

Validation of Shear-Wave Elastography for Detecting Kager's Fat Pad Inflammation: A Pilot Study

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Abstract

Kager's fat pad (KFP) is inflammation-sensitive due to its anatomical location. This study evaluates the ability of Shear-Wave Elastography (SWE) to visualize Kager's Fat Pad (KFP) inflammation as diagnosed by Magnetic Resonance Imaging (MRI). This prospective study involved 33 patients (23 control, 10 with disease) having ankle pain who obtained MRI as the gold standard, followed by SWE. Both affected and asymptomatic ankles underwent scanning. MRI was conducted with a 1.5-T scanner with a specialised ankle coil in a neutral position. The SWE was performed in the longitudinal plane with patients in a prone position and the ankle extended at 90 degrees. The inter-observer reliability analysis showed high consistency in SWE measurements, with an ICC of 0.979 for the right KFP and 0.995 for the left KFP. The Mann Whitney U test revealed that the disease group had significantly higher stiffness (26.05 m/s) than the control group (11.21 m/s), $z = -2.256$, $p < 0.001$. The Receiver Operating Characteristic (ROC) analysis proposed a cut-off stiffness value ≥ 3.85 m/s indicate inflamed KFP (AUC = 0.979). SWE demonstrated high reliability and diagnostic accuracy in detecting KFP inflammation, with an optimal shear-wave threshold reliably distinguishes diseased from control group in KFP.

Background

The major contributors to global disability are musculoskeletal (MSK) disorders, especially in high-income countries¹. Among these, ankle MSK problems account for 40% of all injuries and are a major worldwide health problem², with acute ankle sprains, in particular, accounting for 15–20% of sports-related injuries among athletes, following an initial sprain, prolonged ankle instability has been linked to ongoing issues with gait, ankle posture, and slight changes in Achilles tendon mechanics³. KFP is particularly sensitive to inflammation caused by trauma, infection, or tumours due to its close anatomical proximity to the Achilles tendon^{4,5,6}. The distribution of loads around the KFP may indirectly affect ankle biomechanical modifications, which could result in variations in the density or appearance of the pad⁷.

MRI is an invaluable technique for visualizing several soft tissue structures, including ligaments, cartilage, and vital organs like the brain and eyes⁸. This method's non-invasive nature, multiplanar capabilities, and higher soft tissue contrast resolution have made it very advantageous in MSK imaging. MRI is highly efficient in identifying and assessing different soft tissue abnormalities and MSK infections, including sprains, tenosynovitis, and osteomyelitis⁹. Moreover, the high sensitivity of MRI in detecting soft tissue injuries and tendon/ligament tears facilitates accurate diagnosis and treatment¹⁰. A study by Godoy-Santos et al.¹¹ showed strong signal on T2-weighted and weak signal on T1 MRI images of KFP inflammation in HIV patients who experienced lipodystrophy post protease inhibitors therapy. MRI results for these individuals indicated that KFP inflammation was a major factor in posterior ankle discomfort. However, MRI does have several disadvantages, such as being more expensive and requiring patients to remain still during the long scan. Furthermore, compared to conventional ultrasound, MRI is less accessible and may not be available in all settings¹². Conventional ultrasound is a non-invasive,

cost-effective imaging modality widely used for diagnosing soft tissue pathologies; it detects soft tissue inflammation through changes in echogenicity and disorganization of the typical lobular pattern of the fat pad¹³. The KFP typically appears as a well-defined, ovoid, triangular, and hypoechoic structure on ultrasound¹⁴. However, ultrasound accuracy is operator-dependent and varies with the sonographer's expertise¹⁵. Therefore, additional research into complementary imaging methods is necessary to address these limitations.

Advanced imaging, known as SWE, is a valuable technique for measuring changes in tissue stiffness¹⁶. Recent research has demonstrated that SWE is a reliable method for assessing the flexibility of neck extensors in both relaxed and constricted states¹⁷. When it comes to identifying soft tissue edema and inflammation, SWE has proven to be more sensitive than conventional MSK ultrasonography. According to a study conducted by Swami et al.¹⁸ SWE is helpful for early diagnosis and treatment planning of inflammatory arthritis because of its superior capacity to detect peritendinous edema.

Despite its potential, the application of SWE for imaging inflammation in KFP is currently in its early phase. The current literature has explored the effectiveness of SWE in assessing the stiffness of tendons and muscles, but further research is required to explore its application in KFP. Given the growing interest in non-invasive and cost-effective imaging techniques, it is essential to study the capacity of surface SWE to identify and evaluate KFP inflammation. Therefore, this study aims to determine SWE's ability to visualize KFP inflammation as diagnosed by MRI.

Methods

Participants

This prospective study involved 33 patients who presented to (-) with ankle pain or dysfunction lasting more than one week and were referred for MRI evaluation. Based on MRI findings, 10 patients were diagnosed with KFP inflammation (disease group), while 23 patients showed no signs of KFP inflammation (control group). All patients proceeded to SWE after an MRI scan was done. The study protocol was designed following the Declaration of Helsinki, and approval was obtained from the research ethics committee (-). Written consent was obtained from all patients prior to the commencement of the study, guaranteeing confidentiality and privacy adherence. The exclusion criteria included refusal to participate in the study, claustrophobia, and any contraindications to undergoing an MRI.

Imaging Procedures

MRI image acquisition

MRI examinations were performed using a 1.5-T MRI scanner system with the 16-channel head coil (Magnetom Avanto Dot, Aera, or Sola, Siemens Healthineers, Erlangen, Germany). The patients underwent the standard scanning protocol established by the radiology department of (-), with the patient supine with the ankle positioned in a neutral position. The ankle was kept at a 90-degree angle, with a cushion placed under the ankle and a sandbag was placed above the leg to prevent rotation. The laser beam was localized over the ankle joint. The procedure was taken approximately 40 minutes. The following sequences were used, including localizer, PD FS in three planes, T1 coronal, T2 axial, and DES-3D. No contrast for MRI procedure. Once the MRI was completed, patients proceeded to SWE on the same day.

MRI evaluation

KFP inflammation was determined when a hyperintense signal on T2-weighted images with fat suppression and a hypointense signal on T1 was seen at the fat pad, corresponding with the regular appearance of bone structures, ligaments and tendons. A normal KFP was determined when a hypointense signal on T2-weighted images with fat suppression and a hyperintense signal on T1-weighted images were observed at the fat pad, with or without the regular appearance of bone structures, ligaments and tendons. The MRI procedure was reported by radiologist (-), with 12 years' experience in radiology imaging) at the end of day.

SWE image acquisition

SWE was performed using an ultrasound scanner (Aixplorer®, Supersonic Imaging, Aix-en-Provence, France) equipped with an L18- 5 MHz ultrasound linear array transducer. The procedure was conducted in the longitudinal plane, with the patient lying in a prone position and the ankle extended at a 90-degree angle, using one layer of ultrasound gel and avoiding transducer pressure to prevent image artifacts (Fig. 1a). B mode ultrasound image that displayed KFP in the longitudinal plane. SWE imaging was acquired using the Quantification Box (Q-Box™) to ensure high-quality and reliable shear wave measurements. A 1 mm region of interest (ROI) size was positioned in the Q-Box, which appeared to be blue to capture accurate and consistent stiffness data. Five stiffness measurements in meters per second (m/s) were obtained to calculate the median measurements (Fig. 1b). The same sonographer performed all SWE image acquisitions (- three years' experience in SWE imaging).

Interobserver reliability

All patients were re-scanned by second observer, a radiologist (- with 12 years' experience in radiology imaging) on the same day KFP was scanned. Both radiologist and the sonographer were blinded to each other's during SWE imaging scan.

Statistical Analysis

Data analysis was performed using SPSS version 28 (SPSS Inc, Chicago, Illinois, USA). Continuous data were expressed as the mean and standard deviation (+ SD). Descriptive statistics were used to summarize the demographic and clinical characteristics of the study population. ICC was conducted to assess inter-observer agreement. The Kolmogorov–Smirnov test was used to assess whether the data were normally or non-normally distributed. Statistical tests were performed on the data collected and significance levels were declared at $p \leq 0.05$. The comparison of the stiffness between inflamed KFP and normal KFP was analyzed using Mann-Whitney U test for non-normality distributed data used to evaluate significant differences between the means of two independent groups, MRI findings and SWE measurements. Wilcoxon signed-rank test is used to compare two related samples of same patient right and left ankle for non-normality distributed data. The Receiver Operating Characteristic (ROC) curve was used to assess the discriminatory ability of SWE findings. The optimal cut-off point for SWE was determined by identifying the value with the smallest difference between sensitivity and specificity in diagnosing KFP inflammation, as diagnosed by MRI.

Results

SWE was performed on both the right and left KFP of 33 patients. Based on MRI findings, 10 patients showed KFP inflammation were classified as the disease group, while 23 patients showed no inflammation classified as the control group. Classification was made solely based on MRI results. The demographic characteristics of the patients are summarized in (Table 1).

Table 1		
Demographic characteristics of the patients age, gender, weight, height and BMI (n = 33)		
Characteristics	Normal (n = 23) (mean ± SD)	Inflamed (n = 10) (mean ± SD)
Age, years old	34.78 ± 12.99 ^a	39.00 ± 17.17 ^a
Gender, female, n (%)	13 (70.7%)	6 (60%)
Weight (kg)	76.07 ± 15.68	77.80 ± 13.09
Height (cm)	1.61 ± 0.08	1.64 ± 0.07
BMI, kg/m ²	22.50 ± 0.60 ^b	23.60 ± 0.80 ^b
Normal (18.5–24.9)	26.43 ± 0.67 ^c	28.60 ± 0.70 ^c
Overweight (25–29.9)	30.30 ± 0.70 ^d	34.68 ± 4.05 ^d
Obese (> 30)		
Note. Data are presented as mean ± standard deviation unless otherwise indicated.		
^a No significant age difference between groups ($p > 0.05$).		
BMI categories follow WHO classification.		

Inter-Observer Reliability of SWV Measurements

The ICC test showed no significant difference between measurements for the right KFP ($p = 0.147$) and left KFP ($p = 0.136$). The ICC was calculated to assess the agreement between two observers in measuring KFP stiffness. The results demonstrated high reliability, with an ICC of 0.979 (95% CI: 0.949–0.992, $p < 0.001$) for the right KFP and 0.995 (95% CI: 0.986–0.998, $p < 0.001$) for the left KFP, indicating strong consistency in the measurements obtained by both observers.

Stiffness values between inflamed KFP and normal KFP

Mann-Whitney U test indicated a significant difference between the inflamed KFP in disease group and non-inflamed KFP in normal group, with mean rank (26.05 m/s) as compared to the normal KFP mean rank in control group (11.21 m/s), $U\ 4.500$, $p < .001$ (Table 2).

Table 2
Comparison of stiffness values of the inflamed and normal KFP

Status	N	Mean KFP stiffness m/s	Std. Deviation	Median KFP stiffness m/s
Disease Group	10	5.85 ^a	2.15	5.50
Control Group	23	2.97 ^b	0.67	2.76
Note. Values are presented as mean $\pm$ standard deviation.				
⊠ Mean stiffness significantly higher compared to the control group ($p < 0.05$).				
⊠ Reference value from healthy control participants.				

KFP stiffness values among the disease group

A Wilcoxon signed-rank test showed that there is no significant difference between the inflamed KFP compared to the non-inflamed KFP within the disease group ($Z = -1.070$, $p = 0.285$). Indeed, median stiffness score rating was 4.5 m/s for the inflamed KFP and 3.05 m/s for non-inflamed KFP.

Receiver Operating Characteristic (ROC) Analysis

The ROC analysis was performed to determine the optimal cut-off value for SWE in diagnosing disease KFP stiffness. The area under the ROC curve (AUC) for inflamed KFP is 0.979 with a (95% CI 0.935–1.000), indicating good diagnostic accuracy and supporting the clinical value of SWE in detecting KFP inflammation (Fig. 2). We obtained a shear wave speed of 3.85 m/s of which a value more or equal to this suggested an inflamed KFP. This yielded a sensitivity and specificity of 100% and 90%, respectively.

Discussion

This study aims to determine SWE's ability to visualize KFP inflammation as diagnosed by MRI. Our results on the ICC test revealed excellent reliability for SWE with a 0.979 for the right KFP and 0.995 for

the left KFP. The results indicated that the inflamed KFP had significantly higher stiffness (5.50) than the normal KFP in control group (2.76). The ROC indicating good diagnostic accuracy and supporting the clinical value of SWE in detecting KFP inflammation 0.979.

Ankle pain may arise from KFP disease, a condition that impacts the fat pad within the ankle joint, inflammation and reduced mobility may follow from this degeneration or inflammatory conditions¹⁸. Various studies have utilised 2D SWE, a noninvasive method for measuring tissue elasticity quantitatively in MSK imaging, yielding promising results^{19,20,21,22}.

The demographic characteristics of the study population provide important context for interpreting the findings including age, gender, height, weight and BMI, indicating that the majority of participants were female and fell in the overweight category. KFP is a superficial structure, the impact of increased body mass on shear wave propagation is likely minimal. Therefore, SWE measurements in the KFP remain reliable across a broad range of BMI values. Despite this variation, the study demonstrated a high level of inter-observer agreement, suggesting that SWE remains a reliable imaging modality even in a heterogeneous cohort. This finding is consistent with previous studies that have reported the reproducibility and robustness of SWE in MSK applications, regardless of patient body habitus²³.

Previous studies investigating the reliability of SWE have mainly focused on tendinous and muscular structures, with limited attention given to its application in KFP. In the present study, we addressed this gap by rescanning 33 patients by two independent observers. Our results showed excellent ICC value between two observers. This could be attributed to the use of the Supersonic SWE system, which offers advanced imaging features such as high frame rates and real-time propagation maps that assist in detecting and minimizing artifacts during image acquisition²⁴. While the Quantification Box (Q-Box™) does not control probe placement, it supports consistent analysis of the ROI²⁵. Furthermore, Lin et al.²⁶ emphasized that due to the superficial location of the region, careful management of transducer pressure is essential to minimize signal distortion, thereby improving measurement accuracy and reproducibility. Ensuring that measurements are taken within a consistent area also helps maintain stable stiffness values, unaffected by joint movement, ultimately enhancing the repeatability of the measurements²⁷. This is likely contributing to the excellent inter-observer reliability observed in this study. These findings are consistent with those reported by Berrigan et al.²⁷ who also demonstrated excellent inter-observer reliability in their study. In their research, Achilles tendon stiffness was assessed using the Samsung RS85 system equipped with the SWE's Reliability Measurement Index (RMI). The repeatability parameters increase with higher RMI levels, assisting operators in identifying appropriate images for the SWE assessment and excluding inaccurate SWE acquisitions²⁸.

KFP inflammation typically begins in the acute stage, often triggered by trauma, repetitive micro-injuries, or adjacent joint inflammation. In the acute phase, inflammatory mediators increase vascular permeability, leading to edema within the fat pad⁷. While acute inflammation is typically associated with edema, which corresponds to reduced tissue stiffness, prolonged inflammation can lead to fibrotic

remodeling and tissue densification. These chronic changes are characterized by increased extracellular matrix deposition and reduced tissue elasticity^{29,30}. Ogbonmwan et al.³¹ reported that chronic inflammation, particularly in cases of Achilles tendinopathy, is associated with increased stiffness in the tendon, affecting adjacent structures and potentially altering foot biomechanics. Moreover, repetitive mechanical loading, common in individuals with chronic ankle pathology, may contribute to fibrosis within the fat pad⁵. Klingler et al.³², also demonstrated that repetitive stress on soft tissue structures, including fat pads, can induce fibrotic changes resulting in pain and impaired mobility. In our study the results revealed a significant difference in KFP stiffness between the inflamed and non-inflamed KFP as our patients had symptoms of KFP inflammation for more than seven days which tend to be more chronic.

When one leg is injured, individuals often compensate by shifting more weight to the contralateral (uninjured) limb. This compensatory strategy can lead to increased stress and loading on the uninjured side³³. Sousa et al.³³ reported that subjects with functional ankle instability exhibited bilateral impairment of compensatory postural adjustments of the tibialis anterior in a support position and of the soleus on the uninjured limb, regardless of position. Moreover, individuals with mechanical instability showed a bilateral increase in compensatory activity of the peroneus brevis, as well as heightened activity in the soleus muscle on the side experiencing perturbation. A study by Prado-Costa et al.³⁴ stated that an increase in tendon stiffness and heterogeneity during the physiological healing process, likely attributed to the structural disorganization of collagen fibers and a predominance of type III collagen over the typical type I. Notably, the authors also stated that increased stiffness in the contralateral (uninjured) tendon, which was attributed to the additional mechanical load and compensatory pressure placed on the normal ankle during ambulation. Furthermore, in this study, our results indicated no significant difference in stiffness between the inflamed and non-inflamed KFP within the disease group. This can be due to patients experienced symptoms for more than one week, during which continued use of the uninjured ankle for daily activities may have led to compensatory loading of the contralateral, clinically normal ankle. This increased mechanical demand could contribute to elevated stiffness in both limbs. As a result, it showed insignificant differences between inflamed and non-inflamed KFP.

Greyscale ultrasound, although readily accessible, may yield false-negative or false-positive outcomes due to its restricted capacity to detect tiny variations in tissue stiffness linked to early inflammation³⁵. Grayscale ultrasound can detect significant Achilles tendon thickening; however, it has poor sensitivity and specificity in identifying early or subtle changes, particularly those associated with atherosclerosis³⁶. In mild synovitis, grayscale ultrasound demonstrated moderate diagnostic accuracy (AUC = 0.781) with sensitivity of 66.7% and specificity of 70%, underscoring its limitations in early MSK inflammation detection compared to MRI³⁷. MRI, while highly effective for evaluating soft tissue, is costly, time-intensive, and frequently entails prolonged waiting times, hence restricting its routine application in the early or subclinical phases of disease³⁷. According to our study's maximum area under the ROC curve, a stiffness threshold more or equal to 3.85 m/s was determined as a diagnostic indicator

of inflamed KFP with a sensitivity of 100% and a specificity of 90%. This is particularly significant considering the established constraints of conventional imaging techniques.

The proposed cut-off value enhances its diagnostic utility, supporting SWE as a sensitive and reliable tool for the early detection and monitoring of inflammation in the KFP and other musculoskeletal structures. In conclusion, this study has several limitations. The small sample size may constrain the generalizability of the findings and diminish the statistical power to identify subtle differences between groups. Secondly, an imbalance in the composition of the control and disease groups resulted in a level of sample homogeneity that may have affected the comparison analysis. The disparity in group sizes may generate bias and constrain the reliability of intergroup comparisons. Subsequent research must prioritize larger, multicenter studies to confirm these findings across varied populations and investigate the longitudinal alterations in KFP stiffness throughout treatment and recovery. Furthermore, exploring the utility of SWE in other inflammatory or degenerative conditions of adjacent structures may enhance its clinical applicability.

Conclusion

This study demonstrates the potential of SWE as a reliable, non-invasive, quantitative, real-time imaging tool for assessing KFP stiffness. The significant differences in stiffness values between normal and inflamed KFP highlight the ability of SWE to effectively identify inflammatory changes. Notably, the excellent diagnostic performance, with an AUC of 0.979, underscores the accuracy and robustness of SWE in differentiating inflamed from normal tissue using a cut-off value of ≥ 3.85 m/s. We recommend including the use of SWE assessment of KFP stiffness in patients with posterior ankle pain or suspected inflammation to improve diagnostic accuracy.

Declarations

Conflicts of interest/Competing interests:

The authors declare that they have no conflicts of interest.

Ethics approval:

We obtained approval from the Research Ethics Committee (REC/08/2023), Universiti Teknologi MARA, and hospital approval reference number 500-PJI (18/4/84).

Consent to participate:

Written informed consent was obtained from all participants before inclusion.

Accession codes

N/A

Consent for publication:

All authors have read and approved the final manuscript and consent to its publication.

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Author Contribution

A.I.A. : Conceptualization, methodology, data collection, formal analysis, writing–original draft. S.S.L. : Supervision, project administration, writing–review and editing. M.S.K. : Supervision, data collection, visualization, writing–review and editing. N.S.M. : Administrative, technical, or logistic support.

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Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures

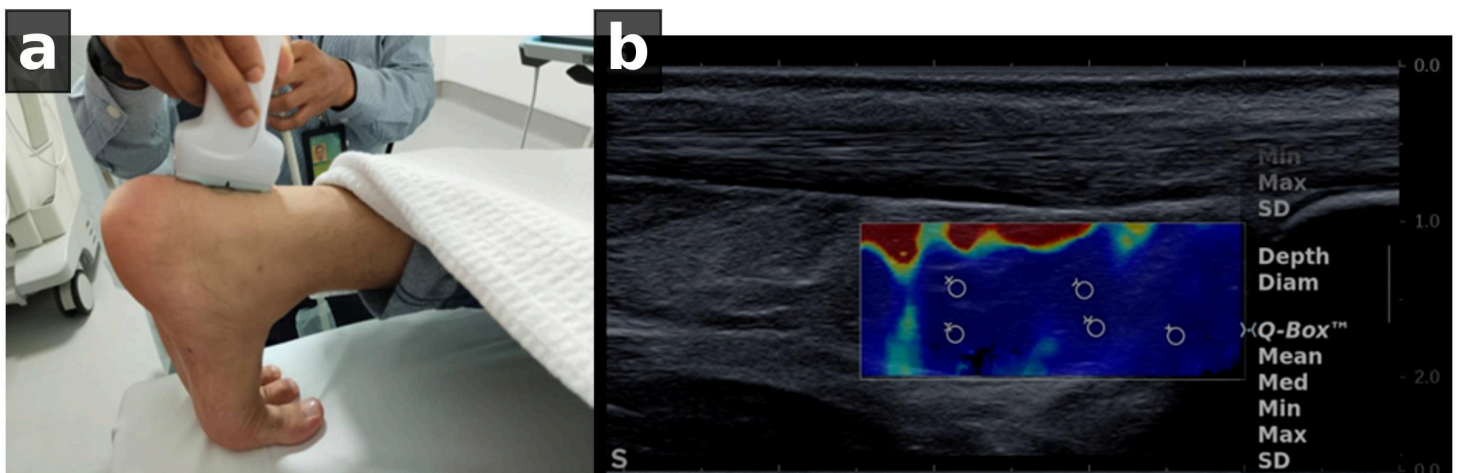


Figure 1

(a) is patient position, (b) 2D SWE shows scanning plane longitudinal, 1 mm ROI =(Region of interest)and one-layer of ultrasound gel used for right KFP =(Kager's fat pad).

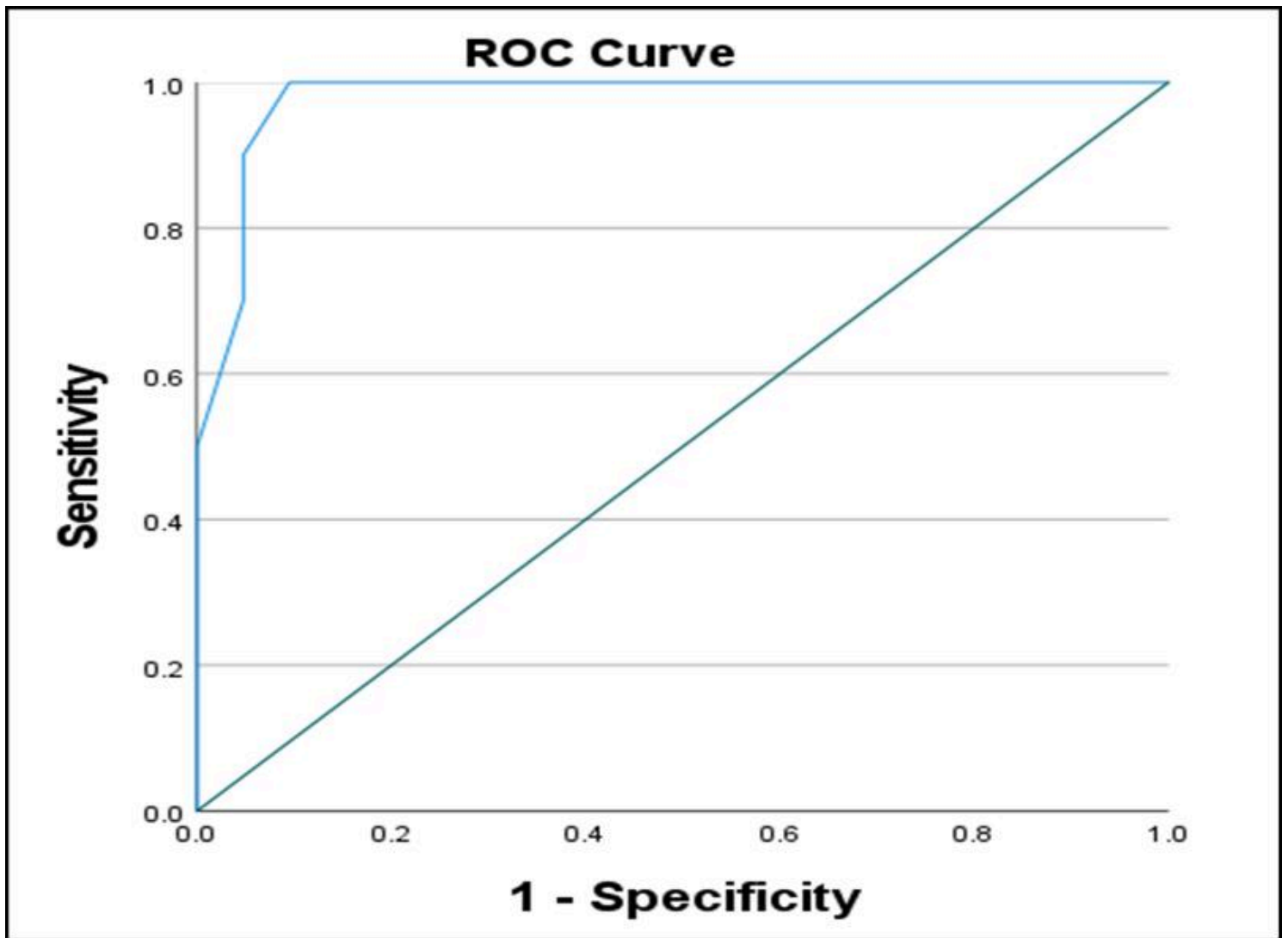


Figure 2

Receiver operating characteristic (ROC) curve of shear wave speed in distinguishing between disease and control groups, area under the curve (AUC)= 0.979 with a (95% CI 0.935-1.000), cut-off value 3.85 m/s, sensitivity 100% and specificity 90%.