

Predictive Efficacy of Dynamic Shear-Wave Velocity Change in the Distal Biceps Femoris Long Head versus Clinical Flexibility Tests for Hamstring Strain in Light Volleyball Athletes: A Prospective Cohort Study

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Abstract

Background: Light volleyball (LVB) is a popular recreational sport with increasing participation. Hamstring strain (HS) is common among LVB players and leads to significant time loss and reinjury risk. Clinical flexibility tests such as passive knee extension (KE), straight leg raise (SLR), and forward flexion distance (FFD) are widely used for HS screening, but prospective evidence of their predictive value is limited and conflicting. Shear-wave elastography (SWE) can quantify muscle mechanical properties, yet its role in predicting future HS remains unclear. This study aimed to compare the predictive value of a dynamic SWE parameter—the change in shear-wave velocity (Δ SWV) of the distal biceps femoris long head (BF_{lh}) from relaxed to maximally stretched position—against KE, SLR, and FFD for 3-month HS risk in LVB enthusiasts.

Methods: In this prospective cohort study, 75 healthy LVB players (42 males, 33 females, age 25.7 ± 6.2 years) underwent baseline measurements of SWV at distal/proximal BF_{lh} and semitendinosus in relaxed and stretched positions (Δ SWV calculated), along with KE, SLR, and FFD. Participants were followed for 3 months to record HS occurrence. Predictive performance was assessed using receiver operating characteristic (ROC) curves, and comparisons between tests were made with the DeLong test.

Results: Nine participants (12.0%) sustained HS. Only distal BF_{lh} Δ SWV was significantly higher in the HS group (median 8.17 vs. 4.40 m/s, $P < 0.001$). Its area under the ROC curve (AUC) was 0.985 (95% CI: 0.954–1.000), with an optimal cutoff of 7.37 m/s, sensitivity 0.889, and specificity 1.000. AUCs for KE, SLR, and FFD were 0.427, 0.536, and 0.603, respectively; the combined AUC was 0.641, all significantly lower than Δ SWV ($P < 0.001$). Firth regression yielded an odds ratio of 28.14 per m/s ($P < 0.001$).

Conclusions: Distal BF_{lh} Δ SWV accurately predicts 3-month HS risk in LVB players, far outperforming KE, SLR, and FFD alone or combined. These findings suggest that dynamic SWE measurement could serve as a valuable screening tool for HS risk, although further validation in larger populations is warranted.

Clinical trial number: Not applicable.

INTRODUCTION

Light volleyball (LVB)—a modified version of traditional volleyball—has gained popularity as a recreational sport that retains the core technical actions of its parent game, including sudden take-offs, spiking, and rapid directional changes, while imposing lower competitive demands on participants.¹ Despite its recreational nature, the sport carries a substantial risk of lower limb injuries, particularly hamstring strain (HS), which frequently occurs during explosive push-off and landing maneuvers.^{2,3} The high incidence of HS in LVB players is largely attributed to excessive passive stiffness and inadequate extensibility of the hamstring muscle-tendon unit, which compromise the tissue's ability to absorb and dissipate energy during high-intensity actions.⁴⁻⁶

A critical distinction must be drawn between joint flexibility and passive tissue stiffness—two related but fundamentally different biomechanical constructs. Flexibility denotes the angular excursion achievable at a joint, which is modulated by a complex interplay of muscle extensibility, neural stretch tolerance, and capsular compliance.^{7,8} Passive muscle stiffness, by contrast, represents an intrinsic material property of the muscle-tendon unit, quantifying its resistive force to an applied elongating load. This parameter can be objectively measured using shear-wave elastography (SWE), which provides a non-invasive window into the mechanical behavior of living muscle tissue.⁹

In routine sports screening, flexibility tests such as passive knee extension (KE), straight leg raise (SLR), and forward flexion distance (FFD) are widely employed due to their simplicity, low cost, and lack of specialized equipment requirements.¹⁰ Although cross-sectional studies have linked poor performance on these tests to prior HS,¹¹ prospective evidence supporting their predictive utility for future injuries remains limited and conflicting.^{10,12} This inconsistency may arise because flexibility tests predominantly capture neural stretch tolerance and pain perception rather than the intrinsic mechanical behavior of the muscle tissue itself.¹³

Recent advances in SWE have enabled direct quantification of muscle stiffness, and studies have shown that individuals with a history of HS exhibit elevated shear-wave velocity (SWV) in the affected hamstrings.¹⁴ However, most existing SWE investigations have relied on single-angle static stiffness measurements,^{15,16} and prospective data linking SWE-derived parameters to future HS risk are scarce. Moreover, no study has directly compared the predictive performance of SWE against the conventional flexibility test battery.

Evidence suggests that the change in stiffness from a shortened to a fully lengthened position may better capture the functional reserve and injury susceptibility of the hamstring than a single static value.¹⁷ Building on this concept, we designed this prospective cohort study to: (1) measure the change in SWV (Δ SWV) across multiple hamstring sites and two joint positions; (2) determine which site/parameter best predicts HS occurrence within 3 months; and (3) directly compare its predictive efficacy against the KE, SLR, and FFD combination. We hypothesized that dynamic Δ SWV would outperform traditional flexibility tests in identifying athletes at elevated HS risk, thereby offering a more accurate and biologically grounded screening approach.

MATERIAL and METHODS

Participants

A total of 100 volunteers were initially screened from local LVB clubs. After applying the eligibility criteria, 75 participants (42 males, 33 females; mean age 25.7 ± 6.2 years) were enrolled in this prospective cohort study. To be eligible, participants had to meet the following requirements: (1) regular LVB participation (≥ 2 sessions/week for the preceding 6 months); (2) age 18–60 years; (3) ability to safely

perform all testing maneuvers; and (4) provision of written informed consent. Exclusion criteria comprised: (1) concurrent enrollment in other flexibility-related studies within 3 months; (2) strenuous exercise within 24 hours before testing; (3) acute hamstring injury at the time of enrollment; (4) history of lumbar disc pathology; and (5) clinical signs of generalized ligamentous laxity.¹⁸ Prior to the experiment, all participants were informed of the detailed procedures, potential benefits, and possible risks, and voluntarily signed an informed consent form. The study was approved by the Institutional Review Board of Taiyuan University of Technology (Approval No. TYUT2025070402) and conducted in accordance with the Declaration of Helsinki.

Study Design and Protocol

This was a prospective cohort study. Participants visited the laboratory only once for baseline measurements and were then followed up online for 3 months. Baseline measurements were conducted in a constant-temperature laboratory at 26°C. The measurement sequence was: SWE measurement first, followed by the three flexibility tests in the order of KE, SLR, and FFD. The entire baseline assessment took approximately 8 minutes per participant.

Participants were instructed to maintain their normal dietary habits and refrain from vigorous physical activity for two days prior to the experiment. During the entire baseline assessment period, all participants were required not to perform any flexibility training or interventions that could affect flexibility (such as static stretching, massage, etc.), other than the requirements of the experimental protocol. Violators' results would be excluded from the study. A flowchart of the study procedures is shown in Figure 1.

Baseline Measurements

Shear-Wave Elastography (SWE) Measurements

Two-dimensional SWE was used to measure the shear-wave velocity (SWV) of the distal and proximal regions of the biceps femoris long head (BFlh) and semitendinosus (ST) of the dominant leg in two positions: a relaxed position (90° hip and knee flexion) and a maximally stretched position (passive knee extension). The Δ SWV between these two positions was calculated for HS prediction. The dominant leg was determined by asking participants which leg they used to land when spiking.

Participant positioning and anatomical landmarking: Prior to SWE measurement, the measurement sites on the dominant leg were marked. The measurement sites for BFlh and ST in the passive maximum stretch position were at 25% (proximal) and 75% (distal) of the respective muscle belly length.¹⁷ First, conventional B-mode ultrasound was used to identify the myotendinous junction of BFlh and ST with the

participant in the prone position, and the sites were marked with a skin marker. The corresponding measurement sites were then calculated using a tape measure.

SWE measurements were always performed in the relaxed position first, followed by the maximally stretched position, to avoid the effect of passive stretching on baseline muscle stiffness. The specific procedures were as follows¹⁷: (1) Relaxed position: the experimenter passively placed the dominant hip and knee at 90° flexion, and the participant was instructed to relax completely without contracting any leg muscles. The ultrasound probe was placed longitudinally over the anatomical landmarks with minimal pressure, and after a stabilization period of 5–8 seconds, the elastography image was recorded; (2) Maximally stretched position: with the hip maintained at 90° flexion, the same experimenter slowly and passively extended the knee. Extension was stopped when either of the following endpoints was reached: (a) the experimenter felt significant resistance to further extension (muscle tautness); or (b) the participant reported a strong but tolerable stretch sensation (rated 7/10 on a numerical rating scale), whichever came first. The final knee extension angle (relative to full extension) was recorded and reused for the same participant in all subsequent measurements to ensure consistency of muscle-tendon unit length. The ultrasound probe was then repositioned over the same skin mark, and the SWE measurement was repeated. During this process, the participant's pelvis was secured to the plinth with a non-elastic strap, and the ankle was maintained at 10° plantarflexion by the experimenter performing the passive knee extension.

SWE parameter settings and Δ SWV calculation: All SWE acquisitions were performed with a Mindray Resona R9T ultrasound platform (Shenzhen, China) using a linear array transducer (L15-3WU) configured in musculoskeletal elastography mode (transmit frequency: 3–15 MHz; imaging depth: 3–5 cm). A standardized acquisition protocol was followed: after probe placement, the system was allowed to stabilize for 5–8 seconds, and an image was accepted only when the built-in motion stability index reached ≥ 4 and the reliability index exceeded 90%. The elastogram was then frozen, and a circular region of interest (ROI) of 5-mm diameter was manually positioned within homogeneous color-coded areas, carefully avoiding myofascial interfaces and visible artifacts. The software automatically computed the mean SWV and its standard deviation within each ROI. Measurements with excessive variability—typically attributable to inconsistent probe pressure or inadvertent muscle contraction—were discarded.¹⁷ For each anatomic site, two valid acquisitions were obtained, and the one with the lower standard deviation was retained for subsequent analyses. All SWE measurements and ROI analyses were performed by the same trained ultrasonographer (Figure 2).

After completing the SWE measurements, Δ SWV was calculated for the distal and proximal regions of BFIh and ST from the relaxed to the maximally stretched position using the following formula:

$$\Delta\text{SWV} = \text{SWV}_{\text{stretched}} - \text{SWV}_{\text{relaxed}}$$

A higher Δ SWV value indicates a greater increase in muscle stiffness from the relaxed to the stretched position, suggesting reduced muscle flexibility.

Flexibility Tests

Immediately after SWE measurement, flexibility tests were performed on the dominant leg in the following order: KE, SLR, and FFD.

Passive knee extension (KE): For the passive knee extension test, participants were positioned supine with the tested hip and knee maintained at 90° of flexion. A standard goniometer was centered over the lateral femoral condyle, with the stationary arm aligned with the femoral shaft and the movable arm tracking the fibula. Participants were instructed to actively extend the knee while the examiner stabilized the pelvis to prevent compensatory rotation. The residual knee flexion angle (relative to full extension) was recorded as an index of hamstring tightness, with smaller angles indicating greater flexibility.¹⁹

Straight leg raise (SLR): The straight leg raise test was performed with participants in the supine position, legs fully extended. The goniometer axis was positioned at the greater trochanter, with one arm parallel to the supporting surface. Participants were asked to relax while the examiner passively elevated the tested limb with the knee maintained in full extension. The maneuver continued until the participant reported a strong but tolerable stretch sensation or until compensatory pelvic motion was observed. The angle between the limb and the horizontal plane was recorded at this endpoint.²⁰

Forward flexion distance (FFD): For the forward flexion distance test, participants stood barefoot on a standardized measuring box with feet shoulder-width apart and knees fully extended. They were instructed to bend forward at the trunk as far as possible while keeping the knees straight, reaching downward with both hands (palms parallel, fingers extended). The distance from the fingertips to the top of the measuring box was recorded using a portable tape measure; positive values indicated fingertips above the box surface (i.e., unable to reach the toes), while negative values indicated extension below the box.²¹

To minimize measurement error, all flexibility tests were performed at least twice with 15 seconds rest between repetitions. If two adjacent measurements differed by $\geq 2^\circ$ or 2 cm, additional measurements were taken until the difference between two adjacent measurements was $\leq 2^\circ$ or 2 cm. The average of the two adjacent measurements was recorded as the final result. All flexibility tests were performed by the same examiner.

Follow-up and Outcome Assessment

The primary outcome was the incidence of HS diagnosed during the 3-month follow-up period. After baseline assessment, participants entered a 3-month follow-up period during which they continued their regular LVB training and matches without any intervention from the research team. Every two weeks, a research assistant contacted each participant by phone or via a messaging application to inquire about any lower limb pain, injury, or training absence.

If a participant reported acute posterior thigh pain during or immediately after LVB activity, a clinical examination was arranged within 48 hours. The examination was performed by a rehabilitation physician who was blinded to the baseline SWE and flexibility test results. HS was diagnosed according to the following criteria based on clinical guidelines²²: (1) sudden posterior thigh pain during sports activity; (2) tenderness on palpation of the hamstring muscles; (3) pain and/or weakness during resisted knee flexion or hip extension. In this study, any first or recurrent HS during the 3-month period was counted as one event; participants with multiple episodes were counted only at the time of the first event.

Sample Size Estimation

A priori sample size determination was performed using PASS 2025 software, applying the Hanley–McNeil method for confidence interval estimation of the area under the ROC curve. With a conservative anticipated AUC of 0.85, a null hypothesis AUC of 0.50, a two-sided alpha of 0.05, and a desired confidence interval half-width (Δ) of 0.10, and assuming a case-to-healthy ratio of 1:7 (corresponding to an expected HS incidence of approximately 12.5%), the minimum required sample was calculated as 64 participants (8 cases and 56 healthy controls). To safeguard against potential attrition, we ultimately enrolled 75 participants.

Statistical Analysis

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and R version 4.2 (R Foundation for Statistical Computing, Vienna, Austria) with the `logistf` package for penalized likelihood regression. The threshold for statistical significance was set at a two-tailed alpha of 0.05. Normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed variables are reported as mean $\pm$ standard deviation (SD), whereas non-normally distributed variables are summarized as median with interquartile range (IQR); categorical variables are expressed as frequencies and percentages.

Between-group comparisons of baseline demographic and clinical characteristics were performed using the independent-samples t-test for normally distributed continuous variables with homogeneous variances, and the Mann–Whitney U test for non-normally distributed or heteroscedastic variables. Sex distribution was compared using Fisher's exact test. Any demographic variable showing a significant between-group difference would have been included as a covariate in subsequent regression models; however, no such differences were observed.

The analytic strategy proceeded in three stages. First, Δ SWV values at the four measurement sites (distal and proximal BFIh, distal and proximal ST) were compared between the HS and healthy groups to identify sites with significant group differences. Only sites meeting this criterion were carried forward to subsequent analyses. For the site(s) thus identified, Spearman's rank correlation coefficients were computed to assess associations with KE, SLR, and FFD. Second, receiver operating characteristic (ROC)

curves were constructed to evaluate predictive performance for HS, with calculation of the area under the curve (AUC) and its 95% confidence interval via bootstrapping (1,000 resamples). The optimal cutoff was determined using the Youden index, from which sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were derived. Third, given the small number of HS events, Firth's penalized likelihood logistic regression was employed to analyze the association between the identified Δ SWV site and HS occurrence, yielding odds ratios (OR) with 95% CI.

Separate ROC curves were generated for KE, SLR, and FFD individually and in combination (the latter via binary logistic regression with all three tests as independent variables). The DeLong test was used to compare AUCs between the identified Δ SWV parameter and the combined flexibility test model. Model calibration was assessed using the Hosmer–Lemeshow test. AUC values between 0.5 and 0.7 were interpreted as low accuracy, 0.7 to 0.9 as moderate accuracy, and above 0.9 as high accuracy.²³

RESULTS

All participants completed the 3-month follow-up with no dropouts, and their data were included in the analysis. Nine participants (12.0%) sustained an HS during the follow-up period (7 first-time, 2 recurrent). Table 1 presents the demographic characteristics and baseline KE, SLR, and FFD values for the HS and healthy groups. The Shapiro–Wilk test indicated that KE, SLR, and FFD did not follow normal distributions; thus, the Mann–Whitney U test was used for between-group comparisons.

Between-Group Comparisons and Correlation Analysis

Table 2 presents the descriptive statistics of SWV and Δ SWV at the distal and proximal regions of BFlh and ST in both the relaxed and maximally stretched positions for the two groups. After normality testing, the data were found to be non-normally distributed; therefore, the Mann–Whitney U test was used for analysis. The Mann–Whitney U test showed that only distal BFlh Δ SWV was significantly higher in the HS group than in the healthy group (median 8.17 m/s vs. 4.40 m/s, $U=585.0$, $P<0.001$), while no significant differences were observed for proximal BFlh, distal ST, or proximal ST Δ SWV ($P\geq 0.118$).

Since KE, SLR, FFD, and distal BFlh Δ SWV all violated normality, Spearman's correlation analysis was performed to examine the associations between distal BFlh Δ SWV and the three flexibility tests. The results showed no significant correlations between distal BFlh Δ SWV and KE ($\rho=-0.057$, $P=0.627$), SLR ($\rho=-0.012$, $P=0.920$), or FFD ($\rho=0.050$, $P=0.673$). Therefore, subsequent predictive performance analyses were conducted only for distal BFlh Δ SWV.

Predictive Performance Analysis

Predictive Performance of Distal BFlh Δ SWV

The ROC analysis for distal BFlh Δ SWV yielded an AUC of 0.985 (95% CI: 0.954–1.000), indicating excellent discriminative capacity. The Youden index optimized the cutoff at 7.37 m/s, at which the test demonstrated a sensitivity of 0.889, specificity of 1.000, positive predictive value of 1.000, and negative predictive value of 0.985 (Figure 3A).

Firth's penalized likelihood logistic regression showed that each 1 m/s increase in distal BFlh Δ SWV was associated with an approximately 28-fold higher risk of HS (OR = 28.14, 95% CI: 4.28–1675.25, $P < 0.001$).

Predictive Performance of Flexibility Tests

The ROC curves for KE, SLR, and FFD individually are shown in Figure 3B. The AUCs were 0.427 (95% CI: 0.215–0.638) for KE, 0.536 (95% CI: 0.366–0.701) for SLR, and 0.603 (95% CI: 0.447–0.658) for FFD. Since all three flexibility tests had AUCs below 0.7, indicating low diagnostic accuracy, sensitivity and specificity were not further calculated. The combined model using binary logistic regression with KE, SLR, and FFD as independent variables yielded an AUC of 0.641 (95% CI: 0.506–0.777), with a Youden index-based cutoff of 0.081, sensitivity of 1.000, and specificity of 0.379 (Figure 3C). The DeLong test showed that the combined flexibility test model had significantly lower predictive efficacy than distal BFlh Δ SWV ($Z = 4.399$, $P < 0.001$).

DISCUSSION

This prospective cohort study represents, to our knowledge, the first head-to-head comparison of a dynamic shear-wave elastography parameter—specifically, the change in shear-wave velocity (Δ SWV) from a relaxed to a maximally stretched position—against a battery of clinical flexibility tests for predicting 3-month hamstring strain risk. By simultaneously sampling four anatomically distinct hamstring sites (distal and proximal BFlh, distal and proximal ST), we were able to identify the distal BFlh as the sole location with significant predictive value, thereby providing novel insights into the site-specific nature of hamstring injury risk.

Our results demonstrate that athletes who sustained an HS within 3 months had significantly higher baseline distal BFlh Δ SWV than those who remained healthy, with an AUC of 0.985 for predicting HS. The optimal cutoff of 7.37 m/s yielded a PPV of 1.00 and NPV of 0.985, indicating excellent performance in identifying individuals who would develop HS within 3 months. To our knowledge, only a few prospective studies in soccer players have used SWE to measure hamstring stiffness in relation to HS,^{6,24} but these measured static muscle stiffness at a specific joint angle and lacked dynamic stiffness comparisons across different angles. The dynamic two-position measurement method employed in our study more closely reflects the functional state of muscles from a shortened to a fully stretched position during actual sports movements, and may be more sensitive in capturing tissue mechanical properties closely related to injury risk. Furthermore, several cross-sectional studies have reported increased BFlh muscle stiffness in individuals with a history of HS,^{14,25} consistent with the baseline comparison results of our

study. However, prospective evidence remains scarce. Thus, our study provides important prospective evidence for the use of dynamic SWE parameters in predicting HS, and is the first to identify distal BFlh Δ SWV as a key predictor for HS risk screening.

The high predictive value of distal BFlh Δ SWV for HS may be explained by the unique biomechanical demands placed on this region during LVB-specific movements. The distal BFlh is subjected to the greatest eccentric strain during the late swing phase of running and jumping,²⁶ and this region has been shown to exhibit longer fascicle lengths and smaller physiological cross-sectional areas, rendering it particularly vulnerable to strain injury.²⁷ Long-term training or previous minor injuries may lead to extracellular matrix proliferation and increased collagen cross-linking in this region, resulting in abnormally elevated stiffness during passive elongation.²⁸ Our findings suggest that the ability of this region to accommodate elongation—as reflected by the Δ SWV parameter—may be a more sensitive indicator of injury susceptibility than static stiffness measures or joint-level flexibility assessments. When Δ SWV exceeds 7.37 m/s, it may indicate that the hamstring soft tissue in this region has lost normal passive extensibility, rendering it unable to effectively absorb energy during high-intensity sports, thereby predisposing to muscle fiber tears.²⁹ This parameter could be integrated into pre-season risk assessment systems for elite athletes to accurately identify high-risk individuals and implement targeted injury prevention interventions.

Although previous studies have suggested that KE, SLR, and FFD have high predictive efficacy for HS,^{10,29} our study found that these tests, alone or in combination, could not effectively predict HS. One possible explanation is that flexibility tests are primarily influenced by neurobehavioral factors such as neural stretch tolerance, pain anticipation, and joint capsule compliance, rather than the passive biomechanical properties of the muscle itself.³⁰ In healthy asymptomatic populations, joint range of motion is largely determined by individual anatomical differences and the central nervous system's threshold for stretch perception, and thus may not reflect the true stiffness state of muscle tissue. On the other hand, the association between poor flexibility and HS history observed in cross-sectional studies may more likely represent a "residual effect" of hamstring scar formation and adhesion after injury, rather than a pre-injury risk factor.⁶ Nevertheless, flexibility tests still offer the advantages of simple operation, no equipment requirement, and extremely low cost, and may serve as a rough baseline assessment reference in grassroots sports teams lacking SWE equipment. However, they should not be over-relied upon as the primary tool for HS risk screening.

Several limitations of this study should be acknowledged. First, the number of HS events was relatively small ($n=9$), and although the effect size was large, there remains a potential risk of overfitting. Second, the relatively small number of female participants precluded sex-based subgroup analysis, which may have reduced statistical power. Third, the follow-up period was only 3 months, which did not cover a full competitive season, and the predictive performance of Δ SWV over longer periods remains unknown. Fourth, we did not collect data on potential confounding factors such as training load, hamstring strength, previous injury severity, or warm-up habits, which may interact with Δ SWV to influence HS risk.

Future multicenter, large-sample, long-term follow-up studies are needed to validate the predictive efficacy of distal BFlh Δ SWV and to explore its combined predictive model with functional tests, training load, and muscle strength.

CONCLUSIONS

This study demonstrates that dynamic shear-wave velocity change in the distal biceps femoris long head (Δ SWV) provides excellent prediction of 3-month hamstring strain risk in light volleyball enthusiasts, outperforming traditional flexibility tests. While previous studies have identified static stiffness measured by shear-wave elastography as a marker of previous hamstring injury, our findings extend this by showing that a two-position dynamic parameter—rather than single-angle measurement—offers superior prospective predictive value. Unlike clinical flexibility tests, which primarily reflect neural tolerance and joint compliance, Δ SWV captures the intrinsic mechanical properties of the muscle-tendon unit during functional elongation. This approach may address the limitations of current screening tools and could be integrated into pre-season risk assessment protocols. Future research should validate the proposed cutoff (7.37 m/s) in larger, diverse populations and explore portable alternatives to laboratory-based elastography. If confirmed, this parameter could enhance injury prevention strategies in recreational and elite sports settings.

Abbreviations

Abbreviations	Full term
BFIh	Biceps femoris long head
CI	Confidence interval
FFD	Forward flexion distance
HS	Hamstring strain
IQR	Interquartile range
KE	Passive knee extension
LVB	Light volleyball
NPV	Negative predictive value
OR	Odds ratio
PPV	Positive predictive value
ROC	Receiver operating characteristic
SD	Standard deviation
SLR	Straight leg raise
ST	Semitendinosus
SWE	Shear-wave elastography
SWV	Shear-wave velocity

Declarations

Ethics approval and consent to participate The study received ethical approval from the Institutional Review Board affiliated with one of the authors (Approval No. TYUT2025070402) and conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to participation.

Consent for publication Not applicable.

Trial registration: Not applicable.

Availability of data and material All processed raw data (in csv files) are available from the lead author for subsequent analysis/inclusion in meta-analysis upon request (please contact via email: Renkang@tyut.edu.cn).

Competing interests None.

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Conflict of Interest: None.

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Tables

Tables 1 and 2 are available in the supplementary files section.

Figures

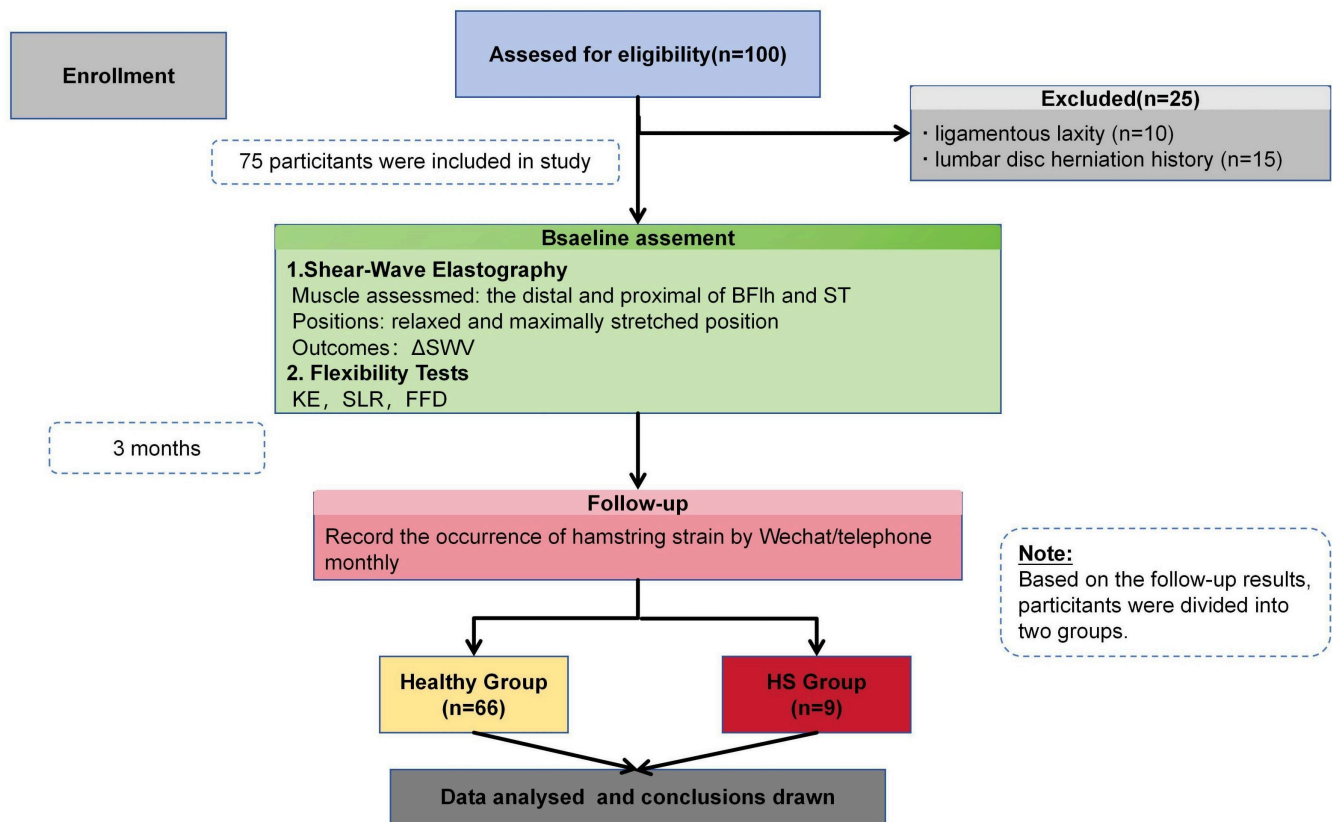


Figure 1. study flowchart

Figure 1

Study flowchart.

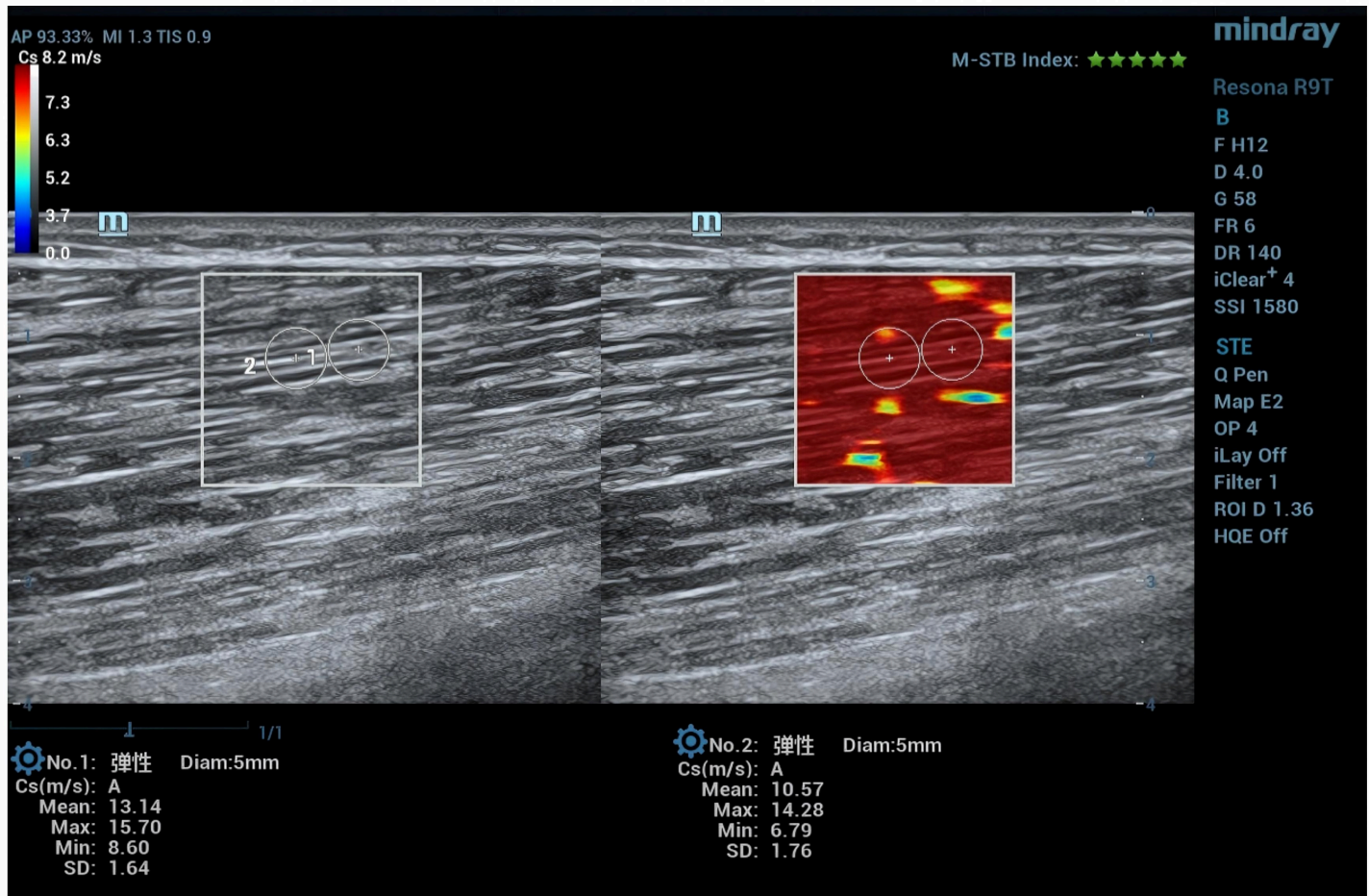


Figure 2. Representative SWE image showing the measurement site (distal BFlh)

Figure 2

Representative SWE image showing the measurement site at the distal biceps femoris long head (BFlh).

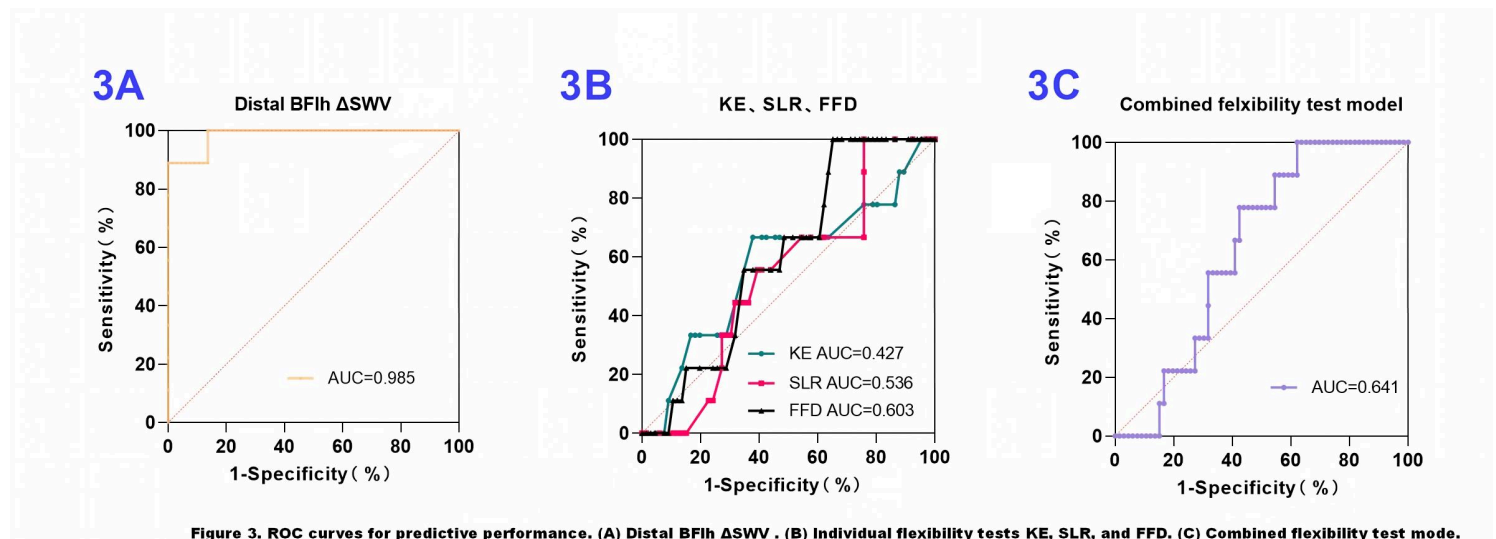


Figure 3. ROC curves for predictive performance. (A) Distal BFlh Δ SWV . (B) Individual flexibility tests KE, SLR, and FFD. (C) Combined flexibility test model.

Figure 3

ROC curves for predictive performance. (A) Distal BFlh Δ SWV . (B) Individual flexibility tests KE, SLR, and FFD. (C) Combined flexibility test model.

Supplementary Files

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