles published on injuries in elite athletes at the Olympic

Games.²⁶ Typically, these studies focus on anatomical location, incidence, and types of injuries. The challenge for physiotherapists is therefore to determine how these data can be used to choose, among the range of available resources, which should be used in practice during these events to obtain the most effective results.

Accumulated evidence indicates that injuries vary substantially between different sports, demonstrating the need to adapt preventive measures to the context of each sport. An event such as the Olympic Games provides a unique sporting competition environment from which valuable information can be obtained about the injuries suffered by elite athletes who are at the peak of their physical and sporting development. Injury data can assist in planning health care before and during the event season. The mechanisms of injury occurrence and the risk factors associated with each Olympic modality should be analyzed in future studies for the development of effective prevention or mitigation strategies, as well as to optimize the diagnosis, treatment, and recovery of athletes during the various sporting events.

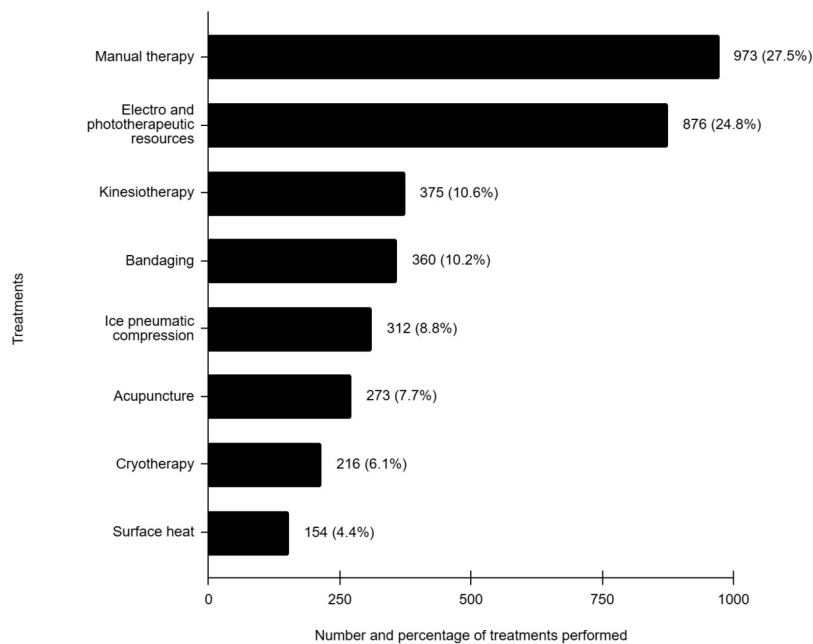


Figure 7. Number and percentage of physiotherapy procedures used to treat athletes during the Rio 2016 Olympic Games.

CONCLUSIONS

The results of this study indicate that 90.7% of the Brazilian athletes ($n=422$) who took part in the Rio 2016 Olympic Games sought care at the physiotherapy department. Judo, handball, artistic gymnastics, and basketball were the sports that most utilized physiotherapy services the most. The most commonly treated injuries were tendinopathies, sprains, contusions, and spinal injuries. The shoulder, knee, lumbar spine, and ankle were the anatomical regions

most affected by injuries. The most frequent treatment procedures utilized by the physiotherapy service were manual therapy, electrophototherapeutic resources, and exercise (kinesiotherapy).

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Original Research

Test-retest Reliability of Biomechanical Measures and Clinical Pain Outcomes in Runners with Medial Tibial Stress Syndrome (MTSS)

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Keywords: reliability, shin splint, runner, center of pressure, pain

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Background

Medial tibial stress syndrome (MTSS) is a common overuse injury in runners, leading to pain and reduced training capacity. Reliable assessment of biomechanical and clinical outcomes is essential to distinguish true clinical change from measurement error and for guiding rehabilitation and return-to-running decisions. However, evidence for the reliability of commonly used measures in MTSS is limited.

Purpose

To determine the test-retest reliability and minimal detectable change (MDC) of common biomechanical and clinical outcomes in runners with MTSS.

Study design

Test-retest reliability study.

Methods

Twenty-two runners with MTSS were assessed twice, three days apart, by the same examiner. Biomechanical outcomes included center of pressure (COP) trajectory during running and cross-sectional area (CSA) and strength of the flexor hallucis longus (FHL) muscle. Clinical outcomes included linear pain distance on palpation along the posteromedial tibial border, and pain level reported using a visual analog scale (VAS). Paired t-tests were used to analyze the differences between sessions. Intraclass correlation coefficients ($ICC_{3,k}$) were calculated to assess reliability. The standard error of measurement (SEM), the MDC and the Bland-Altman plot were calculated.

Results

No significant differences between sessions were observed for any outcome. Test-retest reliability was good to excellent for COP ($ICC_{3,1}=0.92$), linear pain distance on palpation along the posteromedial tibial border ($ICC_{3,1}=0.94$), CSA ($ICC_{3,3}=0.82$), and FHL strength ($ICC_{3,3}=0.88$). SEM and MDC value were 0.86% and 2.38% for COP, 0.77 cm and 2.12 cm for linear pain distance on palpation along the posteromedial tibial border, 0.23 cm² and 0.63 cm² for CSA, and 0.54 kg and 1.49 kg for FHL strength. The Bland-Altman plot shows the agreement of all variables.

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Conclusion

Common biomechanical and clinical outcomes in runner with MTSS demonstrated good to excellent test-retest reliability. The established MDC values provide reference thresholds for interpreting meaningful change and support evidence-based rehabilitation and return-to-running protocols.

Level of evidence

Level 3

INTRODUCTION

Medial tibial stress syndrome (MTSS), commonly known as shin splints, is one of the most prevalent running-related injuries (RRIs) affecting both recreational and competitive runners.¹ Studies indicate that incidence rates of MTSS were ranging from 13.6% to 20% and found the proportion of injuries prevalence 9.1% of all running injuries with higher prevalence rates reported RRIs among novice runners.^{2–4} The condition significantly impacts training continuity and athletic performance, often leading to prolonged periods of reduced activity or complete cessation of training.^{5,6}

The biomechanical etiology of MTSS remains complex and multifactorial. Current evidence suggests that excessive foot pronation during the stance phase of running, combined with altered neuromuscular control of the lower limb, contributes significantly to its development.^{7,8} While foot pronation is a normal motion that facilitates shock absorption, surfaces adaptation, and load transfer during gait and running,^{9,10} abnormal or excessive foot pronation during mid-stance generates increased traction forces on the tibial periosteum during push-off, potentially causing periosteal inflammation which results in pain along the distal posteromedial tibia.^{7,8,11–13} Alterations in muscle function, particularly of the ankle plantar flexors and intrinsic foot muscles, further compound this mechanical stress.^{12,13}

Other biomechanical parameters have been implicated in the development of MTSS. Excessive rearfoot eversion has been associated with altered plantar pressure distribution and impaired load transfer.¹⁴ In addition, runners with MTSS demonstrate a greater medial shift of the center of pressure (COP) trajectory during stance compared with healthy controls,^{15,16} reduced cross-sectional area (CSA) of the flexor hallucis longus (FHL) muscle,¹⁷ and diminished FHL strength.^{18,19} Clinical pain outcomes also include pain patterns localized to the distal two-thirds of the posteromedial tibial border.^{11,12} Additionally, alterations in the structure and function of the FHL muscle have been observed in individuals with MTSS, suggesting their role in both the onset and persistence of symptoms.¹⁹

While these biomechanical parameters appear clinically relevant, their reliable measurement remains challenging in clinical settings. Current assessment methods vary widely, from sophisticated laboratory equipment to simple clinical tests.^{11,20} Advanced tools such as insole pressure equipment,¹⁶ force plate systems¹⁵ and magnetic resonance imaging (MRI)^{21,22} provide detailed and precise data, their practical application is often limited by cost and accessibility. Given the need for reliable and clinically feasible

measurement tools, single force plate systems present an economical and promising approach for assessing center of pressure parameters that can be readily implemented in various healthcare settings compared to laboratory-based multi-plate or motion capture systems. Despite the importance of these measures for understanding MTSS and monitoring treatment outcomes, there is limited evidence regarding their measurement properties, particularly in terms of reliability. The current review found no relevant studies that specifically investigated the reliability of these measurements in individuals with MTSS. This gap in knowledge makes it difficult for clinicians to confidently use these measurements in diagnosis, treatment planning, and outcome assessment.

Therefore, this study aimed to determine the test–retest reliability and minimal detectable change (MDC) of common biomechanical and clinical outcomes in runners with MTSS. Establishing the reliability of these measurements is essential for developing evidence-based assessment protocols and enabling more effective monitoring of treatment outcomes in this population.

MATERIALS AND METHODS

A reliability study was conducted in runners with MTSS. The sample size was determined using intraclass correlation coefficients (ICC) with an expected reliability of 0.75 and a dropout rate of 20%.²³ Based on these parameters, a minimum of 22 participants was required. This study is part of a larger research project that was approved by the Khon Kaen University Ethics Committee in Human Research, Khon Kaen, Thailand. (Reference No. HE662132), the Mae Fah Luang University Ethics Committee on Human Research, Mae Fah Luang University, Chiang Rai, Thailand (Protocol No. EC 23230-25) and registered Thai clinical trials number TCTR20230601008.

PARTICIPANTS

A total of twenty-two participants were recruited for this study. All participants were evaluated by a licensed physical therapist using a history-taking protocol and physical examination for the diagnosis of MTSS.¹¹ The inclusion criteria were: age between 18 and 55 years; pain localized to the distal half of the posteromedial tibial border with a minimum length of 5 cm; exercise-induced pain; and pain during running rated between 4 and 7 on the Visual Analog Scale (VAS), with symptoms persisting for at least three weeks. Additional criteria included a body mass index (BMI)

$\leq 30 \text{ kg/m}^2$, a minimum of three months of running experience, and a running frequency of at least two sessions per week for 45 minutes or a minimum of 10 km. per week, but not exceeding 100 km. per week. Exclusion criteria were neurological disorders; lower limb or spinal injuries within the prior three months; a history of seizures or pacemaker use; chronic disease or stroke; pregnancy or breastfeeding; and rigid flatfoot. All participants received a comprehensive explanation of the study procedures and provided written informed consent prior to enrollment.

PROCEDURE

Test-retest (intra-rater) reliability was assessed by two licensed physiotherapists (PN and ES), each with at least five years of experience in musculoskeletal physical therapy. To ensure blinding, data from the two testing sessions were recorded on separate data sheets by a research assistant (WC). Both assessors were thoroughly familiarized with the testing protocol prior to data collection. Participants were evaluated for pain level and all outcome measures on two separate days with a three-day interval between sessions, during which they maintained their normal daily activities.^{24,25} All assessments were conducted on the affected limb. For participants with bilateral symptoms, the dominant leg was designated as the test limb for data analysis. All measurements followed a consistent sequence with a standardized 5-minute rest period between each test. The assessment protocol included: (1) center of pressure (COP) trajectory during running (completed by PN), (2) linear pain distance on palpation along the posteromedial tibial border (completed by ES), (3) cross-sectional area (CSA) of the flexor hallucis longus (FHL) muscle (completed by PN), and (4) FHL muscle strength (completed by ES). This sequence was maintained across both testing sessions for all participants.

OUTCOMES MEASUREMENT

CENTER OF PRESSURE (COP) TRAJECTORY DURING RUNNING

The COP trajectory was measured using a force distribution measurement system (Zebris FDM-S Medical GmbH, Germany), dimension 69 x 40 x 2.1 cm. (L x W x H) with 2,560 sensors. To prevent the participants from triggering the sensors, the non-active white area of the plate, which contains no sensors, was covered with black masking tape. The force distribution measurement system was positioned at the center of a 12-meter runway constructed from black rubber foam board, which was securely fixed to a non-slip floor to ensure stability and protect against sway (Figure 1).

The COP trajectory was measured once during the stance of the affected foot. Subjects ran barefoot at a jogging velocity of $3.3 \pm 0.16 \text{ m/s}$ along the runway, monitored by a stopwatch, yielding a finishing time range of 3.14 to 3.46 seconds.¹⁵ Since the dimensions of the force distribution measurement system were suitable for only one stance foot, participants were asked to run along the runway twice to fa-

miliarize themselves with the setup and adjust their stride length to ensure that the expected foot would be placed on the force distribution measurement system during running. Participants started at the starting line, and the rater calibrated the force distribution measurement system program before each trial. The rater then initiated the test by pressing the start button and giving the command, "Ready, set, go." After the participants completed the run and their stance foot was placed on the force distribution measurement system, the rater pressed the stop button to conclude the trial.

The COP path image was exported from the Zebris software program, and the COP shift was defined using Adobe Illustrator (Adobe, Inc., San Jose, CA). The shift was measured from the most medial to the most lateral point in millimeters and then divided by the maximum foot width, multiplied by 100, to express the result as a percentage of transverse shift (%transverse) (Figure 2). A lower percentage of transverse shift indicates a more medial shift of the COP under the foot.¹⁶

LINEAR PAIN DISTANCE ON PALPATION ALONG THE POSTEROMEDIAL TIBIAL BORDER

Participants were assessed in the supine position. The assessor flexed the affected knee and allowed the lower leg to relax. The assessor then palpated the area of diffuse pain, starting from the medial malleolus and extending along the distal two-thirds of the posteromedial lower leg, following the posteromedial border of the tibia. The first pain point was identified and marked, then the assessor continued to palpate along the medial tibial border. The subject was asked to indicate the point where pain was no longer present, and this endpoint was marked. Palpation was performed once following the clinical test protocol, and linear pain distance was measured using a tape measure and recorded in centimeters.²⁰

CROSS-SECTIONAL AREA (CSA) OF THE FLEXOR HALLUCIS LONGUS

The CSA of the flexor hallucis longus (FHL) was measured by ultrasound imaging with a 12 MHz linear transducer (Toshiba Famio 30, Toshiba Medical Systems Corporation, Japan). Participants were evaluated in a prone position with the affected foot over the edge of the table. The rater measured their lower leg length from the mid-point between the medial and lateral epicondyle of the femur to the center of the heel at the edge of the calcaneus and marked the midpoint of the calf. The ultrasound probe was placed on the transverse axis at the mid-calf lateral to the fibula.^{26, 27} Participants were instructed to flex their great toe at the distal phalanx to assist the rater in localizing the FHL muscle. The CSA was measured in square centimeters (cm^2) using the trace function of the ultrasound imaging machine. This test was performed three trials, with all markers removed and a 2-minute interval between trials. The mean of the three measurements was recorded and analyzed.

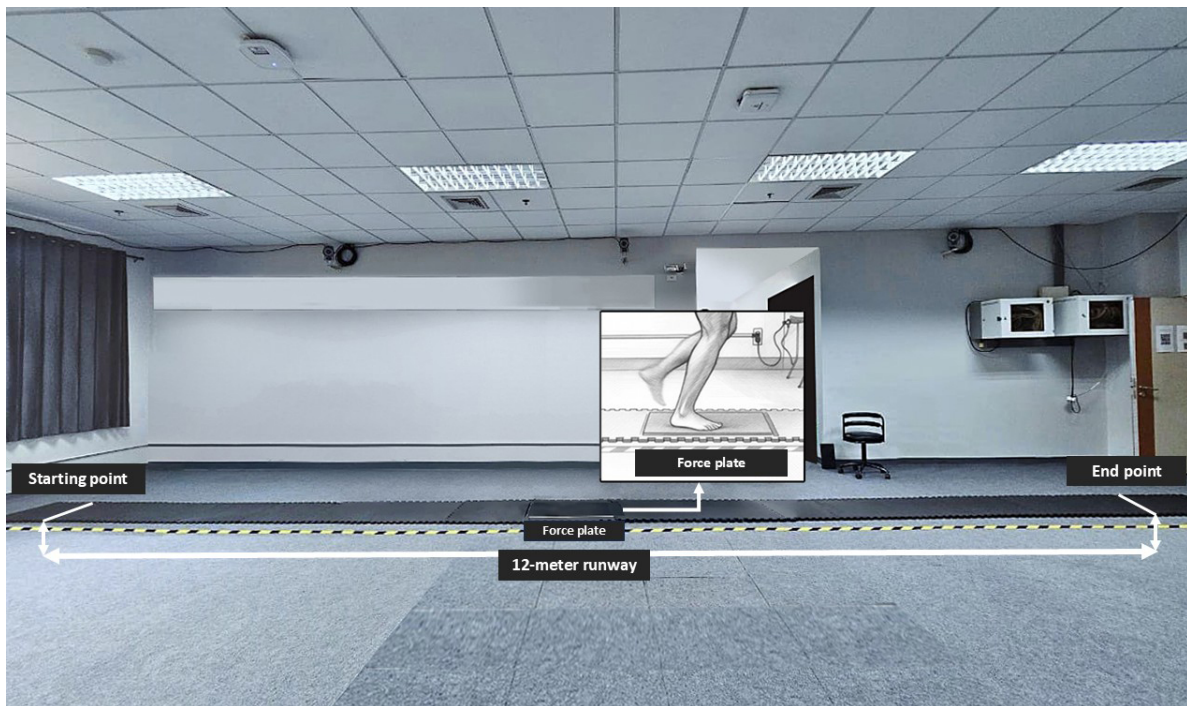


Figure 1. Center of pressure (COP) trajectory during running measured by the force distribution measurement system placed in the middle of the 12-meter runway setting.

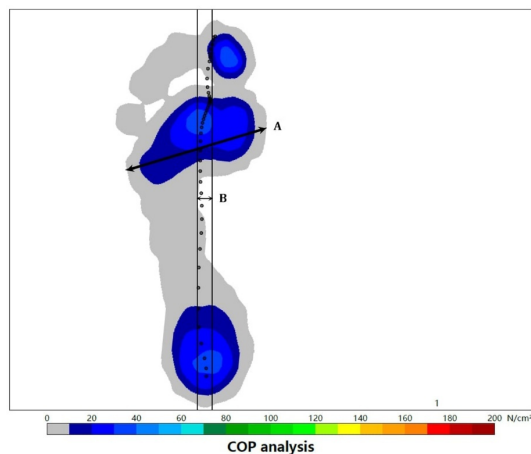


Figure 2. Center of pressure (COP) trajectory during running.

A) the maximum foot width in millimeters; B) the width of the COP trajectory measured by the most medial to the most lateral point in millimeters; COP calculated by $(B/A) \times 100$ reported in the percentage of transverse shift (%transverse).

FLEXOR HALLUCIS LONGUS (FHL) MUSCLE STRENGTH

Participants were assessed in the supine position. The rater measured the FHL muscle strength using the maximal voluntary contraction (MVC) technique. Participants were asked to flex and push their great toe at the distal phalanx against the padded curve of a hand-held dynamometer (The Baseline® hydraulic push-pull dynamometer, Fabrication Enterprises Inc., USA) with maximal force. To minimize movement from the ankle and other toes, the rater positioned the participant's heel at the edge of the table and

provided passive movement and guidance as needed to ensure correct positioning before starting the test. The rater then instructed the participant to "Start" and encouraged them to push with their maximum force for 5 seconds. The test was performed in 3 trials, and rested for a 15-second rest between trials.¹⁸ The strength was recorded in kilograms (kg.) and the average force values from sessional three trials were analyzed.

DATA ANALYSIS

Data analyses were conducted using software SPSS version 29 (IBM Corp, Armonk, NY, USA.). The Shapiro-Wilk test was used to assess the data normal distribution. Descriptive statistics were used to describe the subject characteristics, including means and standard deviations for the continuous variables and number or percentage for the categorical variables. The paired t-test was used to analyze the differences of each measurement between two sessions of assessment, with the significance different level as p-value < 0.05. Intraclass correlation coefficients ($ICC_{3,k}$) with 95% confidence intervals were calculated with a two-way mixed effects model, absolute agreement for test-retest reliability.²⁴ The ICCs values were indicated as poor (<0.5), moderate (0.5 - 0.75), good (0.75 - 0.90) and excellent (0.91 - 1.00).²⁸

The standard error of measurement (SEM) reflects the variability within subjects across repeated measurements in a group of individuals.²⁹ SEM was calculated using the pooled standard deviation of two sessions $(SD \text{ pooled}) \times \sqrt{1 - ICC}$. The minimal detectable change (MDC) is the minimal change that, beyond measurement error, indicates a true change for an individual and was calculated by $1.96 \times SEM \times \sqrt{2}$. The Bland-Altman plot determined the levels

Table 1. Characteristics of participants (n=22)

Characteristics	Mean (% or SD)
Gender	
Female, n (%)	18 (81.82%)
Male, n (%)	4 (18.18%)
Affected side	
Left, n (%)	11 (50%)
Right, n (%)	11 (50%)
Age (year)	25.73 (7.01)
Weight (kg.)	60.50 (9.24)
Height (cm.)	162.50 (6.40)
Body mass index (kg/m ²)	22.83 (2.56)
MTSS pain duration (days)	48.64 (20.94)
Run information	
Frequency (sessions/week)	3.32 (0.65)
Duration (minutes/session)	51.14 (14.88)
Distance (km./session)	5.09 (1.87)
Average distance (km./week)	14.77 (6.43)

n= number; SD= standard deviation; kg= kilograms; cm= centimeters; kg/m²= kilograms per meters square; km= kilometers

of agreement for test-retest measurements. The limits of agreement were calculated for the lower bound, which was mean difference - (1.96 x standard deviation of difference), and the upper bound, which was mean of difference + (1.96 x standard deviation of difference).³⁰ Data was interpreted as 95% of the data points should be within $\pm 2SD$ of the mean difference.

RESULTS

CHARACTERISTICS OF PARTICIPANTS

Twenty-two participants completed the study protocol, including 18 females (81.82%) and four males (18.18%), with a mean age of 25.73 $\pm$ 7.01 years. The mean duration of pain symptoms was 48.64 $\pm$ 20.94 days. The characteristics and running information of all participants are presented in [Table 1](#). The pain level was assessed using the visual analog scale (VAS) and all outcomes from separate measurement days were analyzed using paired t-test, which showed no significant differences (p-value > 0.05) as reported in [Table 2](#).

TEST-RETEST RELIABILITY

The test-retest (intra-rater) reliability was good to excellent, with ICC ranging from 0.82 to 0.94. Outcomes with excellent test-retest reliability included the COP (ICC_{3,1}=0.92) and linear pain distance on palpation along the posteromedial tibial border (ICC_{3,1}=0.94). Outcomes with good reliability included CSA of the FHL (ICC_{3,3}=0.82) and FHL strength (ICC_{3,3}=0.88).

The SEM and MDC for each outcome were as follows; COP at 0.86% and 2.38%, linear pain distance on palpation along the posteromedial tibial border at 0.77 cm and 2.12 cm, CSA of the FHL at 0.23 cm² and 0.63 cm², and FHL strength at 0.54 kg and 1.49 kg, respectively. Test-retest re-

liability results including ICC, SEM and MDC are presented in [Table 3](#).

The Bland-Altman plot shows the mean difference and 95% of the data points were within $\pm 2SD$ of the mean difference for all outcomes ([Figure 3](#)).

DISCUSSION

This study evaluated the test-retest reliability of common biomechanical and clinical outcomes related to the biomechanical etiology of MTSS in runners, including the center of pressure (COP) trajectory during running, linear pain distance on palpation along the posteromedial tibial border, cross-sectional area (CSA), the strength of the flexor hallucis longus (FHL) muscle, and calculated the MDC variables for these measurements in runners with MTSS. The intraclass correlation coefficients (ICCs) ranged from good to excellent (ICC 0.82 - 0.94). The reliability established in this study supports the clinical utility of these biomechanical measurements in MTSS assessment and management.

This study utilized a custom-setting sensor force distribution measurement system placed at the center of the 12-meter runway to assess the COP trajectory during running in MTSS. The COP was calculated as the percentage of transverse shift, and found the excellent reliability ICC value of 0.92. The COP under the foot variables were evaluated in previous studies with different methods.^{16,31,32} Kinoshita et al.¹⁶ evaluated the COP outcomes based on biomechanical problems of MTSS, specifically COP shifting, using the percentage of transverse shift of the COP but did not report the reliability. While no reliability data have been reported for COP measurements in MTSS cases, previous studies have documented the reliability of COP measurements under the foot using force distribution measurement sensors. Lynall et al.³³ assessed the COP path under foot during walking in healthy subject using the force plates (Bertec Corp., Columbus, OH) embedded in a 6-meter walkway with five days between measurements. They reported

Table 2. Comparison of measurements between sessions.

Variables	T 1 Mean (SD)	T 2 Mean (SD)	Mean differences (95%CI)	p- value
VAS (cm.)	4.74 (0.96)	4.70 (0.91)	0.04 (-0.13, 0.21)	0.62
COP (%transverse)	13.35 (2.89)	13.47 (2.98)	-0.13 (-0.87, 0.62)	0.73
Linear pain distance on palpation along the posteromedial tibial border (cm.)	8.80 (3.16)	8.73 (3.31)	0.07 (-0.60, 0.75)	0.83
CSA of the FHL (cm ²)	3.82 (0.57)	3.86 (0.51)	-0.04 (-0.23, 0.15)	0.66
FHL strength (kg.)	4.77 (1.48)	4.92 (1.55)	-0.15 (-0.61, 0.30)	0.49

VAS= pain level using a Visual Analog Scale; COP= center of pressure, %transverse= percentage transverse shift of the COP trajectory during running; cm= centimeters; CSA= cross-sectional area; cm²= centimeters square; FHL= Flexor hallucis longus muscle; kg= kilograms; T1= the first measurement; T2= the second measurement on 3 days interval between session; SD= standard deviation; CI= confidence interval

Table 3. Test-retest reliability analysis for biomechanics outcomes.

Variables	T1 Mean (SD)	T2 Mean (SD)	ICC (95%CI)	SEM	MDC
COP (%transverse) (ICC _{3,1})	13.35 (2.89)	13.47 (2.98)	0.92* (0.80, 0.97)	0.86	2.38
Linear pain distance on palpation along the posteromedial tibial border (cm.) (ICC _{3,1})	8.80 (3.16)	8.73 (3.31)	0.94* (0.86, 0.98)	0.77	2.12
CSA of the FHL (cm ²) (ICC _{3,3})	3.82 (0.57)	3.86 (0.51)	0.82† (0.57, 0.93)	0.23	0.63
FHL strength (kg.) (ICC _{3,3})	4.77 (1.48)	4.92 (1.55)	0.88† (0.70, 0.95)	0.54	1.49

COP= center of pressure; %transverse= percentage transverse shift of the COP trajectory during running; cm= centimeters; CSA= cross-sectional area; cm²= centimeters square; FHL= Flexor hallucis longus muscle; kg= kilograms; T1= the first measurement; T2= the second measurement on 3 days interval between session; SD= standard deviation; ICC= intraclass correlation coefficient; CI= confidence interval; SEM= standard error of measurement; MDC= minimal detectable change; *Excellent, †Good.

good to excellent reliability with ICC ranging from 0.89 to 0.95. In this previous study, the test was repeated if participants failed to place their foot on the force plates correctly similarly to this current study. However, in the current study, participants were asked to practice twice before start the test to estimate their step length, with the goal of minimizing the need for repeated trials. Although different tasks and devices were used in this study, the sensor force distribution measurement system employed was similar to those used in previous studies examining COP in cases of MTSS. The high reliability of COP measurements observed in this study supports their utility in assessing foot biomechanics and guiding program interventions. To improve ecological validity, COP may also be evaluated under shod conditions, as footwear alters foot mechanics.³⁴

The palpable linear pain distance at the posteromedial tibial border was the essential criterion for diagnosing the MTSS.^{11,35} Previous studies using the difference technique to measure the pain along the posteromedial border of the tibia using the algometer pressing technique found moderate to excellent intra-rater reliability (ICC 0.53-0.90) in asymptomatic runners.³⁶ Newman et al.²⁰ determined the predicted onset of MTSS and found that the clinical test

shin palpation test (SPT) is related to the condition of MTSS. In the present study, the technique applied followed the SPT to measure the actual distance of pain as confirmed by the subjects to diagnose and define the linear pain distance on palpation along the posteromedial tibial border. The results showed an excellent test-retest reliability ICC value of 0.94. No previous studies have reported the reliability of this method; however, the pain palpation following the SPT indicated the same area of crural fascia attachment associated with MTSS lesion, suggesting its suitability for this technique.³⁷ The reliability of linear pain distance on palpation along the posteromedial tibial border measurement confirms its value as a diagnostic and monitoring tool, enabling clinicians to document and track symptoms objectively.

The FHL contributes to stabilizing the longitudinal arch of the foot. It originates from the distal two-thirds of the posterior surface of the fibula and passing along the intermuscular septum and deep crural fascia within the posterior compartment of the lower leg where traction-induced periostitis associated with MTSS typically occur during the push-off phase of running.³⁸ Mattock et al.¹⁹ investigated lower leg muscle structure in runners with MTSS and found

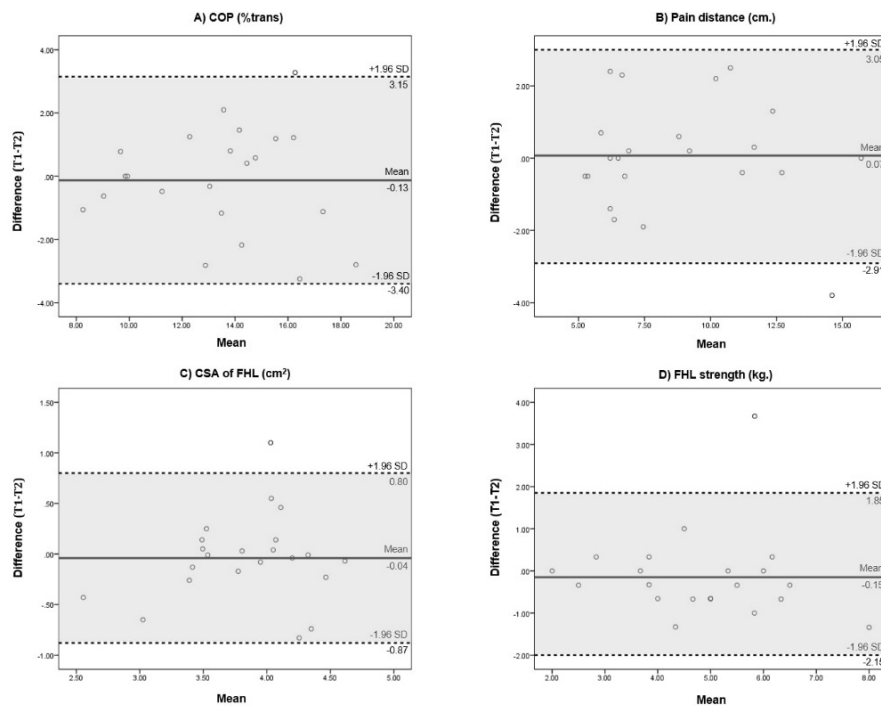


Figure 3. Bland-Altman analysis for test-retest measurement.

A) The center of pressure (COP) trajectory during running; B) Linear pain distance on palpation along the posteromedial tibial border; C) Cross-sectional area of flexor hallucis longus (CSA of FHL); D) Flexor hallucis longus muscle strength (FHL strength); Dots indicated the differences between measurements plotted against their mean; Solid line indicated the mean difference between measurements; Dashed line and shaded area indicated 95% limits of agreement (mean difference $\pm$ 1.96 x standard deviation of difference)

the CSA of FHL was smaller in MTSS leg compared to the asymptomatic leg prior to collecting data, the assessor conducted a reliability test, which reported high reliability for CSA measurement (ICC = 0.93). Previous study on healthy individuals have reported excellent inter-rater reliability for measuring CSA of FHL muscle with ICC of 0.91.³⁹ Moreover, Mickle et al.²⁵ demonstrated the reliability of ultrasound imaging for assessing the CSA of FHL muscle in healthy adult located two anatomical locations at 40% and 50% of the lower leg length from the medial malleolus to the tibial condyle reporting ICC value of 0.92 and 0.98, respectively. In the present study, the measurement was applied at the mid-calf that approximately 50% of the lower leg length, and showed good test-retest reliability ICC value of 0.82 that supporting the reliability of this probe location for evaluating the CSA of FHL muscle.

FHL strength has been identified as a factor related to MTSS. A previous study reported reduced strength in the symptomatic leg of MTSS runners evaluated by a hand-held dynamometer.¹⁹ Although this study demonstrated acceptable reliability for lower leg strength (ICC > 0.78), it did not report specific reliability data of FHL strength.¹⁹ There is no study have reported the reliability of FHL strength measurements using a hand-held dynamometer in runners with MTSS. However, FHL strength has been reported intra-rater reliability in healthy active adults using different protocol and models of hand-held dynamometers, researchers found ICC ranged from 0.68 to 0.92, indicating good to excellent reliability.⁴⁰ Another study, which measured great toe flexor muscle strength using the intrinsic foot dynamometer, also reported good to excellent intra-rater reliability,

with ICC values ranging from 0.86 to 0.87.⁴¹ The present study found good intra-rater reliability for FHL strength, with an ICC value of 0.88, which is consistent with the reliability values reported in previous studies.⁴¹ This suggests that the current protocol provides reliable parameters for rehabilitation planning and monitoring progression in MTSS cases.

The reported MDC values provide clear thresholds for identifying clinically significant changes, while the SEM values assist in interpreting measurements. Currently, there are no published reports specifying the values for tests used for MTSS. This study employed standardized and reliable measurements using readily accessible clinical equipment, enabling evidence-based assessment and treatment monitoring for runners with MTSS.

A strength of this study is that participants were assessed for baseline variables prior to each testing session, with no significant differences found in pain level and all outcomes between sessions, indicating that symptoms remained stable across both days. Participants also maintained their usual daily routines, reducing the influence of external factors during the rest period between sessions. Additionally, the experienced raters underwent protocol familiarization prior to testing, and a research assistant recorded the data to maintain assessor blinding of recorded values across sessions.

LIMITATIONS

This study has some limitations to consider. First, the sample consisted exclusively of recreational runners with

MTSS, which limits the generalizability of the findings to other populations such as long-distance or competitive athletes, whose running mechanics and biomechanical demands may differ substantially. Consequently, these results may not be directly applicable to high-performance runners. Future research should evaluate these assessment protocols across diverse athletic populations with varying training volumes. Second, all assessments were performed by experienced raters who were highly familiar with the testing procedures. To ensure consistent reliability in clinical and research settings, novice assessors should undergo structured training and supervision before independently applying these protocols.

CONCLUSION

The biomechanical measures and clinical pain outcomes demonstrated good to excellent reliability including COP trajectory during running ($ICC_{3,1} = 0.92$), linear pain distance on palpation along the posteromedial tibial border ($ICC_{3,1} = 0.94$), FHL CSA ($ICC_{3,3} = 0.82$), and FHL strength ($ICC_{3,3} = 0.88$) with established test-retest protocols. These findings provide clinically relevant reference values for minimal detectable change and standard error of measurement that distinguish true clinical changes from measurement variability. The assessment protocols offer reliable, clinically feasible tools for monitoring rehabilitation progress and evaluating intervention effectiveness in recreational runners with medial tibial stress syndrome. Future research should explore applying these protocols across di-

verse clinical settings and evaluate their sensitivity to change following various interventions.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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Clinical Commentary/Current Concept Review

Brisement Injection with Physical Therapy: A Novel Approach to Managing Glenohumeral Joint Osteoarthritis

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Glenohumeral osteoarthritis (GHOA) presents significant challenges for patients, often resulting in debilitating pain, stiffness, and progressive loss of function. While conventional non-operative treatments such as physical therapy, medications, and corticosteroid injections can provide relief, their benefits may diminish over time. For many patients, total shoulder arthroplasty may not be a viable option due to associated risks or the demands of an extensive recovery process. This leaves a critical need for alternative innovative and effective treatment options. The synergistic pairing of brisement and PT aims to improve range of motion, reduce pain, and enhance strength and function. This approach has the potential to fill gaps in the current treatment landscape for GHOA. The purpose of this clinical commentary is to introduce a novel treatment approach combining brisement, an ultrasound-guided hydrodilatation procedure, with a structured physical therapy program to manage GHOA.

INTRODUCTION

Osteoarthritis (OA) is an increasingly prevalent disease, leading to disabling pain, functional impairment, and deformity. In 2019, OA affected 527.8 million people worldwide, with 41.5 million incident cases, an almost 50% increase since 1990.¹ The number of people with symptomatic OA is proportionally higher in countries with developed market economies and rising rates of obesity, such as the United States. There is also a substantial economic burden placed on health systems due to greater utilization of government sponsored services and years of work lost. This strain is only anticipated to grow as the American population ages.²⁻⁴ Reduced health-related quality of life including impact on mental health, general health, and sleep are widely recognized sequelae associated

with pain and loss of physical activity in persons with OA.^{2,4,5}

When focusing on the shoulder joint, it is difficult to ascertain the true epidemiology of glenohumeral OA (GHOA) in the United States due to lack of population-based reports. Studies performed within the past two decades estimate a wide range of prevalence, from 5-21%⁶⁻⁸ depending on geographic population. Despite the limited understanding of GHOA prevalence, the rising number of shoulder arthroplasties suggests an increase in symptomatic disease.⁹⁻¹¹

Options for management of GHOA continue to evolve as the complex pathogenesis becomes better understood. Degeneration of the interfacing articular cartilage and underlying subchondral bone, along with inflammation, scarring, and thickening of the richly innervated synovial capsule and surrounding soft tissue, act as noxious stimuli and contribute to mechanical limitations.^{3,12}

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Conventional conservative treatments are categorized into non-pharmacologic and pharmacologic modalities, often used synchronously to achieve maximal benefit.¹³⁻¹⁵ A widely accepted clinical recommendation includes a well-planned, structured strengthening and range of motion (ROM) program implemented under therapist guidance. In combination with systemic medications or intra-articular injections to disrupt the inflammatory process, improvements in symptoms and function can be achieved.¹⁶

However, with refractory disease, patients and their care team are left to consider alternative pathways. Orthobiologic joint injections including platelet-rich plasma, bone marrow aspirate concentrate (BMAC), and micronized fragmented adipose tissue (mFAT) have promising preliminary outcomes.^{17,18} Due to inconsistency of injectate compositions and remittance that often falls outside of insurance-payer coverage, they may be considered less desirable options.

The brisement procedure, or articular capsule hydrodilatation with an injectate composed of a steroid or anti-inflammatory, local anesthetic, and normal saline or sterile water, has potential to fill the gap as an affordable, low risk alternative which effectively targets OA pain while simultaneously improving ROM. Brisement has been widely applied for the successful treatment of adhesive capsulitis, with superior outcomes when performed in close temporal proximity to mobility interventions by a physical therapist (PT).^{19,20} Mechanistically, the administration of intra-articular steroid paired with disruption of synovial adhesions and capsular thickening, targets pathologic pathways identified in the development of GHOA.²¹ A team-based application of the brisement procedure, consisting of injection and immediate therapy, is proposed within this commentary as a novel, effective, accessible, and low-risk option for treatment of GHOA in the carefully selected patient. The purpose of this clinical commentary is to introduce a novel treatment approach combining brisement, an ultrasound-guided hydrodilatation procedure, with a structured physical therapy program to manage GHOA.

PATHOPHYSIOLOGY OF GHOA AND RATIONALE FOR BRISEMENT WITH PHYSICAL THERAPY

The pathogenesis of OA is complex with cellular and biochemical alterations within the cartilage, bone, synovium, and surrounding soft tissue resulting in joint dysfunction.¹² Cartilage erosion leads to subchondral damage and osteophytic growth. Changes to the synovium are present in both early- and late-stage osteoarthritic disease. Several distinct synovial phenotypes have been identified, characterized by varying degrees of vascularity, inflammatory mediators, hyperplasia, fibrin deposition, and macrophage infiltration. These biologically active metabolites contribute to inflammation, fibrosis and ultimately, mobility restriction.^{21,22} Osteophyte formation and capsular thickening may also be seen in certain patterns of glenoid wear as a compensatory mechanism to splint or immobilize the painful glenohumeral joint (GHJ).²³

Benefits of joint hydrodilatation for management of osteoarthritis have been described as early as 1984. In a triple-blinded RCT of hip capsular distention for OA, pain relief and improvements in ROM were observed for 12 weeks after the procedure.²⁴ While the mechanism for symptomatic improvement is currently unknown, it can be theorized that the physical disruption of the restrictive fibrous tissue along with the modulation of synovium-generated inflammatory processes through volume-mediated capsular stretch and anti-inflammatory injectate, contribute to improved pain and function. To the authors' knowledge, hydrodilatation of the GHJ has not been reported for management of symptomatic OA.

Ultrasound guided suprascapular nerve blocks have been utilized in hydrodilatation procedures for adhesive capsulitis due to the nerve's role in sensory innervation of the GHJ and its accessibility via ultrasound guidance. The decision for regional analgesia is made to improve patient tolerance of the large volume subsequent injection and immediate manipulation.¹⁹

The glenohumeral musculature and non-contractile soft tissue surrounding the GHJ are important stabilizers of the humeral head within the glenoid. They also act as key mobilizers, dependent on strength and flexibility. With GHOA, muscular and soft tissue imbalances cause alterations in kinematics which further contribute to dysfunction.²⁵ Glenoid wear patterns may result in rotation, translation, or subluxation of the humeral head. Changes in muscular recruitment to maintain anatomic movement or avoid painful movement lead to muscle atrophy and soft tissue contracture.²⁶ As outlined in this commentary, the physical therapy program for GHOA used in conjunction with brisement targets these liable tissues. Identification of tonic musculature and management with joint, scapular, and thoracic mobilization is followed by stretching and eventual strengthening. Addressing these external constraints of the GHJ by the PT are critically important for achieving maximal outcomes in ROM after brisement. The role of the PT is not only to address post procedure ROM and function but to identify those patient-specific factors that contributed to development of, or perpetuated, the problem once developed.

PATIENT SELECTION

GHOA has a presentation that, like many arthritic conditions, has a variety of unique features. In selection of a patient who may be a candidate for the brisement procedure, there are several important clinical considerations:

1. Significant glenohumeral degeneration is not an exclusion; however, the procedure should be avoided in patients with concomitant severe cuff arthropathy and those that have more than minimal posterior rim erosion (Type B glenoid wear, [Table 1](#)).
2. Avoidance in patients with active cervical radiculopathy, due to the potential inhibition of GHJ mobility.
3. Avoidance in patients with significant rotator cuff weakness. Ability to actively move the shoulder is required for efficacy of the physical therapy program.

Table 1. Walch Classification of Glenoid Wear in Glenohumeral Osteoarthritis

Walch Classification of Glenoid Wear	
Type A	Concentric wear, no subluxation of HH, well centered A1: no or minor central erosion A2: deeper central erosion, line connects anterior/posterior glenoid rims and transects HH
Type B	Biconcave glenoid, asymmetric glenoid wear and HH subluxated posteriorly B0: pre-osteoarthritic posterior subluxation of HH B1: posterior joint narrowing (no posterior bone loss), osteophytes, subchondral sclerosis B2: posterior rim erosion, retroverted glenoid B3: mono-concave, posterior wear, at least HH subluxation >70% OR retroversion >15 degrees
Type C	C1: Glenoid retroversion >25 degrees, regardless of erosion C2: Biconcave, posterior bone loss, posterior translation of HH
Type D	Glenoid anteversion or anterior HH subluxation <40%

Abbreviations: HH humeral head

*Table adapted from description of glenoid morphology in primary glenohumeral arthritis²⁷

4. Avoidance in patients who have had rotator cuff surgery in the prior six months. The procedure can be considered based upon discussion and clearance with the performing surgeon.

A unique consideration for the application of the brisement procedure in patients with osteoarthritis, as compared to those with adhesive capsulitis, is the potential for bony joint mobility restrictions related to the arthritic process. For this reason, it is recommended to have plain films performed and reviewed by the treating physician at a reasonable interval prior to the brisement procedure. Discomfort should be openly communicated between the patient and therapist during all hands-on treatment.

DESCRIPTION OF BRISEMENT PROCEDURE

SUPRASCAPULAR NERVE BLOCK

First, a suprascapular nerve injection either at the suprascapular notch or at the spinoglenoid notch is performed. This nerve block allows the patient to better tolerate the large volume second injection as well as the post-procedural manual stretching. Typically, a posterior musculoskeletal ultrasound (MSK-US) approach is utilized (Figure 1) to inject 3-5 cc of 1% lidocaine under the transverse ligament surrounding the notch.

POSTERIOR GHJ INJECTION

Next, the GHJ is visualized and injected via MSK-US from an in-plane medial to lateral approach. Once needle placement is confirmed, 20-30 cc total injectate is administered (Figure 2). Typically, the injectate includes 40 mg Triamcinolone, if the patient has a hemoglobin A1c < 8.0, and a mixture of 10-19cc of NS or sterile water and 10 cc Ropivacaine. In the poorly controlled diabetic patient with hemoglobin A1c > 8.0, there is the option to substitute steroid with injection of 30mg – 60 mg of Ketorolac, provided that renal function is preserved.

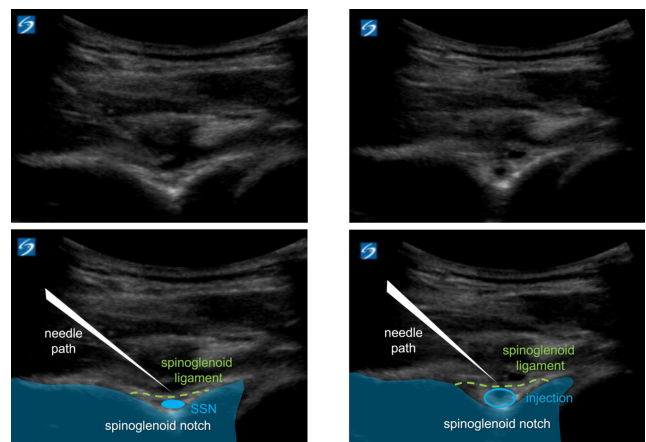


Figure 1. Ultrasound guided suprascapular nerve (SSN) block performed at the spinoglenoid notch via posterior, medial to lateral, in-plane approach; the needle tip is visualized descending towards the SSN (A). Appropriate placement of injectate into the notch results in elevation of the spinoglenoid ligament and SSN (B).

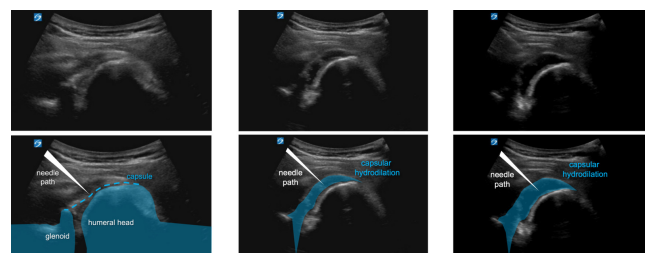


Figure 2. Ultrasound guided glenohumeral joint brisement injection. Posterior, medial to lateral, in-plane approach is utilized, demonstrating needle placement under the joint capsule and subsequent capsular dilatation with injection.

MANUAL THERAPY PROGRAM

PRE-INJECTION

Pre-injection measurements of ROM by the PT should be obtained to provide an objective baseline for the assessment of progress. Active range of motion (AROM) measurements are taken in sitting and passive are taken in supine, using standard techniques. At a minimum, seated AROM of the involved shoulder should consist of flexion / elevation, functional internal (IR) and external rotation (ER) with the arm at the patients' side. Additional measurements should include IR and ER at 45 and 90 degrees of abduction ([Table 2](#)). These measurements should be taken prior to injection as well as during any follow up appointments.

POST-INJECTION

Additional details of the initial visit are provided in [Table 2](#).

Supine Passive Range of Motion (PROM) measurements are the focus following the intervention on day one. Seated AROM measurements can be a challenge to acquire that early following the procedure.

Immediately after the brisement procedure (by their physician) the patient is seen in physical therapy and is placed in a supine position of comfort. Manual techniques on average begin within 10 minutes of the injection. To get a baseline assessment and develop a degree of patient comfort with mobility, the upper extremity is passively moved gently into flexion and then abduction, avoiding any pain or end point stretching. This is followed by the same for IR and ER, performed with the humerus supported by a towel in 45 degrees of abduction. The patient is to notify the therapist if the pain reaches a 4-5/10 level (on Verbal Numerical Rating Scale), as this will often be a stopping point for a technique to avoid aggravation.

Following the passive range of motion, soft tissue work is performed to reduce the reflexogenic tonic guarding of the rotator cuff and pectoral muscles. The most tonic of these muscles need to be addressed to improve ROM. The pectoralis minor, subscapularis, infraspinatus, and teres/latis-simus complex are the most common muscle groups in the shoulder complex that develop increased tone and will often require attention during treatment. Interventions consist of scapular mobilization, soft tissue mobilization, joint articulation, and forms of stretching when tone is reduced such as a proprioceptive neuromuscular facilitation hold relax. For this reason, the patient is frequently treated in side-lying. This position is often preferred due to patient comfort and the ability of the clinician to address various angles of motion within the transverse plane while allowing for progressive ranges of abduction. As soft tissue restrictions in tone decrease, Grade 2 to 3 GH joint mobilizations laterally, inferiorly and less often, anteriorly or posteriorly may be performed. Additionally, the sternoclavicular, acromioclavicular, first and second rib, and thoracic regions should be evaluated and addressed with mobilizations if restrictions are present.

HOME EXERCISE PROGRAM

As motion improves, home instructions are given to correct postural impairments and maintain mobility in supine and standing. Repetition number and hold times can vary depending on irritability levels, with longer holds in less irritated tissue. The focus on mobility is on frequency and repetition, not on intensity. The home exercise program (HEP) is initially performed in the department and cued for proper execution ([Table 2](#)). Adjustments can be made depending on patient characteristics.

Multiple components of education are provided after completion of the session including frequency of home practice and the expectation that discomfort should continue to diminish. Patients often experience fear-avoidance in the performance of the HEP and should be reminded that pain tolerance should be used to guide number of repetitions and duration of static hold, stepping up or down based on the experience of a 5/10 level Verbal Numerical Rating Scale. Best practices regarding posture and sleeping positions are discussed.

The initial HEP is to be performed one to three times daily depending on need. Those with greater restriction should be instructed for a higher frequency. Patients should return in one week for progression of mobility and muscle coordination training. The authors recommend one to three follow-up visits, as progress and needs dictate after each visit.

Those who experience improvements in range of motion generally retain or continue to experience progressive gains until the time of first PT follow-up. While the presence of more significant OA may inhibit gains in range of motion, improvement in pain often yields patient satisfaction in function. For this reason, changes in ROM should not be used as a primary predictor of function at the initial visit.

PHYSICAL THERAPY FOLLOW-UP

Follow-up therapy visits are used to track progress, advance exercises, and address muscle coordination, with the goal of improving shoulder mobility, strength, and function. The second PT visit begins with a warmup for 3 minutes, on the upper body ergometer or pulleys, followed by ROM measurements. If minimal gains are made, manual techniques and current home exercises are performed, and when able, progressed. If active ROM is improved and pain levels remain minimal, the individual may be started on AA/AROM (active assist or active ROM) in all planes while standing and possibly light motor recruitment and coordination exercises to scapular and shoulder muscles. Strength-focused activity can be initiated when functional ROM of approximately 80% is achieved. Manual interventions are at the discretion of the therapist as needed. Education and cues involving postural influences are reinforced.

The anticipated number of PT visits following brisement is generally less than four, and frequently only one to two. By discharge, patients should have a well-rounded shoulder routine. The general recommendations for mobility include 5 to 7 sessions at home per week in all planes of motion. The recommendation for strengthening exercises is a rou-

Table 2. Outline of therapist assessment, treatment, and HEP prescription at initial visit

Initial Physical Therapy Visit
ROM Measurements * To be performed prior to injection and repeated after initial manual therapy is complete. Ensure posterior shoulder and coracoid are stabilized - Seated AROM at 0° ABD – average of 3 measurements - Flexion - Functional IR/ER - Supine PROM at 45° ABD and 90° ABD – average of 3 measurements - Flexion, ER, and IR
Manual Therapy - Supine shoulder and scapular mobility - PROM oscillations leading in flexion and ABD – repeat 5 to 10 times - PROM IR/ER at side leading into higher ranges ABD – perform 5 to 10 times each direction with goal of 90° ABD - Active scapular retractions, emphasizing lower trapezius contraction - Selective joint mobility, soft tissue work, PNF stretching based on assessment - Repeat PROM/stretching to shoulder 5 times in direction of IR/ER in flexion, then abduction - Side lying shoulder and scapular mobility - Scapular PROM in PNF directions and massage/soft tissue mobilization to teres/latissimus complex, pec minor, and infraspinatus - perform 5 to 10 times - Scapular stretching to pec minor – 30 second hold, repeat 3 times - Horizontal ADD/ABD below 90° flexion – 5 to 15 second hold, repeat 5 to 10 times each direction - Supine PROM in flexion, ABD, IR/ER and in a large circular motion prior to HEP performance - repeat 1 to 5 times each direction
HEP Prescription * Goals: restore AROM/PROM * Performed 1-3 times daily with goal of 10-20 repetitions - AAROM supine cane flexion – 5 second hold in each position 5 times palm in supination 5 times palm in pronation - Repeat 5 times with palm in supinated grip *Option to grasp in ER if impingement pain is present - AAROM supine cane ER at 45° ABD, humerus resting on towel – 15 second hold, repeat 5 times - Supine horizontal ADD stretch – 15 second hold, repeat 5 times - AAROM supine cane IR/ER at 90° ABD, humerus resting on towel – 5 second hold, repeat 10 times - AAROM standing cane extension – 5 second hold, repeat 10 times - Standing cane functional IR – 5 second hold, repeat 10 times - Standing scapular retractions – 5 second hold, repeat 10 times
HEP Education - Encourage AROM within pain-free ranges in ADLs - Educate on postural corrections and shoulder complex mechanics - Instruct to avoid pain >4-5/10 with exercise and ADLs, with modification of frequency or duration of hold if morning pain escalates with current regimen - Encourage ice or heat to manage discomfort - Restrictions: avoid return to high level activities until follow-up with PT

Abbreviations: ROM, range of motion; AROM, active range of motion; ABD, abduction; IR, internal rotation; ER, external rotation; PROM, passive range of motion; ADD, adduction; PNF, proprioceptive neuromuscular facilitation; AAROM, active assisted range of motion; HEP, home exercise prescription; ADLs, activities of daily living

tine performed three times weekly of coordination and recruitment. Modifications are expected and education on exercise progression and regression principles should be discussed in detail.

ADVERSE EFFECTS

Standard of care injection precautions and risks including infection and bleeding should be discussed by the physician at the time of the procedure. Patients are instructed to report concerning symptoms at each point of medical contact.

There are no anticipated adverse effects related to therapeutic interventions beyond what would be expected during

manual testing. Patient-provided feedback regarding pain tolerance during manual techniques and therapeutic exercises is important to avoid aggravation of tissue.

COORDINATION OF CARE

As this is a team-based approach, involving a temporal interaction with the patient, physician, and physical therapist, it is critical for the physical therapist to have space and time to work with the patient before and after the procedure. In traditional clinic-based settings this may pose a challenge. Success can be achieved with partly coinciding visit slots available on the physician and PT schedules labeled 'TEAM' visits to allot time for both parties to see the

Table 3. Outline of therapist assessment, treatment and HEP prescription at follow-up visits

Follow-up Physical Therapy Visits	
Timing	Recommendation for first follow-up at 1-3 weeks, with a total of 1-3 visits
ROM Measurements	Repeat ROM measurements, performed at first visit
Manual Therapy and HEP progression	* Goals: restore function, return to physical activity - Patient specific warm up mobility with upper body ergometer and/or pulleys - Address deficits in posture, cervicothoracic mobility, and scapular mechanics - Progress HEP - Include AROM and light strengthening when able - Example exercises: - Standing wall slides, cane AAROM ABD and IR - Standing horizontal ADD stretch - Corner or wall pectoral stretches - Band or dumbbell row - Counter push ups
Discharge	- Consider in-person discharge when there is adequate patient satisfaction, improved functional ROM, and HEP can be performed with patient confidence - Re-issue HEP with stretching and strengthening of entire complex to be performed 2-4 times weekly, long term - Educate on modification of sporting activities as appropriate

Abbreviations: ROM, range of motion; HEP, home exercise prescription; AROM, active range of motion; AAROM, active assisted range of motion; ABD, abduction; IR, internal rotation; ADD, adduction

patient in the physician's office. This may be done with greater ease when the PT practice is near or adjoining to the physician's clinic. For example, advanced scheduling is crucial and is recommended to be done by office staff with access to both parties' schedules. After physician consent for the procedure, initial PT assessment and measurements can be taken, followed by physician-performed US guided injections, then post-injection therapy by the PT. In this manner, both the therapist and physician have flexibility while the other is in the room working with the patient.

LIMITATIONS

There may be barriers to the successful execution of this collaborative treatment. First, the administering physician must have accessibility to and skill with MSK-US. To ensure precise placement of peri-neural anesthetic and additional injection under the joint capsule, the authors do not recommend proceeding without ultrasound guidance. Insurance coverage of and patient-belief towards PT could also influence feasibility of performance, and financial limitations should be addressed prior to scheduling. Generally, ultrasound guided GH injections are covered by majority of insurances in the USA. Lastly, patients may have medical contraindications to corticosteroids and NSAIDs, which would make them unsuitable candidates.

CONCLUSION

This clinical commentary presents a novel treatment strategy to address significant pain and functional impairment associated with GHOA. To the authors' knowledge, this is

the first publication describing the use of hydrodilatation of the GHJ to treat symptomatic GHOA. The approach includes a team-based strategy, combining the ultrasound-guided brisement procedure and nerve block with a structured physical therapy protocol.

This innovative application of a practiced procedure with physical therapy collaboration can improve range of motion, reduce pain, and enhance strength and function in GHOA. It is applicable to a wide patient population, with only few contraindications and does not require 'down' time.

Following publication of this clinical commentary, future research directions will include a proof-of-concept study analyzing both short- and long-term outcomes of the brisement hydrodilatation procedure for GHOA. Overall, this multidisciplinary approach offers a promising, minimally invasive option for patients with GHOA, potentially improving clinical outcomes and quality of life while minimizing the need for surgical intervention.

DISCLOSURES

Adam Kimberly- is a paid lecturer with Optimal Dry Needling Solutions via IAOM

Jason A Genin – is a paid consultant for Hydrocision

Richard Kring- is a paid consultant for Cleveland Clinic international partners and personal clients. He received honoraria for lectures presented at state, national or international conferences and universities.

Leo Oliviera- receives teaching payments from Trice Medical, Lipogems, Bioventus

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Clinical Commentary/Current Concept Review

Interdisciplinary Health and Performance Management of the Sliding Athlete: A Clinical Commentary

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Given the unique demands which combine the nuance of training and competition venues as well as speed and dynamics of “playing” surface, sliding sport athletes are exposed to a variety of physiological and environmental demands which heighten injury risk and challenge performance. Despite these considerations, literature highlighting both the sports demands and needs of the sliding athlete is scarce. The purpose of this commentary is to describe the unique challenges associated with the medical management of sliding sport athletes and offer recommendations for developing an integrated approach for mitigating injury risk and optimizing performance within this population. Additionally, the commentary aims to inform the reader of the variance of technique, from the technical start to sliding finish, as well as injury patterns and performance considerations across the three sliding sports of Bobsled, Luge, and Skeleton. Further, strategies to optimize performance outcomes, such as mental imagery and visualization, and implementation of an integrated support team model will be discussed.

Level of Evidence

5

INTRODUCTION

The sliding sports of Bobsled, Luge, and Skeleton require an athlete to tactically navigate a steeply pitched, winding, icy track surface while reaching speeds over 93 mph.¹ Sliding athletes must develop fine motor skills which allow them to navigate a track under variable circumstances which may include, at times, subzero temperatures where the slightest error may result in catastrophic injury. In addition, they must also adapt to withstand persistent exposure to varying levels of gravitational forces from taking more than fifty runs during some training weeks across a season that is often six months long. Each sport type is variable and nuanced, from equipment utilized to technical requirements,¹ which will be detailed in various sections of this commentary. The existing variance between each sliding sport needs to be considered to gain an understanding of the

sport demands and unique variables influencing health and performance across each discipline, all of which will be discussed. Given the technical variability between sliding disciplines, understanding common injury patterns and sport demands within disciplines is beneficial when developing medical management plans. However, research-supported recommendations and literature focus on the sliding sport athlete are lacking. As a result, recommendations to the field in developing a multi-faceted medical management program for this athlete population are mostly anecdotal and rely upon field experience. Therefore, the purpose of this commentary is to describe the unique challenges associated with the medical management of sliding sport athletes and offer recommendations for developing an integrated approach for mitigating injury risk and optimizing performance within this population.

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TECHNICAL ANALYSIS

The sports of Bobsled, Luge and Skeleton vary across many technical aspects. From variations in sled architecture and start/sliding techniques to training programs and race categories, the unique sports demands are described to provide the reader with an understanding of each sliding sport. Additionally, special consideration is given towards the start as a competitive start is widely considered to significantly increase the chances of overall success in sliding sports.²⁻⁴ While biomechanical patterns in the start may vary between each sliding sport, with the lower body extremities more involved in a bobsled and skeleton start compared to the upper body in luge, the common objective is to accelerate the sled with precision and speed to optimize post-load-*ing* velocity.⁵

BOBSLED

Bobsled is composed of three disciplines with sleds varying from approximately 2.80 meters in length (mono bob) to 3.80m in length (4-man bob). Some athletes participate in more than one discipline.⁶ Each discipline must abide by maximal weight restrictions for competition. With crew, the cumulative weight of the women's monobob must be less than 248kg, 2-Man bob 330kg (women's) and 390kg (men's), and 4-Man bob 630kgs.⁶ Positions in the sled include the driver, who engages steering below the cowling (protective covering) in the front of the sled to navigate the track, followed by push athletes who sustain a head tucked and maximally trunk flexed sitting position in the sled once loaded. The push athlete in the rear of the sled is considered the brakeman/woman and is responsible for braking inertia of the sled on the runway once crossing the finish line. Athletes push their bobsled over approximately 50 meters while on a grooved surface before transitioning into the sliding phase.⁶

START TECHNIQUE

The Bobsled start is composed of the introductory phase, the pushing/reversing phase, the acceleration/thrust phase and the achievement of maximum speed.⁷ In monobob, the pilot pushes from the rear of the sled while grasping two handles formed into the cowling of the sled with the elbows, trunk and lower quarter in a semi-flexed position while their feet are grounded on a board attached to the track.⁸ This same technique is applied by the brakemen/women in 2-man/woman bobsled, however the position of the pilot and other push athletes in 2-man/woman and 4-man bobsled vary as these athletes are positioned to the side of the sled in a staggered stance behind a lateral push bar.

The introductory, or "hit" phase ([Figure 1a](#)), typically occurs with explosive trunk and hip flexion followed by rapid lower limb extension as the athlete pushes off the start block. While pushing, athletes focus on maintaining forward propulsion as they push the sled without shedding speed (slowing) from exerting too much downward or inward force on the push bar.⁸ This transition into the push-

ing phase incorporates the first driving step occurring simultaneously with the initial propulsion of the sled to break inertia. As the sled is pushed from the block, athletes maintain partial trunk flexion while driving one foot forward in a shortened stride that lengthens as they overcome the initial inertia, increase distance from the block, and enter the acceleration/thrust phase ([Figure 1b](#)).⁸ The athletes achieve maximal speed as the sled passes beyond the "crest", or the point of increased slope. Beyond the crest, the sled hits a critical intersection where gravitational forces and the speed already produced overcomes athletes' capacity to add substantial increases in momentum to the sled, at which point the pilot, followed by brakemen/women, load ([Figure 1c](#)) into the sled in a choreographed manner, from front to back, that minimally affects speed.⁸ Due to the combination of overspeed, which results from the combination of maximal speed being achieved in combination with gravitational influence as the sled transitions down the crest, and an increased trunk extension moment while pushing as athletes prepare to transition into loading the sled, the biomechanical demand on the hamstring and posterior chain muscles is increased which can be a catalyst for acute muscular injuries.

EQUIPMENT

Bobsled athletes wear a full-body synthetic race suit under which is a required Kevlar burn vest to mitigate the severity of ice burns in the case of a crash, helmets meeting specific safety standards, and low-cut ice sprinting spikes ([Figure 2](#)) composed of a minimum of 250 micro-spikes located on the forefoot plate to provide traction.⁶ Face shields and goggles are typically worn exclusively by the pilots of the team.

LUGE

Luge is comprised of four disciplines: singles and doubles for both men and women as well as the mixed event and team relay.⁹ Sled weight is also regulated with a single sled minimum-maximum weight of 21-25kg and 25-30kg for doubles sleds.⁹ These weights may vary slightly at the youth and junior class levels.⁹ Luge athletes slide down the track on their backs with their chin in a slightly tucked position and feet against the kufens, or steels, that curve upwards in front of the sled, where slight pressure is applied for steering while maintaining stability in their lower legs and shoulders within the sled shell. At the finish, the sled is decelerated by the athlete transitioning to an upright sitting position with their booties in contact with the ice surface while lifting the front of the sled.

START TECHNIQUE

The six phases of the Luge start are the block, the compression, the pull, extension, push-off then paddles. This is where each Luge athlete uses their explosive power to gain the most traction and build speed to descend the track. The block phase ([Figure 3a](#)) begins with the athlete rocking the sled forward past the start handles while leaning the

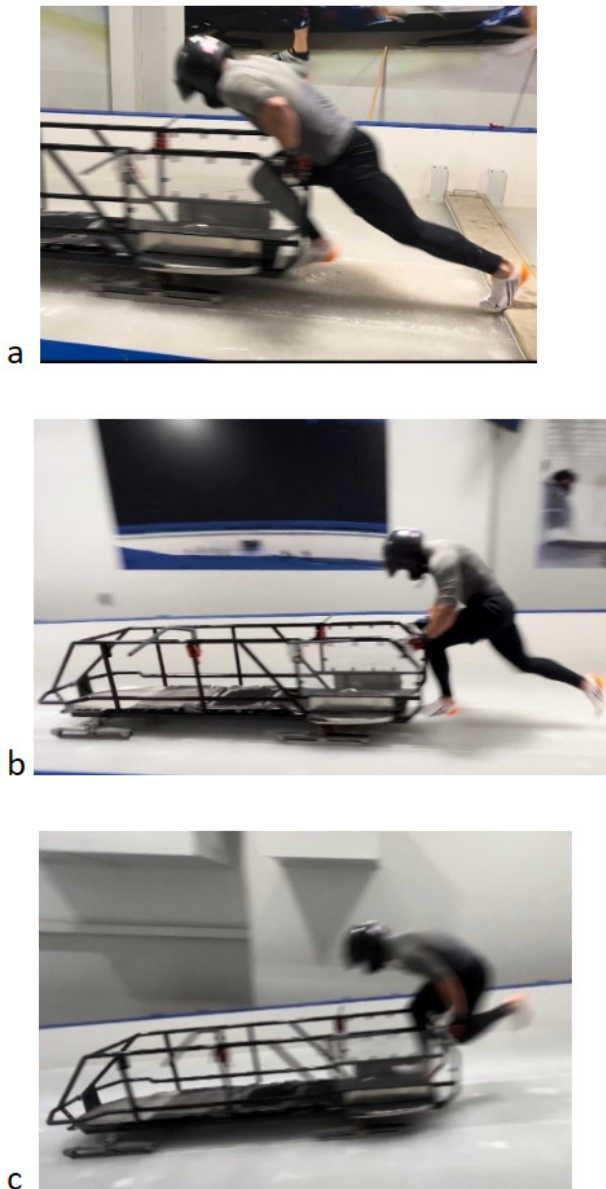


Figure 1. Phases of the Bobsled start: a) Hit Phase, b) Acceleration/Thrust Phase, c) Load Phase

trunk backwards. Next, is the compression phase ([Figure 3b](#)) where the athlete ballistically pushes backwards on the handles, entering full hip flexion and shoulder flexion. This allows the athlete to utilize the stretch-shortening cycle to move into the pull phase. During the pull phase, the athlete tenses and locks in upper body musculature, engages the hips and pulls against the start handles which then transitions them into the extension phase, which is the longest phase of the start. The extension phase ([Figure 3c](#)) occurs when the athlete begins forward propulsion with the hips and extends the trunk upright to a 90-degree angle and ends when the hips are in line with the start handles. Immediately following is the push-off phase ([Figure 3c](#)), which is continued forward propulsion by pushing off the start handles.

The athlete then finishes the start sequence with the paddle phase which typically consists of three to six pad-



Figure 2. Bobsled/Skeleton sprinting spikes

dles using the hands on the ice, depending on the track length ([Figure 4](#)).

Once the athlete has finished their specific number of paddles, the athlete(s) settle into their sliding position on the sled and complete their run.⁴ For the start in a doubles sled, the bottom athlete, or one positioned closer to the back of the sled, grabs and pulls on straps instead of handles. The straps are attached to the top athlete's or driver's suit behind the arms to connect both athletes as they work together to propel the sled forward from the start position.

EQUIPMENT

Luge athletes wear a full body synthetic race suit, a UVEX helmet with face shield, race booties and specialized 4mm race spikes ([Figure 5](#)) on their pointer, middle and ring fingers to gain traction during the paddle phase of their start.⁹

Some athletes also wear weight vests or shorts to meet their allotted weight maximum, of which was referenced previously. The sleds for Luge differ between singles and doubles disciplines as they are tailored to the athlete who is in contact with the sled. A singles athlete is the only body on the sled, therefore that athlete is measured, and the pod (sled frame) is made to fit their body type and height, whereas for a doubles sled, the bottom athlete is the one who is measured, as this athlete is in contact with the sled.

SKELETON

Skeleton consists of a single slider and no combination disciplines. The maximum combined weight for both the sled and athlete is 120kgs for men and 102kgs for women with the maximal sled weight alone set at 45kgs for men and 38kgs for women.^{10,11} Similar to Bobsled, the athlete pushes their sled from a sprinting start for 50 meters before loading and transitioning into their sliding position which consists of lying stomach down on the sled with the chin just a few inches off the ice and head in a neutral position while steering with subtle pressure applied from the upper torso into the sled frame.

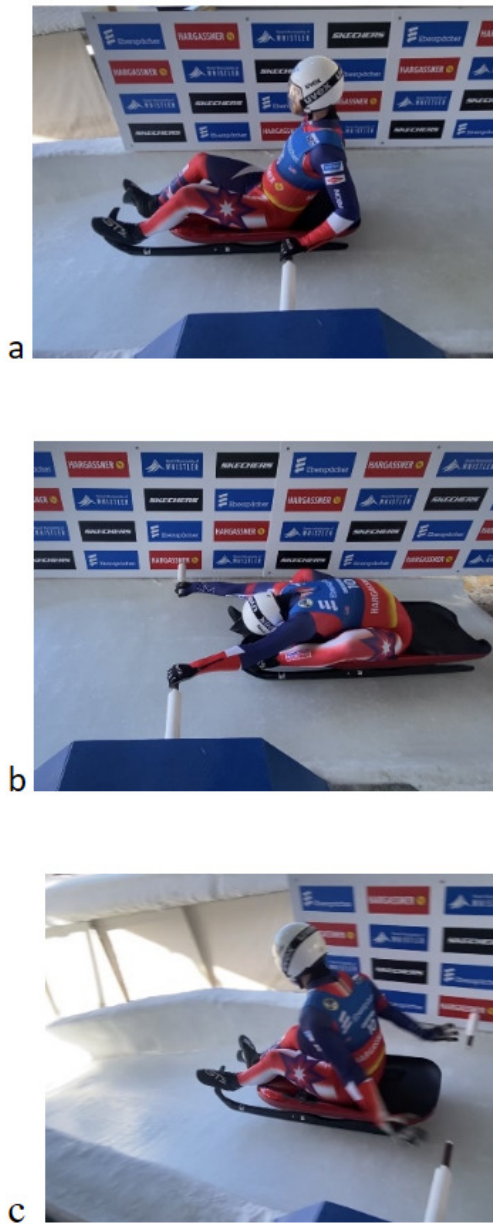


Figure 3. Luge start: a) Block phase, b) Compression phase, c) Extension into Push-Off Phase

START TECHNIQUE

The Skeleton start can be divided into five distinct phases: block, drive, transition, maximal pushing velocity, and load. Specific to Skeleton, notable physical and technical parallels have been drawn between the initial acceleration in sprinting and pushing.¹² Additionally, sprint velocity, which is determined by step frequency and stride length, is an aspect that coaches aim to enhance through training to optimize post-loading velocity.¹³ The block phase commences with the athlete gripping the saddle, or sled frame, with one hand to stabilize the sled flat down on the ice while positioning their feet in a split stance, with the back foot on the starting block and the front foot resting on the ice, resembling a sprint block setup. Subsequently, the athlete loads the hip through flexion and extension, rocking



Figure 4. A Luge athlete demonstrates the paddle phase of the start. Photo Credit: Ken Childs



Figure 5. Luge glove spikes. Photo Credit: Ken Childs

the sled forward and backward to break its inertia, a process that may be repeated several times to prepare for the next phase. The drive phase ([Figure 6a](#)) commences with hip extension, propelling forward as they push against the block, utilizing their center of mass to accelerate the sled. The angles of the torso and shins during this phase exhibit similarities to those observed in sprint acceleration as the athlete retracts the foot for the initial steps.¹² This phase concludes when the shin reaches a vertical position during swing phase relative to the ice. In the transition phase, there is a gradual increase in both step frequency and stride length. Athletes may adjust their step count based on the track's profile,¹⁴ potentially due to insufficient strength-speed qualities to maintain sled acceleration over the gradient. During the maximal pushing velocity phase ([Figure 6b](#)), both step frequency and stride length peak prior to loading, with the athlete positioned at the highest gradient of the track profile. The load phase ([Figure 6c](#)) represents the final opportunity for the athlete to generate velocity, as they bring their hands across the saddle in front of their



Figure 6. Skeleton start: a) Drive phase, b) Maximum pushing velocity phase, c) Loading Phase



Figure 7. A Skeleton athlete transitions into the sliding position. Photo Credit: Ken Childs

torso, establishing a stable position to propel forward with the outside leg onto the sled.

Subsequently, the athlete adopts a prone position ([Figure 7](#)) on the sled, gripping the lower part of the saddle. Typically, the start is completed within 14-18 steps depending on the track profile.

EQUIPMENT

Skeleton athletes wear a full-body synthetic fabric race suit and, like bobsled, specialized low cut ice sprinting spikes ([Figure 2](#)) with a minimum of 250 spikes in the forefoot to allow the greatest amount of traction on ice.¹¹ Skeleton helmets are full coverage with a uniquely shaped design to allow for both chin protection and cervical extension which support the sliding position and in meeting established certification standards.¹¹ Skeleton athletes are not required to wear burn vests.

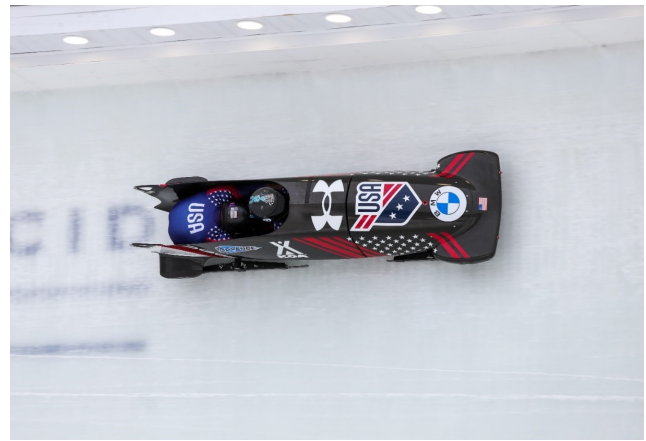


Figure 8. A Bobsled team navigates a curve on a sliding track. Photo Credit: Ken Childs

SLIDING TRACK CONSIDERATIONS

There are currently 15 tracks on the luge competitive race circuit, and 14 on the bobsled-skeleton competitive circuit.^{15,16} Track length, top speeds, gravitational force influence, maximum gradient, average gradient, and curve exposures vary from track to track, influencing the variability of technical and physical demands that exist from track to track ([Figure 8](#)).

The initial characteristics of each track are distinct and vary in profile, which influences individual starting strategies. Traditionally, Bobsled and Skeleton start on a 2% gradient, accelerating the sled to the 15m first official timing eye, gradually increasing speed down the 8-12% gradient track before loading into the sled.^{6,11} A split time is recorded at 65m at the second official timing eye. In contrast, luge start ramps feature a steeper gradient of 20% to 25% and range in length from a minimum of 10m to a maximum of 30m, this may vary depending on upper or lower start in the track. The first official timing eye must be installed no further than 5m after the start handles and the second sequentially 100m to 150m further in the track.⁹ These track characteristics play an influential role in athlete skill development strategies and return to sport from injury planning.

SLIDING ATHLETE HEALTH MANAGEMENT

INJURY AND ILLNESS EPIDEMIOLOGY

Given the combination of speed and navigation on a curved, icy track, sled crashes across all three sliding sports are a realistic probability. The average rate and severity of injury may change with each sliding track due to differences in top speeds, G-forces, and overall track technicality. Reviews of global occurrence studies at the Winter Olympics from 2014 through 2022 show acute injury occurrence/re-current injury rates varying from 5-11% for Luge, 8-18% for Skeleton, and 14-18% for Bobsled.¹⁷⁻¹⁹ The 2016 Youth Olympic Winter Games in Lillehammer in 2016 resulted in overall injury rates of 14% for Bobsled, 3% for Skeleton, and

35% for Luge.²⁰ Discrepancies between youth and Olympic level athlete injury rates may be due to competitor field size, experience level, and track technicalities. A retrospective study encompassing 43200 runs over four years for the Whistler Sliding Center showed that the overall injury rate was 0.5%.²¹ Of the injuries found 20% were concussions, 39% abrasions, 14% fractures, 20% strains, sprains, and 5% miscellaneous.²¹

From a musculoskeletal injury perspective, overuse conditions with gradual onset and thigh tendon rupture were identified injury conditions, in addition to head injuries and concussion in the sport of Bobsled.^{17,22} Additionally, the rate of injury occurrence was higher in training than competition.¹⁷ Furthermore, Bobsled was identified as having a higher injury risk whereas Luge had statistically lower injury risk when compared to other Winter Olympic sports.^{17,22}

The incidence of head injury and concussion within sliding sports has not been completely described despite reported incidences.^{1,22} There appears to be a growing awareness and recognition of symptoms, typically in the form of headaches and fogginess, which may occur in response to exposure to bumpy tracks and/or multiple runs.²³ Although head injuries and concussions occur in sliding sports, further research is required to determine the exact incidence and prevalence of these injuries as well as underlying causes for symptoms that manifest.

Additional consideration regarding environmental conditions, in particular cold weather, must be given within these athlete groups. Given the focus on optimizing aerodynamics within competition, athletes only wear helmets, speed suits and thin gloves as protection against the elements while sliding at over 80mph in sub-freezing temperatures. Therefore, hypothermia is a realistic possibility and must be considered within management strategies that are implemented.

SPECIFIC INJURY/ILLNESS MANAGEMENT CONSIDERATIONS

Illness is another contributing factor of which providers must effectively manage to ensure that contagion, when present, does not spread to other members of the team and hinder performance. Reviews of global occurrence studies at the Winter Olympics from 2014 to 2022 indicate illness rates varied from 3-11% for Luge, 8-28% for Skeleton, and 5-14% for Bobsled.¹⁷ Female sliders consistently showed a higher occurrence of illness compared to males. Across the sliding disciplines, Skeleton and Bobsled had a high rate of illness, in particular affecting the respiratory system, compared to other winter sports whereas Luge had the lowest rate of illness.^{17,22}

Both unique injuries and medical considerations exist within sliding sports. Medical providers must develop a system for extracting and triaging athletes out of cold, icy tracks where up to four athletes may have severe injuries and be unable to move due to their injuries or being trapped by the sled. This requires providers to be both adequately informed of venue emergency procedure protocols and prepared with the appropriate attire befitting of responding to

athlete injuries in a cold weather and sliding track environment, such as traction cleats or crampons and outdoor winter gear.

Team medical providers work closely alongside track personnel and emergency medical technicians to ensure safety of the athlete in the instance of a sled crash. Critical attention must be paid to movement and location of the sled within the track following a crash, regardless of location of the athlete, as a moving sled imposes significant harm upon responders and the athlete(s) involved. Once the sled's momentum has ceased, typically in the lowest gravitational point of the track, it is then safe to enter the track under the direction of track personnel to respond to the involved athletes. Initial assessment should screen for alertness, orientation and life-threatening trauma prior to more detailed neurological and orthopedic screens. In a suspected case of cervical spine injury, it is critical that any obstruction, such as the sled or a responsive teammate on top of an unresponsive one, is removed with caution in order to allow for proper assessment and management of the injured athlete, including spine motion restriction via use of a cervical collar as well as either a scoop stretcher or spine board for hospital transport. Given the risk for hypothermia, thermal blankets should be available for transport. It should be noted that in any crash, in particular those occurring during Bobsled, there is a possibility of athletes ejecting and/or losing contact with their sled further up the track so multiple medical support teams located at various points along the course ensures more timely response in these situations. Streamlined communication and alignment within the response plan by all involved stakeholders is critical to the success of implementing emergency protocols for sliding sports.

"Ice burns" are friction burns that occur when sliders collide with the wall or are pinned against the ice from their sled during a crash for prolonged periods, which can be a more common occurrence when the heavier bobsleds crash. These can range from third to first degree burns with large surface areas being affected. While some athletes may be wearing burn vests, however, the vest does not protect the shoulders, arms, or legs, which are the most exposed body regions.

In the cases where an intervention greater than a bandage is needed, similar treatment methods for friction burns are used to treat ice burns which entails 48-72 hours of silver hydrogel dressing followed by one to six weeks of hydrogel dressing depending on the severity.^{24,25} First degree burns require immediately cooling the burn with cold running water for 10-15 minutes followed by cleansing with soap and water and placement of a cold compress used for keeping the burn area clean.^{24,25} Second degree burns require cooling the area with cold water and ensuring that it is cleaned with soap and water as well as applying an antibiotic ointment.^{24,25} Third degree burns require debridement and cleansing before the application of a silver sulfadiazine cream.^{24,25} Absorptive, antimicrobial dressings can be applied and secured with poly stretch bandages on both second and third degree burns to keep the area covered for 24-48 hours post injury.^{24,25}

RETURN TO SLIDING CONSIDERATIONS

Standardized return-to-play protocols for a variety of medical conditions, including concussion²⁶ and musculoskeletal injury, are challenged when sports-specific phases of these protocols are re-introduced, especially in-season. Bobsled and Skeleton athletes can re-introduce sprint drills and heavy sled pushes as an alternative for starts. Some training centers may also have ice-surface start houses which allow sleds for all three sliding sports to be used on ice in a controlled setting without going down a track. However, these training centers are niche and unlikely to be available while racing during the season which requires athletes, coaches, and medical providers to improvise. Ultimately, athletes must be exposed to sliding down the track. In theory, it may seem more appropriate, from a return to sport progression standpoint, to transition athletes from lower start points on the track compared to immediately returning to sliding from the top. However, the athlete would then have to alter their steering from their typical or normal to compensate for entering turns at a lower speed which potentially may ultimately increase crashing risk. Additionally, logistical complications such as track availability during race training periods, the track being properly staffed by track crews and medical personnel, limited track runs per training session and, in the case of Bobsled and Luge, the availability of additional athletes to fill a sled for training runs influences the process of building sliding tolerance in an abbreviated window of time prior to the next race competition. This poses a unique challenge for the sliding athlete that may not be encountered by other sports.

For return to sliding sport following injury, progression and timing depend on the injury type and sliding discipline demands. For example, a Luge athlete may likely have an earlier return to sport date compared to Bobsled and Skeleton athletes following a hamstring injury due to the technical demands of each sport discussed previously. Due to the sprinting requirements and lower extremity demands in the sports of Bobsled and Skeleton, considerably greater stress is placed on the posterior thigh musculature compared to Luge and as a result a longer rehab course would be required to gradually build adaptive soft tissue loading capabilities before returning to sport (Appendix A). Alternatively, in the case of a shoulder strain or instability, a Luge athlete may require more extensive shoulder rehabilitation to regain the necessary range of motion and strength required within the sport (Appendix B). Consideration towards phases of the start, sled transition, sliding position and dynamic loading capacity of the injured soft tissue must be considered when building out progressions in both rehab and return to sport specific training.

Following concussion, athletes should be guided through a six-step return to sport progression according to the guidelines set forth by Patricios et al.²⁶ These progressions would include gradual exposure to light and medium intensity exercise to assess response before transitioning into sports-specific non-contact activities prior to higher intensity, contact activities based on sport demands.²⁶ For the

sliding sports, additional consideration must be given towards the exposure to gravitational and acceleration forces within the sport. While the best preparatory exposure to these demands within sliding is sliding itself, the athlete can be exposed to a variety of plyometric, body roll and proprioceptive exercises designed to assess an athlete's ability to tolerate multidirectional rotational and gravitational forces on land before transitioning back into sliding (Appendix C).

TECHNICAL DEVELOPMENT AND PERFORMANCE OPTIMIZATION

STRENGTH PROGRAMMING

It is essential for strength and conditioning professionals to establish a technical framework aimed at developing biomechanical qualities that enhance start performance. This can be accomplished through clearly defined objectives that align strategically with the training program's goals.²⁷ However, with evidence-based guidance for sliding sport strength programming being limited, practitioners must be attentive to individualizing program recommendations based upon the needs of the athlete(s), with specific consideration towards the technical demands within each sport.^{28,29}

Variability in training exists between sliding sports, with Luge emphasizing upper body physical development, in contrast to Bobsled and Skeleton. Colyer et al. identified three critical biomechanical qualities that predict start potential in Skeleton athletes: sprint ability, lower body explosive strength, and strength-power characteristics.^{5,30,31} Similar correlations have been noted in Bobsled, including sprinting, anaerobic power, and isokinetic knee strength to start capacity.^{28,29} It is recommended that Bobsled and Skeleton athletes incorporate resistance training to build strength and power in addition to speed training methods like sprints and plyometrics to improve explosive power in the lower body.³² As Luge athletes improve their technical efficiency, the significance of upper body strength in start performance increases.⁴ Additionally, research indicates that isometric bench pull strength is a key factor affecting maximum push-off speed in various tests assessing physiological elements of the start.³

Furthermore, given the characteristics of gravity-affected sports, integrating hypertrophy training could lead to improved finish times, as evidence suggests that the mass of the athlete-equipment system impacts winning times in Skeleton and Luge.³³ Skeleton athletes can experience sustained G-forces of up to five Gs during a corner and significant vibrations due to bumps in the ice.³⁴ Similar longitudinal and centrifugal forces will also impact Bobsled and Luge athletes.³⁵ Due to the required head position throughout a run, it could be beneficial to incorporate neck stability/strengthening programs to enhance neck girth and cervical stabilization which may help reduce head accelerations and thereby lower the risk of concussion.³⁶

Practitioners should exercise caution when considering the implementation of strength and conditioning programs

as improper training can negatively impact start performance if training volume is not managed appropriately. Athletes typically undergo several months of off-season training, starting with higher volume, lower intensity, and lower specificity, and then transitioning to lower volume, higher intensity, and higher specificity as they approach the in-season competition phase. It is important for athletes to continue training strength, power, and speed qualities throughout the season to maintain a competitive start. Additionally, periodic medical assessments and fitness profiling, including analysis of strength, force production, and biomechanical loading patterns is helpful in both screening for patterns indicative of higher injury risk as well as developing programming individualized to each athlete.

VISUALIZATION AND MENTAL IMAGERY TRAINING

Success in sliding sports relies heavily on the athlete's mental representation of the tracks on which they race. They must build and maintain a memory for each curve, the challenges therein, and their tactical approach related to how navigation of one curve sets them up for the next. Given track runs per session and actual sliding time can be limited during competition weeks in-season, athletes have limited time to learn and relearn each track on tour and build robust mental models. To boost learning, memory, and performance, sliding sport athletes rely on a combination of film, track walks, and motor imagery, or, to use sliding sport terminology, "mind runs."

Mind runs are a standard feature of sliding sport training. Athletes close their eyes and visualize sliding down the entire track or sections of it, seeing and feeling themselves navigate each curve and often moving their upper bodies to "steer" subtly – imagining their optimal line. Athletes perform mind runs in between actual training runs, before races, in conjunction with watching film, or any time they wish to mentally rehearse. Some coaches encourage athletes to do mind runs while in a sled to create a higher fidelity sliding experience. Athletes may do abbreviated mind runs shortly before approaching the start line to refresh performance cues for a track's most consequential curves. A large body of research suggests that motor imagery improves motor representations, or organized mental blueprints for everything the motor task requires, of complex motor tasks³⁷ and motor performance^{38,39} while also improving sport-related confidence.⁴⁰

When conceptualizing mind runs, the Physical, Environment, Task, Timing, Learning, Emotion, Perspective (PET-TLEP) model of imagery⁴¹ and similar research^{38,40} should be considered. Incorporating multiple senses, vividly setting the scene of the track while including other people and surroundings from a first-person perspective, incorporating physical cues and movements through dynamic motor imagery, striving for at least a portion of mental reps to occur at "racing speed", and calibrating imagery duration and complexity to the athlete's current level training or performance are all strategies that can be implemented to optimize the effectiveness of the mind run. For example, if an athlete has just returned to pre-season sliding after months off the track, their imagery may simply focus on

the feeling of relaxation they want to achieve in the sled. As the athlete completes more runs, they may use imagery to rehearse more complex approaches to specific curves and specific lines they want to draw on the track. This may also include the athlete wearing their helmet and speed suit, getting into sliding position on a sled and mimicking precise steering movements to navigate a specific curve or set of curves.

For athletes who are less experienced with complex and structured motor imagery, it is helpful to start small and build images gradually. Layered stimulus response training (LSRT)⁴² is an approach that systematically layers progressively complex stimuli to help athletes generate and control images.⁴³ Further, research suggests that LSRT may lead to greater improvements in the performance of complex motor skills, like golf putting, relative to standard imagery practice.^{42,44}

The basic steps of LSRT are *image*, *reflect*, and *develop*.⁴⁴ A sliding sport athlete may start by focusing solely on short-duration, low-complexity scenarios, like the moments before their start and the start itself. The athlete will begin by building an *image* – setting the visual scene of a specific track, feeling their speed suit on their body and the cold temperature on their skin. They should hold onto this image until it becomes fuzzy or they lose control. Then, exit the image and *reflect*. How vivid was the experience? Did they experience any psychophysiological changes in conjunction with the imagery scenario (e.g., increased heart rate or sweating before the start of a race)? What senses (e.g., sound) or sensory details (e.g., spectators) were missing? The athlete then re-enters and further *develops* the original image – picking a small number of additional sensory cues and layering these on top of the imagery foundation they built. The athlete may repeat this process and gradually increase the duration and complexity of images as they gain greater imagery mastery.

INTEGRATED SUPPORT APPROACH

In elite and high-risk sports, fostering an integrated approach is critical to the success of not only the athletes who are being supported but also the collaborative efforts across various stakeholders, such as medical providers, sports psychologists, dietitians, strength coaches and technical/sport coaches, involved in the process of optimizing athlete health and availability. Effective communication strategies not only optimize the integration of knowledge and experience of involved stakeholders but also enhance athlete health.⁴⁵ An ideal transdisciplinary model is one in which athlete injury updates and performance development goals are communicated across all disciplines involved while integrating athlete voice in the processes of rehabilitation and goal planning to collaboratively develop treatment and return to sport progression plans while also identifying opportunities for appropriate referral to additional providers. Various examples of incorporating a transdisciplinary framework within sliding athlete care might include developing a psychologically-informed rehabilitation protocol for an athlete who is anxious about returning to sliding af-

ter a head injury, incorporating vestibular or visuomotor drills into strength and conditioning programming through collaboration between medical providers and coaches, and implementing the expertise of sport dietitians and psychologists to help an injured athlete optimize fueling for performance while coping with sport-related body weight and shape pressures. Environments which foster collaboration, trust, and clear communication among staff in these examples, while providing athletes with a positive vision and consistent support, are likely to yield better outcomes, such as reduced injury rates, improved adherence to training programs, and increased availability.^{45,46} Cohesion within the athlete support team will not only foster efficient communication practice but could also allow for both athletes and support personnel to best navigate challenges as they arise, such as injury or perceived competitive environment “failure”.⁴⁶

SUMMARY

Sliding sport athletes are exposed to a technical and high-risk competitive environment. Given the nuance between each discipline, it is important for the medical provider to gain familiarity with sport demands and potential challenges which may be encountered when managing health

and performance of the sliding sport athlete. These considerations include start and sliding techniques, equipment and variability among tracks on an international competition circuit.

An understanding of emergency procedures, injury and illness epidemiology, and return to sport considerations unique to both sliding sports and track venues is an important component of mitigating risk and optimizing health-care of the sliding athlete. Strategically planning strength and conditioning programs while integrating mental imagery practice to best meet the needs of the sliding athlete can positively influence performance. A holistic, transdisciplinary approach should be integrated to best leverage the knowledge and expertise of medical providers, coaches and support staff in optimizing athlete health and performance.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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SUPPLEMENTARY MATERIALS

Appendix A

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Appendix B

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Appendix C

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Appendix D

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Clinical Commentary/Current Concept Review

Physiotherapy and Exercise Therapy after Surgical Treatment of Femoroacetabular Impingement Syndrome: A Clinical Commentary from the QKG – Society for Cartilage Regeneration and Joint Preservation

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There are many approaches to physiotherapy and exercise-based rehabilitation following surgical treatment of femoroacetabular impingement syndrome (FAIS). Focus on a multidimensional approach, integrating tissue healing timelines with patient-specific functional recovery strategies is important. Key surgical considerations, such as labral- and/or capsular management and cartilage regeneration, alongside their implications for postoperative rehabilitation must be considered. The purpose of this clinical commentary by the Society for Cartilage Regeneration and Joint Preservation (QKG) is to provide a comprehensive framework for the physiotherapy and exercise-based rehabilitation following surgical treatment of FAIS. The framework outlines distinct time- and criteria-based phases of rehabilitation, from preoperative preparation (prehabilitation) to long-term recovery, emphasizing an individualized assessment and care, supported by recent research linking musculoskeletal outcomes to psychosocial drivers, emphasizing the need for personalized rehabilitation strategies.

Level of evidence

5

INTRODUCTION

Femoroacetabular impingement syndrome (FAIS) is one of the most common causes of pain and functional limitations in young to middle-aged hip patients.¹ The symptoms are attributed to premature contact between the femoral neck and the acetabulum. The main causes of this are bony bulges with resulting tailing disorders at the femoral-neck-head transition (cam morphology) or an excessive coverage of the femoral head by the acetabulum (pincer morphology).^{2,3} This is exacerbated by abnormal femoral and acetabular version, as well as abnormal movement-related kinematics of those affected.^{4,5} If conservative treatment has failed and the patient continues to have symptoms or dysfunction, surgery may be the treatment of choice. It is therefore not surprising that the number of hip arthroscopies in this patient group has increased steadily over the last decade.^{6,7} Previous reviews of postoperative exer-

cise rehabilitation have examined different aspects of recovery. Hemstock et al.⁸ focused on weight-bearing and range of motion recommendations.⁸ Meanwhile, Takla et al.,⁹ Holling et al.¹⁰ and Hanish et al.¹¹ proposed time-based rehabilitation protocols alongside general postoperative guidelines.⁹⁻¹¹ However, these consensus statements and reviews lacked detailed descriptions of possible exercise parameters and progressions for individual muscle groups. Furthermore, a detailed description of impairment- and activity-based performance tests with benchmark values are needed to optimize rehabilitation. While existing studies provide a general framework, they do not offer practical guidance for clinicians. This clinical commentary by the Society for Cartilage Regeneration and Joint Preservation (QKG) seeks to provide a comprehensive framework for the physiotherapy and exercise-based rehabilitation following surgical treatment of femoroacetabular impingement syndrome (FAIS).

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Table 1. Possible limitations in the acute postoperative phase – early proliferation^{8,11-15}

Affected structure	Limitation (weight bearing or ROM)	Time frame
Cartilage	15-20 kg restrictive weight bearing	6 weeks
Capsule	Flexion: ≤ 90° Extension: 0° Abduction: ≤ 45° External rotation: ≤20°	3 weeks
Labrum		
Bone (femoral)	15-20kg restrictive weight bearing	3-4 weeks

It comprises the experiences and convictions of the physiotherapists and orthopaedic surgeons of the QKG and is also based on a narrative synthesis of the current literature.

TISSUE HEALING AND WEIGHT BEARING/ROM RESTRICTIONS

The healing of the addressed structures following the individual procedures (cartilage regeneration procedures, femoroplasty, acetabuloplasty, labral repair, reconstruction, capsuloplasty) exerts a significant influence on the timing and content of the rehabilitation process and forms the basis for certain movement limitations.

REHABILITATION

BIOPSYCHOSOCIAL FRAMEWORK

The treatment of patients with hip pain should not follow a one-dimensional biomedical perspective. Musculoskeletal complaints are regarded as complex, biopsychosocial phenomena, that are perpetuated by different multidimensional drivers. The revised American Physical Therapy Association Guideline by Ensek et al.¹⁶ recommends an International Classification of Functioning, Disability and Health (ICF) based rehabilitation model addressing impairments of body function and structure, activity limitations and participation restrictions in those with nonarthritic hip joint pain.¹⁶

Beck et al.¹⁷ and Perez et al.¹⁸ found a significant influence of sensitization processes in the central nervous system (Central Sensitization Inventory Scores (CSI)) on postoperative outcomes.^{17,18} Rhon et al.¹⁹ showed an increase in concomitant diseases (e.g. mental health disorders, chronic pain, cardiovascular disorders) after hip arthroscopy.¹⁹ Finally, psychosocial, such as kinesiophobia or catastrophizing, and contextual factors (e.g. the health care system or the therapeutic alliance) exert a significant influence on postoperative outcomes.^{20,21} According to Jochimsen et al.²² the odds of having elevated post-operative pain at rest were 45 times and 4.5 times higher for those with low self-efficacy and high pain catastrophizing ($p \leq 0.03$), respectively.²² Consequently, clinicians are advised to use patient-reported outcome measures (PROMs) to assess for depression, anxiety (i.e. EQ-5D anxiety/depression dimension), low self-efficacy (i.e. Pain Self-Effi-

cacy Questionnaire), and kinesiophobia (i.e. Tampa Scale of Kinesiophobia) at baseline and at least one other follow-up point that includes discharge in those with nonarthritic hip joint pain.^{16,23} Patients with persistent hip pain often show unfavorable beliefs about “damaged” hip structures, which can lead to avoidance behavior, overprotective movement patterns and a significantly reduced quality of life (distress, sleep disturbances, etc.).²⁴ In a holistic understanding, these complex factors should be understood as cognitive or behavioral barriers to an active therapy approach or a long-term favorable outcome and should be addressed accordingly in postoperative rehabilitation.^{21,25-27}

Using a psychologically informed practice model, musculoskeletal rehabilitation clinicians can integrate psychological and mind-body techniques—such as SMART (Specific, Measurable, Attainable, Relevant, Time-bound) goal setting, diaphragmatic breathing, pain science education, basic cognitive restructuring, mindful pain awareness, and progressive muscle relaxation—into traditional exercise-based programs in an individualized patient-centered approach.²⁸

A PHASED MODEL

Movement-based rehabilitation after surgical procedures is based on a tissue healing framework (see [Table 1](#)), the measured individual impairments and the individual progress of those affected. It has therefore become common practice to structure the recommendations within a rough tissue-specific timetable.^{11,15,26} According to Kaplan et al.,²⁷ there is a continuous improvement in PROMs in the first six months.²⁷ According to their data, postoperative treatment should therefore be planned for at least six months and longer time frames should be considered, especially for patients receiving cartilage regeneration procedures. A home program might be equally effective as a treatment under constant supervision and is able to potentiate the effects of clinically based treatments.^{29,30} However exercise programs that are carried out independently should be supervised and adapted to a certain degree. Ideally, sufficient preoperative preparation should be implemented before surgery.²⁶ A phase model combines connective tissue healing times with the principles of sports science and is the preferred model of the QKG.

PREHABILITATIVE PHASE (PREHAB)

Patients with FAIS exhibit functional (strength) and structural (atrophy and fat infiltration of muscle) contributions

to movement impairments that may be correlated with poorer postoperative outcomes.^{17,31-34} Therefore, the aim of prehab is to improve functional capacities of those affected to accelerate postoperative recovery.³⁵ All interventions should be adapted to individual needs and person specific goals to meet the demands of patient-centered care.³⁵ While there is evidence for the effectiveness of prehab in other fields (e.g. prior to acl reconstruction), there are no results available for hip arthroscopy - excluding the data from Grant et al.^{36,37} However, in their pilot study, an 8-week home exercise program before surgery showed higher strength values (knee extension and hip flexion) and a better quality of life (EQ-5D-5L) compared to no prehabilitation treatment.

If prehab is used, an active training program should be developed, consisting of motor control exercises (postural control, dynamic control of joint alignment), strengthening of the muscles of the thigh and hip, and general endurance training to maintain aerobic capacity. In addition, the following areas should be addressed within patient education:

- Biomechanical education: Modification of symptomatic movement patterns, such as anterior pelvic tilt or avoiding sitting with high hip flexion and crossed legs, can potentially increase pain-free ROM.³⁸
- Learning how to use crutches safely in everyday life.
- Therapeutic pain education: Information about the expected trajectories of musculoskeletal pain can reduce fear of movement and catastrophizing thoughts in the postoperative phase.³⁹
- Behavioral therapy elements: Emotional reactions after trauma/surgical procedure exert a significant impact on postoperative rehabilitation outcomes. Fear of movement, catastrophizing and low self-efficacy should therefore be identified and addressed early on.^{20,40-42} In therapeutic communication, care should be taken to ensure that patients are not further worried by a strong focus on maladaptive biomedical illness perceptions.^{24,43}
- Modification of lifestyle factors: Smoking, obesity and reduced sleep quality are predictors of poor postoperative pain control or outcome.^{44,45}
- Expectations: Expectations are a significant factor influencing postoperative outcomes.^{46,47} Individually adapted, realistic and relevant goals should therefore be formulated.

ACUTE POSTOPERATIVE PHASE (0-2 WEEKS)

During the first two weeks, the focus is on protecting the healing structures and on controlling the inflammatory reaction. For this purpose, the restrictions in [Table 1](#) may apply, depending on the surgical procedure.

To ensure safe and protected ROM, 40% and 48% of surgeons respectively recommend the use of hip braces.^{8,48} Braces can effectively reduce ROM in flexion.⁴⁹ However, the clinical benefit seems to be minor at best. Fischer et al.⁵⁰ showed a reduction in fear of movement as a result of hip bracing. However, the clinical impact cannot yet be assessed due to the lack of data. Others only found less pain

and a better quality of life in men (VR-12-MCS). Due to the low statistical power, Wentzel et al.⁵¹ cast doubt on the clinical relevance of their results. Even more importantly, however, complications or recurrent interventions were not prevented by hip bracing in any of the studies. The protective effects therefore seem to be neglectable.^{50,51} Considering the higher costs, hip braces should not be prescribed routinely, but only in individual cases according to the authors opinion.

Restrictive weight-bearing is reserved for patients who have undergone cartilage regeneration procedures or extensive femoroplasty/CAM correction ([Table 1](#)). Otherwise, early weight bearing as tolerated does not seem to cause any disadvantages.^{8,52-54} It should be noted that joint reaction forces in the hip joint are determined less by ground reaction forces than by muscle forces crossing the joint.⁵⁵ This fact becomes particularly evident when considering the magnitude of joint reaction forces in non-weight-bearing exercises ([Table 2](#)).⁵⁵⁻⁵⁷ Therefore, to reduce joint forces, muscle contraction intensities must be considered; a sole focus on weight-bearing is biomechanically implausible and is currently not recommended.⁵⁸

Early mobilization is uniformly recommended for the purpose of nourishing the cartilage regenerate (in the case of cartilage regeneration procedures) and preventing adhesions.^{11,59,60} Philippon et al.⁵⁹ initially start with passive mobilization techniques (continuous passive motion (CPM), manual circumduction, [Table 3](#)) and supplement the program with active automobilization (e.g. bicycle ergometer taking use caution with saddle height/crank length adjustment with low resistance or movement in water).⁵⁹ The exact parameters for the mobilization techniques used have not been published. The Tissue Regeneration Working Group of the German Society for Orthopaedics and Trauma Surgery (DGOU) recommends CPM for three hours over six weeks after knee joint surgery.⁶¹ Philippon et al.,⁵⁹ on the other hand, recommend 4-8h a day.⁵⁹ A randomized controlled trial by Munsch et al.⁶² including 54 patients who underwent arthroscopic acetabular labral repair reported a statistically significant decrease in pain levels in patients using CPM 4-6 hours daily throughout the first two postoperative weeks compared to patients in the control group (no CPM).⁶² Further studies are needed to evaluate the benefits of CPM especially in cases of hip arthroscopy in conjunction with cartilage repair techniques.⁶³

Due to the low primary stability in cartilage regenerative procedures, strength- and hypertrophy-oriented resistance training for the muscles surrounding the hip is due to the high mechanical stress not possible in this phase. However, for the prevention of muscle atrophy and the early treatment of arthrogenic muscle inhibition (AMI), strength training on the healthy side (cross-education), neuromuscular electrical stimulation or mental training can be used ([Table 4](#)).⁶⁴⁻⁷⁰

General aerobic endurance training using an upper body ergometer can reduce lower limb pain, maintain fitness and improve results in patient reported outcome measures.⁷¹⁻⁷⁴ In addition they exhibit an anti-inflammatory effect.^{75,76} Unfortunately, the available studies refer to the treatment

Table 2. Resulting compressive joint reaction force during exercises/movements without weight bearing⁵⁵⁻⁵⁷

Intervention of movement	Compressive joint reaction force (in % of body weight)
Stretching of the rectus femoris	179%
Hip abduction on the cable pulley (10kg resistance on the free moving leg)	167%
Hip abduction in long sitting against TheraBand	245%
Isometric contraction in supine position (different levels)	50-230%
Breaststroke	193%

Table 3. Parameters for passive early mobilization⁵⁹

Parameter	Continuous passive motion	Passive circumduction
Intensity	Pain and tension free (NRS 0-2)	
ROM	Week 1: 10-45° flexion Week 2: 0-60° flexion Week 3: 0-70° flexion From week 4: 0-80° flexion	Small circular movements (approx. 20-25cm) in 60-70° hip and knee flexion
Duration	4-8 hours per day for 4-8 weeks (labral cartilage regeneration procedures)	60 repetitions, 3-4 times a day for 10 weeks

Table 4. Possible exercise parameters in postoperative acute phase⁶⁴⁻⁷⁰

	Cross Education	Mental training (motor imagery)	Neuromuscular electrical stimulation
Device	Resistance machines	-	NMES device
Intensity	High, ≥80% of maximal strength	Maximum, 100%	Visible, palpable contraction, RPE 8/10
Repetitions	6-12	25	15 reps of 10 seconds on, 30 seconds off
Sets, rest between sets	3, 2 minutes	2-3	1
Frequency per week	2-3x	3x	Daily, 2-3x
Duration	8 weeks	4 weeks	6 weeks

of patients with knee pain or patients preparing for knee and hip replacement surgery. No data is available in post-operative hip rehabilitation. However, in view of the favourable metabolic, neuroimmune and cardiovascular effects, the authors recommend supplementary aerobic endurance training.

All supervised exercises should be performed with low pain ("green pain light" <3/10 NRS) and only be carried out when the tissue irritation level is adequate. Regression of the exercises and passive modalities (e.g. cryotherapy) are indicated in cases of high irritability.

EARLY PROLIFERATION PHASE (UP TO ABOUT 6 WEEKS)

In this second phase, partial weight-bearing requirements continue to dominate in cartilage regeneration procedures, so mobilization of the hip plays an essential role. In this context, it is important to note that achieving full hip mobility (compared to the unaffected side) is not realistic.⁷⁷ Even after a mean follow-up of 31,3 months in goniometric measurements, the improvement varies significantly

(0.1-12.2° in flexion, 3.6°-21.9° in internal rotation and -2.6-12.8° in external rotation). It can therefore be assumed that other factors are limiting postoperative ROM than a mechanical block to movement from abnormal bony morphology of the proximal femur and/or acetabulum.⁷⁷

In addition to mobilization, patients with FAIS show abnormal movement strategies in everyday activities (e.g. walking or squatting). These motor control changes correlate with PROMs and cartilage health.⁷⁸⁻⁸⁰ Surgical interventions alone do not lead to a sufficient improvement in movement behavior.^{79,81} The improvement of movement quality in general as well as gait and walking speed should therefore be given high priority.

Due to the intraoperative trauma and the concern about instability of the hip joint, joint stabilizing exercise interventions should be started as soon as possible. From the results of basic biomechanical research, it can be deduced that all hip muscle groups possess an important function for joint stability.⁸²⁻⁸⁶ The anterior muscular stabilizers (iliopsoas and iliocapsularis) are considered to play a key role as antagonists to counteract anterior shear forces.^{84,87-89}

Table 5. Required active ROM (peak values) in different planes of motion during everyday activities⁹¹

Activity/Direction of Movement	Flexion-Extension	Abduction-Adduction	Internal-External Rotation
Walking	57.5° - 19.6°	21.6° - 9.18°	14.9° - 12.4°
Step down	39.96° - 1.6°	5.4° - 9.4°	6.05° - 20.2°
Step up	67.07° - 3.55°	4.9° - 10.59°	5.59° - 9.27°
Full squat	121.30° - 11.2°	29.5° - 22.4°	18.7° - 31.6°

Therefore, they should be integrated into the exercise program early on, but in accordance with the corresponding tissue irritability level. In principle, it is recommended to start muscle activation with static contractions of low to moderate intensity in a medium joint position (see progressions in Appendix 1).⁹⁰ In addition to the muscles covering the hip from all sides, exercises for the abdominal and back muscles should be integrated due to their postural influence on the pelvis.⁹⁰

LATE PROLIFERATION PHASE (UP TO ABOUT 12 WEEKS)

Full weight bearing and the individual's full ROM should be achieved by this stage at the latest. Walking without crutches should be permitted if the pain level is adequate (<3/10 NRS), movement quality is sufficient (no limping) and if the available ROM is appropriate. Of note one-dimensional activities of daily living require relatively large ranges of motion in several planes (Table 5).⁹¹ In addition, some limitations contradict each other considerably, such as the requirements for a "normal gait" are incompatible with a required limited range of motion. Limitations must therefore be adapted sensibly and suitably to the functional goals.

The strength of the hip muscles is reduced in the first few weeks due to surgical intervention. After three months postoperatively, the knee and hip flexors strength levels, as well as those of the hip abductors and external rotators, are usually below the preoperative level.⁹² Even after six months, Servant et al. found significant deficits in the strength of the external rotators of the hip.⁹³ Compared to healthy individuals, reduced strength values in the hip flexors and extensors are still present after twelve months, so normalization of the strength values often occurs later.^{94,95}

For these reasons, structured strength training should be started early, depending on the individual's loading tolerance (see progressions in Appendix 1). This can be started using methods that produce favorable neuromuscular adaptation with low mechanical loading of the hip joint. Regarding hypertrophy effects, exercise intensities of around 30% of the individual's maximal strength performance show comparable effects to high load interventions, provided the exercise volume (sets x repetitions x load) is comparable.⁹⁶ The methods of choice would be low load resistance training with or without blood flow restriction (Table 6). To date, there are few studies available for the latter method in hip pathologies. Nevertheless, Hwang et al.⁹⁷ show adaptations even proximal to the applied cuff and Høgholt et al.⁹⁸

emphasize the feasibility in clinical use in patients with greater trochanteric pain syndrome.^{97,98}

Balance and neuromuscular control exercise for joint alignment, as well as gait retraining, complement the exercise program in this phase.

Progression within the proliferation phase should not be based on rigid time parameters but should be adapted to each individual's impairments and competence in performance. In this context, Martin et al.¹⁰¹ recommended test procedures that assess performance and load the hip joint at different intensities.¹⁰¹ In this phase, tests with low and medium intensity are particularly important (Appendix 1 and 2):

- Strength: Five times sit to stand test (5TSTS)
- Balance: One-leg stance test with eyes open and closed (OLS)
- Walking speed: Self-selected walking speed (SSWS, 20 meters)

Normal/good performance can be found in Table 7.

REMODELING PHASE (12TH-26TH WEEK)

In the remodeling phase, the focus is on the development of different strength qualities and dynamic movement patterns.

In the context of strength training, linear periodization models have proven to be effective in the rehabilitation of musculoskeletal disorders.¹⁰⁴ The external load is gradually increased over months, while the exercise volume decreases. This assures progressive increases in load without jeopardizing the cartilage graft in cartilage regeneration procedures. According to the position statement of the ACSM (American College of Sports Medicine) the majority of the training is devoted to the 6-12 repetition maximum for muscle hypertrophy and should be performed at intensities of 80-100% of the 1 RM for increasing maximum strength. An increase in weight of 2-10% should be considered when the current workload can be performed for 1-2 repetitions over the desired number on two consecutive training sessions.

The activation of the key muscle groups in the individual movement planes has been the subject of various studies in the past.¹⁰⁵⁻¹¹¹ Accordingly, for high-intensity exercise interventions, single-leg loading in the frontal plane for the hip abductors, the "Copenhagen adduction exercise" for the hip adductors, step-up or split squat variations for the hip extensors and the "Active Straight Leg Raise" for the hip flexors can be recommended (Progressions provided

Table 6. Exercise parameters for low load interventions^{99,100}

Parameters/Methods	Low Load Resistance Training	Blood flow Restriction training
Exercise	Knee, hip extension, hip abduction, leg press, bridging	
Intensity	30% of maximal strength	20-40% of maximal strength
Repetitions	>30-40	30-15-15-15
Sets, rest between sets	3, 1-2 minutes	4, 30-60 sec.
Frequency per week	3x	2-3x
Duration	10 weeks	≥6 weeks

Table 7. Low and medium intensity tests (Appendix 1 and 2)^{80,102,103}

5TSTS		OLS	SSWS (20 meters)
Age	Mean (CI 95%)	- open eyes: 45 seconds - closed eyes: 30 seconds	→1.5m/s
14-19	6.5±1.2 (6-7) sec.		
20-29	6±1.4 (5.6-6.5) sec.		
30-39	6.1±1.4 (5.5-6.8) sec.		
40-49	7.6±1.8 (6.6-8.6) sec.		

in Appendix 1).¹⁰⁵⁻¹⁰⁹ The short rotators of the hip joint are activated to the greatest extent by a combination of hip rotation and hip extension, such as in the “prone heel squeeze”.^{110,111}

Dynamic movement patterns (walking, running, jumping, changing direction) are particularly important for athletically ambitious patients and should be trained according to the principles of motor learning.^{112,113}

- Training of various movement strategies based on the principle of differential learning. This strategy aims to expose patients to as many different combinations within a class of skills (walking, jumping, running, etc.) as possible.
- Using explicit feedback during movement execution (emphasizing external feedback, i.e. to decrease knee valgus in single leg squat the instruction to “reach towards the cone with your knee is given”).
- Consideration of patient preference when selecting exercises (self-controlled learning, i.e. freedom of choice in selection, level of difficulty, sequence of exercises or self-controlled feedback).
- Enhancing expectancies i.e. by providing positive feedback about patients performance or positive (“this performance is greater than the average”) compared to negative (“below the average”) social-comparative feedback.

Reynolds et al.¹¹⁴ and Kraeutler et al.¹¹⁵ propose a structured framework for recreational runners regarding a return to running program after hip arthroscopy that integrates both clinical and exercise methodological aspects (Table 8).^{114,115} In sports with a high proportion of acceleration and deceleration forces, the program should be expanded to include intensive plyometric loads.

To objectify the treatment process, performance tests with medium-high load loading and PROMs should be used

during/after this phase (Appendix 1 and 2). These values are often regarded as functional milestones for unrestricted participation in sports^{27,101,116}:

- Strength Assessment: Maximal strength testing using handheld dynamometry or isokinetics
- Balance Assessment: Mod. Star Excursion Balance Test (mSEBT)
- Assessment of dynamic control: Medial and lateral triple hop test (MTHT, LTHT)
- PROMS: Copenhagen Hip and Groin Outcome Score (HAGOS), Patient-Reported Outcome Measure Information System (PROMIS), Modified Harris Hip Score (mHHS), Hip Outcome Score ADL/Sport (HOS-ADL/SS), short version of the Hip Outcome Tool (iHOT-12), Hip-Return-to-Sport after Injury Scale short and long version (H-RSI). The threshold values of the clinical scores shown in table 9 were determined at a certain time point and for specific cohorts (PROMS: 2-year postoperative, labral repair/debridement + acetabuloplasty/femoroplasty). Therefore, they cannot be applied across the board to all patient groups and are only exemplary.

Normal/good performance values can be seen in Table 9. Please bear in mind that general standard values do not necessarily correspond to specializations in sports.

MATURATION PHASE (>26TH WEEK)

The final phase is aimed at regaining sport-specific skills and, depending on individual goals, enabling participation in physical activities. For professional athletes, success is often defined by a return to play to pre-injury level, while for recreational athletes, success is also designated by achieving clinically relevant improvements in patient-reported outcome measures.¹²³ However, the timing and pos-

Table 8. Return to Running program^{114,115}

Parameters	Recommendation
Inception (time)	→3 month: labral surgery + femoral/ acetabuloplasty →4.5 months: cartilage regeneration procedures
Start (function/clinic)	• Pain: <3/10 (NRS) during exercise • Good movement quality when stepping down • Adequate performance in low intensity tests (see Table 7) • 30 minutes walking possible
Progression	Goal: 1.5km • Week 1: 75% walking – 25% jogging • Week 2: 50% walking – 50% jogging • Week 3: 25% walking – 75% jogging • Week 4: 100% jogging • >Week 5: Increase distance by 10% per week
Criteria for progression	• Pain: <3/10 during exercise • Symptom worsening <24h • Short-term stiffness of the hip joint <10 minutes • No limping

Table 9. Medium-high loading test, PROMS (Appendix 1 and 2)^{27,95,116-122}

Isometric maximum strength ^T	Single-legged-squat test (SLST) and step-down test (SDT)	Modified Star-excursion balance Test (mSEBT)	Medial or lateral triple hop Test (MTHT, LTHT [‡])	Patient reported outcome measures (PROM-Scores (#))
Extension: >3Nm/kg Flexion: >2Nm/kg Abduction: >2Nm/kg Adduction: >2.5Nm/kg ADD/ABD ratio: 120%:100% Flexion/ Extension ratio: 100%:100% LSI: >90%	Overall impression of test performance as <i>passing</i> and four of the five specific criteria must be negative for deviation. A passing grade on at least one of the three repetitions was needed for the overall evaluation to be graded as passing. Therefore, failing two of the three tests still resulted in passing.	≥95% leg length score <4cm difference in individual directions	MTHT: >390cm LTHT: >340cm LSI: >90%	HOS-ADL: MCID 9.7, PASS 88.2 HOS-SS: MCID 14.3, PASS 76.4 mHHS: MCID 9.2, PASS 83.25 iHot-12: MCID 13.9, PASS 72.2 H-RSI (short version) >65%*/>85%** H-RSI (long version) >60%*/>85%** PROMIS Pain Interference: MCID -4.7, PASS 57 PROMIS Physical Function: MCID 5.8, PASS 45.6 HAGOS-Pain: PASS 69 HAGOS-Symptoms: PASS 63 HAGOS-ADL: PASS 83 -HAGOS-Sport/Rec. PASS 61 -HAGOS-Physical activity: PASS 44 -HAGOS-Quality of life: PASS 43

MCID: minimally clinically important difference PASS: patient accepted symptom state, *first value corresponds to the RTS regardless of level, **corresponds to return to performance or return to preinjury level, #: All MCID or PASS values are validated for the 2-year follow-up.

^T Values for hip extension and hip adduction validated in relation to return to sport and difficulties in specific sports activities; values for hip abduction and hip flexion correspond to mean values + 1 SD

[‡] Values correspond to mean value

sible criteria for a safe navigation on the return continuum have not been well studied in this patient population. In an evaluation of $n=130$ studies, functional criteria are still undervalued, and fixed timeframes dominate the decision-making process. Depending on the sporting requirements, around 70% of athletes return between the third and ninth month postoperatively.¹²⁴ However, these studies often exclude patients who have undergone a cartilage regeneration procedure. In these cases, unrestricted participation is not recommended before the 9th to 12th month.¹³

In addition to the time-based criteria, Hugenberg et al.¹¹⁶ recommended successful completion of a functional test battery regarding mobility, strength, coordination and PROMS for an unrestricted RTS (Table 9).¹¹⁶

On average, 85.4% of athletes successfully return to play (RTP). However, the corresponding pre-injury level is reached less frequently, in 72.6% of cases.¹²⁴ As a limitation, there is currently a lack of specific data on the influence of individual surgical procedures or their combination on RTS rates. The results after hip arthroscopy at the long-term follow-up (127.2 months) can be described as good to very good.¹²⁵ The PASS criteria are achieved in 88.9% of cases for the mHHS and in 80% for the HOS-SS. Poorer results are seen in patients after debridement of the labrum or with a pronounced CAM morphology (alpha angle $>78^\circ$), major femoral cartilage damage $>2\text{cm}^2$, or in those with a greatly reduced joint space at the time of surgery.^{125,126} It is therefore imperative that these factors are given due consideration when formulating a prognosis for the anticipated postoperative outcome.

CONCLUSION

This clinical commentary presented by the QKG – Society for Cartilage Regeneration and Joint Preservation provides a summary, evidence-based framework for rehabilitation following surgical treatment of femoroacetabular impingement syndrome (FAIS). By integrating tissue healing timelines with individualized, criteria-based rehabilitation

phases, the approach aims to achieve optimal recovery by striking a balance between post-surgical protection and functional restoration. The multidimensional biopsychosocial model underscores the importance of addressing not only physical impairments but also psychological, cognitive, and contextual factors that influence outcomes. Tailored interventions, from prehabilitation to long-term recovery, emphasize early mobilization, progressive muscle strengthening, and dynamic movement retraining, guided by patient-specific goals and functional milestones. The commentary highlights the necessity of precise exercise prescriptions aligned with surgical procedures, such as cartilage regeneration, labral repair, or bony corrections, to optimize postoperative outcomes. Ultimately, this framework may support clinicians in delivering patient-centered care, improving patient-reported outcomes, and facilitating a safe return to daily activities or sports, with high rates of athletes achieving return to play, though outcomes vary based on surgical complexity and patient factors. Continued research is needed to refine functional criteria for return to sport and to further elucidate long-term outcomes, particularly for those who have undergone cartilage regeneration procedures.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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SUPPLEMENTARY MATERIALS

Appendix 1. QR Code Exercises

Download: https://ijspt.scholasticahq.com/article/146239-physiotherapy-and-exercise-therapy-after-surgical-treatment-of-femoroacetabular-impingement-syndrome-a-clinical-commentary-from-the-qkg-society-for-attachment/307570.pdf?auth_token=Wi95CCetgeKhr-BomhOq

Appendix 2. Assessments

Download: https://ijspt.scholasticahq.com/article/146239-physiotherapy-and-exercise-therapy-after-surgical-treatment-of-femoroacetabular-impingement-syndrome-a-clinical-commentary-from-the-qkg-society-for-attachment/307569.docx?auth_token=Wi95CCetgeKhr-BomhOq

MSK Ultrasound Bites: Tips and Tricks

Diagnostic Musculoskeletal Ultrasound in the Evaluation of Adductor Longus Injuries: Implications for Rehabilitation Providers

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Adductor longus injuries represent a significant clinical challenge in sports medicine and rehabilitation, given their impact on athletic performance and risk for recurrence. Diagnostic musculoskeletal ultrasound (MSK-US) provides a dynamic, cost-effective, and radiation-free modality for evaluating adductor pathology, including tendinopathy, partial tears, and complete ruptures. This article reviews the role of MSK-US in the assessment of adductor longus injuries, emphasizing sonographic anatomy, diagnostic accuracy, and clinical utility. Special attention is given to the integration of ultrasound findings into rehabilitation decision-making, including early injury characterization, monitoring tissue healing, and guiding safe return-to-sport progression. For rehabilitation providers, proficiency in the use and interpretation of MSK-US enhances diagnostic precision and supports a more personalized, evidence-informed rehabilitation approach.

Clinical Implications: Competency in MSK-US evaluation of the adductor longus enables rehabilitation professionals to contribute meaningfully to early diagnosis, injury grading, and interdisciplinary care decisions.

INTRODUCTION

Groin injuries account for up to 10–18% of all sports-related musculoskeletal complaints, with the adductor longus being the most commonly affected muscle of the adductor group. Accurate and timely evaluation is essential, given the functional role of the adductor longus in hip adduction, flexion, and stabilization during high-demand movements such as cutting, sprinting, and kicking resulting in acute injury. However, many injuries to the adductor longus are chronic and repetitive in nature. The mechanical enthesopathies generally present with pain of the inner and top of the thigh which radiate downwards toward the knee. Adductor rupture does occur but is rare compared to overuse. Most commonly in the younger athlete rupture of the tendon occurs as an antero-inferior public avulsion fracture.¹

Magnetic resonance imaging (MRI) is widely considered the gold standard for complex groin pathology. However, diagnostic musculoskeletal ultrasound (MSK-US) provides a practical, dynamic, and cost-efficient alternative that allows direct visualization of the tendon and muscle in real time. The portability of ultrasound makes it particularly attractive for both clinical and sideline evaluation.^{2,3}

SONOGRAPHIC ANATOMY OF THE ADDUCTOR LONGUS

The adductor longus is a large triangular shaped muscle located in the medial thigh compartment. Its origin varies. It can attach anteriorly from tendon fibers (40%) at the pubic body just inferior to the pubic crest, and also to the public symphysis posteriorly via muscular fibers (60%).^{4,5} It can also originate from just muscle fibers or all tendinous fibers. However, it generally inserts on the middle third of the linea aspera of the femur. It is a relatively small muscle in size measuring approximately 11.6 mm in length with a thickness of 3.7 mm with a cartilaginous enthesis.^{5,6}

NORMAL SONOGRAPHIC APPEARANCE

The patient is typically examined in the supine position with a linear transducer. The thigh should be abducted approximately 30 degrees, externally rotated and the knee flexed.⁷ Assessment of the adductors begins with identifying the central aponeurosis of the adductor longus, then moving more proximally the musculotendinous junction or tendon proper. These images can be taken in either long

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axis (LAX) parallel to the muscle and tendon fiber orientation or short axis (SAX) perpendicular to the muscle and tendon fiber orientation.

The adductor longus is easily identified as it is the most superficial of the adductors. Asymptomatic cortical irregularities may be seen due to enthesopathy but may also be seen due to incomplete fusion of secondary ossification centers.⁸ Anisotropy is a common issue as the tendon runs in an oblique direction. The longus tendon is easily seen at its origin at the body of the pubis, just lateral to the pubic symphysis and slightly inferior to the crest. It will appear as a well-defined triangular hypoechoic structure in the SAX view.^{9,10}

KEY SONOGRAPHIC LANDMARKS

- **Proximal tendon origin:** Hyperechoic fibrillar tendon adjacent to the pubic symphysis.
- **Musculotendinous junction:** Transition from tendon to pennate muscle belly, a common site of injury.
- **Dynamic imaging:** Resisted hip adduction enhances visualization of subtle defects or tendon gapping.

DIAGNOSTIC UTILITY OF MSK-US

ACCURACY AND SENSITIVITY

- Ultrasound demonstrates high sensitivity in detecting partial- and full-thickness adductor longus injuries, with the advantage of dynamic evaluation and contralateral comparison.
- Compared with MRI, MSK-US provides faster, lower-cost evaluation, though MRI may still be warranted in complex cases or when broader differential diagnoses are considered.

TYPICAL PATHOLOGICAL FINDINGS

- **Acute strains/tears:** Hypoechoic or anechoic regions within tendon or musculotendinous junction; associated hematoma.
- **Chronic tendinopathy:** Tendon thickening, heterogeneous echotexture, reduced fibrillar pattern, and possible neovascularization on Doppler.
- **Complete rupture:** Loss of continuity with tendon retraction, surrounding hematoma, and fluid collection.

ADVANCED TECHNIQUES

- **Power doppler/Color doppler:** Useful in identifying neovascularization in tendinopathy.
- **Microvascular imaging (MVI):** May improve sensitivity in detecting low-flow neovessels, with potential relevance in chronic cases.

COMPARATIVE ROLE WITH OTHER MODALITIES

- **Clinical examination:** Critical first step but limited in grading severity.
- **MRI:** Comprehensive cross-sectional imaging; superior for complex or multi-structure involvement.
- **MSK-US:** Portable, dynamic, repeatable, cost-effective; optimal for serial monitoring and sideline assessment.

CLINICAL IMPLICATIONS FOR REHABILITATION PROVIDERS

Although rehabilitation planning is not the primary focus here, the evaluation phase directly informs care decisions. For example:

- Grading partial vs. complete rupture affects timelines for load progression.
- Identifying tendinopathy versus acute tear differentiates between rest, progressive loading, or surgical referral.
- Serial ultrasound imaging allows objective monitoring of healing before return-to-play clearance.

Thus, MSK-US is not simply diagnostic—it is integral to the continuum of clinical reasoning for rehabilitation providers.

CONCLUSION

Diagnostic MSK-US is a powerful and practical tool for evaluating adductor longus injuries. Its ability to provide immediate, dynamic, and repeatable insights makes it highly valuable in sports medicine and rehabilitation settings. While MRI remains important for complex cases, ultrasound offers unique advantages at the point of care, particularly for rapid diagnosis, injury grading, and monitoring. Rehabilitation providers who develop competency in sonographic evaluation are positioned to enhance diagnostic precision and improve patient outcomes.

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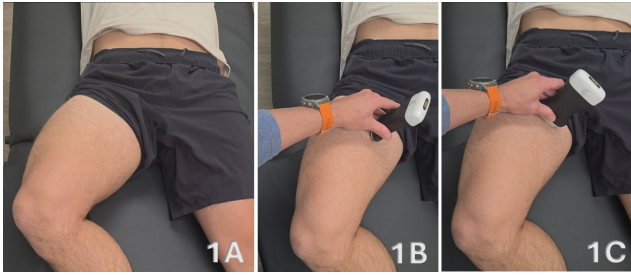


Figure 1A: Patient Positioning

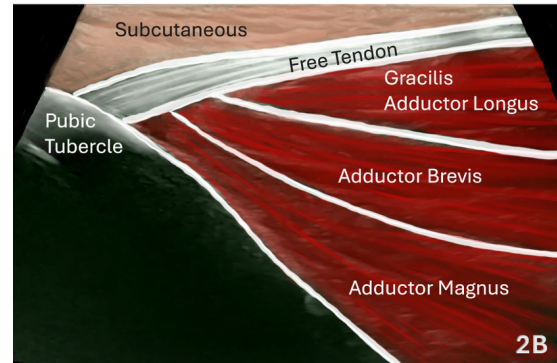
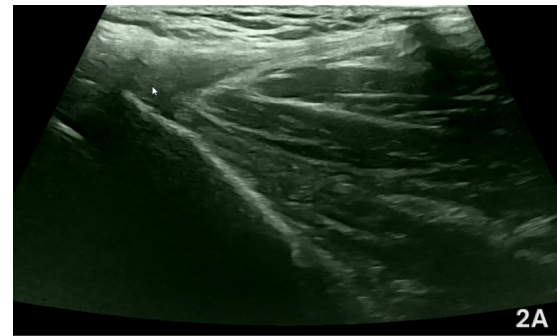
The patient is positioned supine with the hip in neutral and the knee slightly flexed (~20–30°) to relax the adductor compartment. The thigh should be externally rotated slightly to expose the medial aspect. Support the knee with a towel roll as needed. For proximal tendon evaluation, ensure the groin and pubic region are appropriately draped and exposed for access from the pubic symphysis to the mid-thigh. Imaging is performed at rest, with optional dynamic adduction against gentle resistance to assess contractile thickening or focal pain reproduction.

Figure 1B: Transducer Placement for Adductor Longus in LAX

To obtain a LAX view, place a high-frequency linear transducer parallel to the long axis of the adductor longus muscle and tendon, centered along the medial thigh from its origin at the pubic body and pubic crest. The transducer marker should face proximally toward the patient's head. Optimize depth so that the full tendon-to-muscle transition is visible. In this orientation, the fibrillar tendon extends distally and merges into the hypoechoic muscle belly. Slight heel-toe angulation helps minimize anisotropy. Follow the tendon proximally to its superficial insertion adjacent to the pubic symphysis, noting the relationship to the gracilis (superficial and medial) and the adductor brevis (deep and posterior).

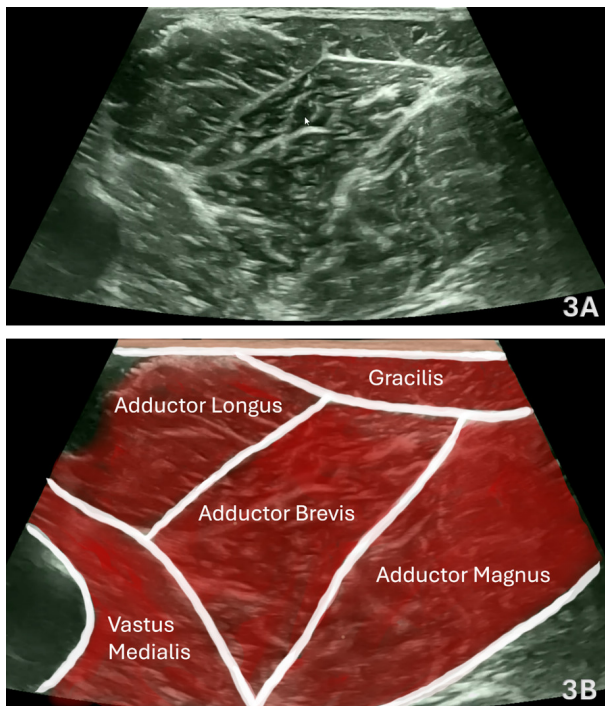
Figure 1C: Transducer Placement for Adductor Longus in SAX

For SAX imaging, rotate the transducer 90° so the marker points toward the patient's right. Begin at the proximal origin of the adductor longus just inferior to the pubic tubercle, identifying the round to oval echogenic tendon surrounded by hypoechoic muscle tissue. In this plane, the gracilis appears medial and slightly superficial, while the adductor brevis and magnus lie deep and posterior. Sweep proximally toward the pubic insertion and distally through the muscle belly to ensure continuity and assess for localized disruption, edema, or hematoma. Subtle probe tilting should be used to maintain perpendicular insonation and prevent anisotropy of the tendon fibers.



Figures 2A and 2B: Normal Adductor Longus in LAX

Refer to Figure 1B for the transducer position for this image. In LAX, align the transducer parallel to the adductor longus fibers and center the muscle belly longitudinally. The adductor longus appears as a hypoechoic, pennate muscle with a uniformly fibrillar tendon proximally that transitions smoothly into the muscular portion distally. The tendon demonstrates parallel hyperechoic lines converging toward its bony attachment on the pubis, just lateral to the symphysis. Deep to the adductor longus, portions of the adductor brevis and adductor magnus can be visualized, while the gracilis lies more superficial and medial. Optimize imaging so the proximal tendon and its insertion are clearly visualized, positioning the posterior border of the muscle in the lower third of the image with the focal zone at or just deep to this level. Use slight heel-toe adjustments to minimize anisotropy and maintain a consistent insonation angle. Document tendon continuity, echotexture, and thickness at rest, and, when appropriate, during gentle resisted adduction to assess for contractile integrity and pain reproduction.



Figures 3A and 3B: Normal Adductor Longus in SAX

Refer to Figure 1C for the transducer position for this image. In SAX, position the transducer transversely just posterior to the adductor longus tendon and center over the muscle belly. The gracilis serves as a consistent superficial and medial landmark, with the adductor longus positioned deep to it, and the adductor brevis and adductor magnus lying deeper and more posterior—forming the characteristic layered appearance of the medial thigh (gracilis → longus → brevis → magnus). The intramuscular tendon of the adductor longus may be seen centrally as an oval echogenic structure surrounded by hypoechoic muscle tissue. Use light transducer pressure to avoid compression artifacts and maintain consistent depth and contrast. Sweep proximal ↔ distal along the muscle to evaluate continuity from the pubic attachment through the myotendinous junction and into the distal belly. Apply gentle probe toggling to minimize anisotropy, particularly near the tendon, ensuring that echogenicity accurately represents fiber alignment. Document tendon thickness, echotexture, and continuity bilaterally for comparison, noting any focal hypoechoicities, loss of definition, or asymmetry that may indicate tendinopathy or partial tearing.



Figure 4. Adductor Longus Tear (LAX and SAX)

Figures 4A and 4B demonstrate a complete non-bony avulsion of the adductor longus tendon from its pubic attachment, with approximately 32 mm of tendon retraction and an intervening fluid-filled defect consistent with acute hematoma or edema. The retracted tendon end appears thickened and oedematous, indicative of acute injury. The adductor brevis, adductor magnus, gracilis, and pectineus muscles demonstrate normal echotexture and continuity, confirming that the injury is isolated to the adductor longus.¹¹

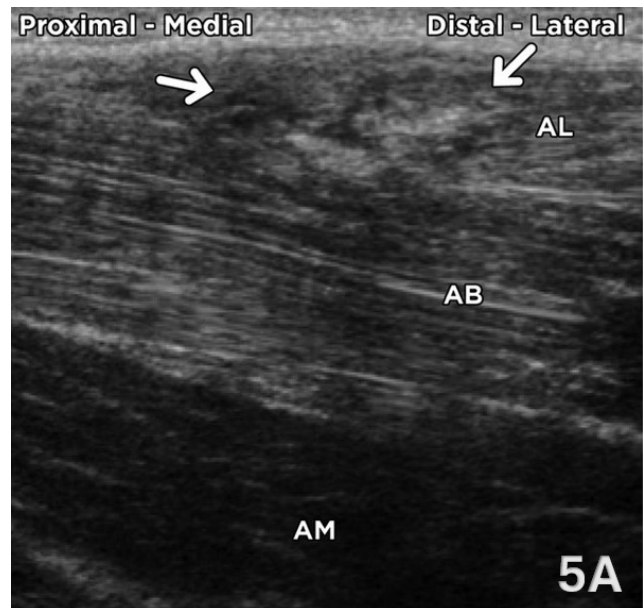


Figure 5. Partial Adductor Longus Muscle Tear in LAX

Figure 5A shows a partial adductor longus muscle tear in a 22-year-old male tennis player presenting with an acute tearing sensation in the right inguinal region. A longitudinal oblique ultrasound image of the proximal adductor compartment demonstrates focal heterogeneity, architectural distortion, and fiber discontinuity within the adductor longus (AL), consistent with a partial muscle tear. The adductor brevis (AB) and adductor magnus (AM) appear intact and maintain normal echotexture and architecture.¹²



Figure 6. Adductor Longus Tendinosis in LAX

Figure 6A shows a chronic adductor longus tendinopathy in a 36-year-old male runner with a history of bilateral groin pain. LAX ultrasound imaging of the contralateral left adductor longus demonstrates a thickened, hypoechoic tendon origin consistent with tendinosis, accompanied by a small focal detachment at the pubic attachment (arrow). The adjacent adductor brevis, adductor magnus, gracilis, and pectineus muscles appear normal in echotexture and architecture, confirming that the pathology is isolated to the adductor longus.¹³



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