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ORIGINAL ARTICLE

Radiology

The Two-Dimensional Shear Wave Elastography (2D-SWE) in Assessing Abdominal Aortic Wall Stiffness

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Abstract

Background: Ultrasound elastography, a non-invasive imaging modality, holds promise for assessing tissue stiffness, offering potential applications in the evaluation of cardiovascular disease. This study aimed to quantify local stiffness of the abdominal aortic wall using two-dimensional shear wave elastography (2D-SWE) in adults without underlying medical conditions, and to evaluate its reproducibility.

Methods and Results:2D-SWE measurements of infra-renal posterior wall of the abdominal aorta (PWoAA) were obtained from 50 subjects. For intra- and inter-observer reproducibility, five 2D-SWE measurements of PWoAA were averaged, and the measurements were performed two times by observer A and once by observer B (n=750). Intraclass correlation coefficient (ICC) and Bland-Altman plot were used to establish bias and limit of agreement (LoA) between PWoAA elasticity measurements.

Ultrasound 2D-SWE of PWoAA was 3.87±0.99 kPa. Intra-observer agreement of PWoAA ultrasound 2D-SWE elasticity measurements was moderate with an ICC value of 0.69 (95% CI: 0.56–0.82, $P<0.001$). Bias in intra-observer measurements was 0.18±0.92 kPa (95% LoA: -1.62–1.99). Similarly, inter-observer agreement was moderate with an ICC value of 0.56 (95% CI: 0.22–0.75, $P=0.002$). Bias in inter-observer measurements was -0.02±1.09 kPa (95% LoA: -2.16–2.11). There was no significant difference in the 2D-SWE measurements of the aortic walls, both within the same observer (mean difference [MD] 0.17, 95% CI: 0.07–0.44, $P=0.16$)) and between two different observers (MD=0.02, 95% CI: 0.33–0.28, $P=0.86$).

Conclusion: Our findings demonstrated moderate reproducibility of ultrasound 2D-SWE in assessing abdominal aortic wall elasticity, with no significant differences within or between observers. Further research is warranted to optimize the clinical application of this method for assessing arterial wall stiffness, particularly in patients with cardiovascular disease, including those with abdominal aortic aneurysms.(**International Journal of Biomedicine. 2025;15(4):690-694.**)

Keywords: ultrasound elastography • 2D-SWE • aortic stiffness

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Abbreviations

AS, aortic stiffness; **ICC**, intraclass correlation coefficient; **LoA**, limit of agreement; **PWoAA**, posterior wall of the abdominal aorta.

Introduction

Aortic stiffness (AS) characterizes elastic resistance to deformation. It is intricately influenced by the dynamic interplay between vascular smooth muscle cells and extracellular matrix components, including fibrillin fibers, elastin, and collagen.[1] This biomechanical property assumes significance, as elevated AS reflects maladaptive responses to hemodynamic stress and imposes an increased afterload on the heart. It is considered a non-invasive indicator of metabolic disorders and a critical factor in assessing cardiovascular risk.[2,3]

Several methodologies have been used to assess AS non-invasively.[2] Pulse wave velocity (PWV) is a widely utilized approach that calculates the speed of the pressure wave along the aorta. This is achieved by measuring the pulse transit time between the carotid and femoral sites and determining the distance between them.[4] In addition, ultrasound-based techniques, including aortic arch pulse wave velocity (aaPWV) and carotid-femoral pulse wave velocity (cfPWV), by assessing pulse wave Doppler, have been reported to provide valuable insights for measuring AS.[5,6]

Ultrasound two-dimensional shear wave elastography (2D-SWE) enables quantitative measurements of tissue stiffness in real-time.[7] It employs acoustic radiation force impulses induced into tissues through focused ultrasonic beams, capturing the real-time propagation of resultant shear waves.[8] This enables the display of elasticity as a colored map overlay on a B-mode image, providing a holistic visualization of tissue stiffness.[9] Although ultrasound 2D-SWE is promising a diagnostic tool in assessing liver diseases, thyroid nodules, and breast conditions, its potential for evaluating abdominal aortic wall stiffness remains an underexplored. Therefore, in this study, we aimed to quantify the local stiffness of the abdominal aortic wall using 2D-SWE ultrasound in adults without underlying medical conditions, and to evaluate its reproducibility.

Materials and Methods

This observational pilot study was approved by the Research Ethics Committee at King Abdulaziz University (Reference No 202-23). The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (2000; revised October 2013, Fortaleza, Brazil). Written informed consent was obtained from all the participants. Subjects at least 18 years old, with no underlying medical conditions, not on regular medications, and not regular smokers were included in the study. Exclusion criteria included diagnosed with cardiovascular diseases, diabetes, on regular medicines, a regular smoker, and pregnancy. Participants were recruited between April and August 2023

Each participant was asked to attend a research clinical assessment room at the Department of Radiologic Sciences, Faculty of Applied Medical Sciences, King Abdulaziz University, once in the morning following an overnight fasting period.[10,11] The participants were screened for eligibility during the visit, and their heights and weights were taken. Then, they were asked to lie in a supine position for approximately 20 minutes. Afterward, brachial blood pressure and heart rate were measured by placing a Microlife monitor cuff on the upper arm, followed by ultrasound imaging of the abdominal aorta for normality assessment. The ultrasound imaging procedures were conducted using a high-resolution ultrasound system, EPIQ Elite (Philips Health Care ultrasound imaging system), with 2D-SWE capability using a 5-1MHz curvilinear transducer for optimal image acquisition. Ultrasound 2D-SWE was assessed in real-time.

Ultrasound 2D-SWE of infra-renal PWoAA were obtained by placing the ultrasound transducer along the midline of the abdomen in the longitudinal plane. A sufficient amount of gel was applied while participants lay in a supine position with their arms resting by their sides, and they were instructed to hold their breath at an end-expiratory level to ensure uniform depth of aorta visualization during assessments and the acquisition of high-quality elastography images. Measurements were taken during diastole in kPa. The dual-screen mode of 2D-SWE was activated, displaying both the confidence map and the stiffness map overlaid on the B-mode ultrasound image. A sample gate of 1mm in size was placed on the PWoAA under the guidance of the confident map to ensure reliable data is acquired (Figure 1). Aortic wall elasticity from each patient was estimated from the average value of five 2D-SWE measurements. Five 2D-SWE measurements from each participant were repeated three times by two certified clinical sonographers with efficient training on ultrasound 2D-SWE (twice by observer A and once by observer B). Both observers were blinded to their own measurements and those of the other observer to ensure unbiased data collection.

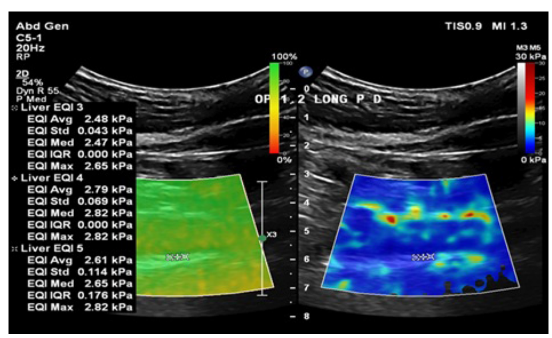

***Figure 1.** Ultrasound confidence map and elastography images of 2D SWE measurements from the posterior wall of the infra-renal abdominal aorta. (Reprinted by permission of Elsevier from "Reproducibility of ultrasound 2D shear-wave elastography on abdominal aortic wall" by Alsayegh et al. Ultrasound in Medicine and Biology, 2024;50:S30-S31, World Federation for Ultrasound in Medicine and Biology Congress).*

Statistical analysis was performed using the intraclass correlation coefficient (ICC) and Bland-Altman plots to evaluate intra- and inter-observer reproducibility and establish bias and limit of agreement (LoA) between PWoAA elasticity measurements. A paired t-test was used to compare the mean elasticity measurements taken from the same individuals by the observers. Analysis was performed using

SPSS Statistics (Version 21.0, Armonk, NY: IBM Corp) and PRISM 7 (GraphPad Software, La Jolla, CA, USA). Statistical significance was set at a *P*-value ≤0.05.

Results

A total of 50 subjects (24 male and 26 female) with no underlying medical conditions were recruited for this study, with a mean age of 22.86±5.92 years and a mean BMI of 23.18±4 kg/m². The mean 2D-SWE measurement of PWoAA was 3.87±0.99kPa (Table 1).

Table 1.
Participant characteristics (n=50).

Characteristics	Descriptive statistics (mean±SD)
Age (years)	23.86±5.92
Weight (kg)	61.39±12.33
Height (m)	1.62±0.08
BMI (kg/m^2)	23.18±4.02
SBP (mmHg)	121.92±12.88
DBP (mmHg)	77.64±10.89
HR (bpm)	76.7±13.80
2D-SWE of PWoAA (kPa)	3.87±0.99

BMI, body mass index; DBP. diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure.

Intra-observer agreement of PWoAA ultrasound 2D-SWE elasticity measurements was moderate with an ICC value of 0.69 (95% CI: 0.56–0.82, *P*<0.001). Bias in intra-observer measurements was 0.18±0.92 kPa (95% LoA: -1.62–1.99) (Figure 2A, B). Similarly, inter-observer agreement was moderate with an ICC value of 0.56 (95% CI: 0.22–0.75, *P*=0.002). Bias in inter-observer measurements was -0.02±1.09 kPa (95% LoA: -2.16–2.11) (Figure 3A, B). There was no significant difference in the 2D-SWE measurements of the aortic walls, both within the same observer (mean difference [MD] 0.17, 95% CI: 0.07–0.44, *P*=0.16)) and between two different observers (MD=0.02, 95% CI: 0.33–0.28, *P*=0.86) (Figure 4).

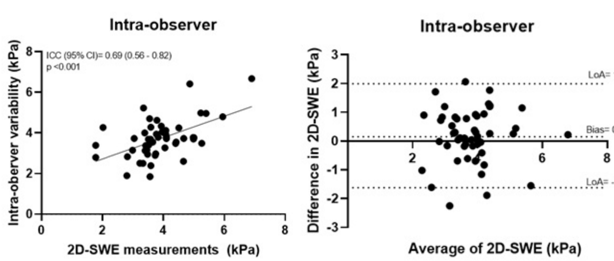

Figure 2. *Intra-observer and Bland-Altman agreement of 2D-SWE of the posterior wall of the abdominal aorta. (Reprinted by permission of Elsevier from "Reproducibility of ultrasound 2D shear-wave elastography on abdominal aortic wall" by Alsayegh et al. Ultrasound in Medicine and Biology, 2024;50:S30-S31, World Federation for Ultrasound in Medicine and Biology Congress).*

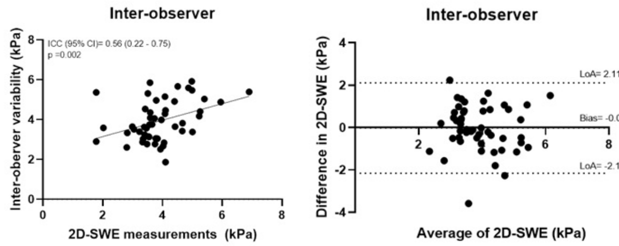

Figure 3. *Inter-observer and Bland-Altman agreement of 2D-SWE of the posterior wall of the abdominal aorta. (Reprinted by permission of Elsevier from "Reproducibility of ultrasound 2D shear-wave elastography on abdominal aortic wall" by Alsayegh et al. Ultrasound in Medicine and Biology, 2024;50:S30-S31, World Federation for Ultrasound in Medicine and Biology Congress).*

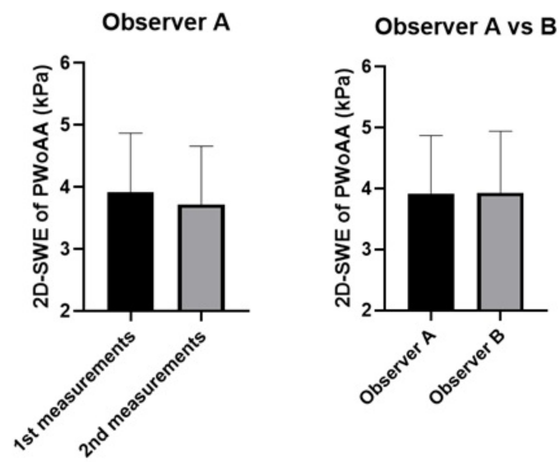

Figure 4. *Comparison within and between observers in measuring 2D-SWE of the posterior wall of the abdominal aorta (PWoAA) (mean±SD).*

Discussion

To the best of the author's knowledge, this is the first study to quantify the local stiffness of the abdominal aortic wall using ultrasound 2D-SWE and to evaluate its reproducibility in healthy subjects. The analysis revealed that the ultrasound 2D-SWE measurement of the infra-renal PWoAA is 3.87±0.99kPa, with moderate intra- and inter-observer agreement. Despite this agreement, there were no significant differences in 2D-SWE of PWoAA within or between operators These findings suggest that ultrasound 2D-SWE is a reliable method for assessing the local stiffness of the abdominal aortic wall, and that additional work is required to improve the reproducibility of this technique for measuring arterial wall stiffness and to evaluate its clinical use in patients with cardiovascular diseases, including those with abdominal aortic aneurysms.

In the present study, the local stiffness of the infra-renal PWoAA was quantified using ultrasound 2D-SWE, revealing a mean stiffness of 3.87±0.99kPa. The shear wave speed in meters per second can be converted to the Young's modulus in kilopascals using the formula $E=3(vS^2 \cdot \rho)$.[12] The AS reported in our study is notably lower than the findings from a recent study by Elgeti et al.,[13] where a value of 19.35 kPa was found when converting the reported mean stiffness value of 2.54 m/s from healthy non-smoker and smoker subjects using time-harmonic elastography from the upper aorta. The acceleration of aortic stiffening, often associated with aging, is further exacerbated by various cardiovascular risk factors, such as diabetes, obesity, smoking, and high cholesterol.[1,13,14] This could explain the different values of AS, as the study by Elgeti et al.[13] involved an older population than ours, which could influence the stiffness measurements due to age-related changes in arterial properties. The location where AS is assessed may play a critical role in influencing study outcomes. As previously mentioned, Elgeti et al.[13] focused on the upper aorta, whereas our study targeted the infra-renal (lower) PWoAA. It has been reported that mechanical properties of the aorta exhibit significant variation along its length, with the ascending and thoracic segments typically demonstrating greater stiffness than the abdominal portion due to differences in arterial wall composition—specifically, lower elastin and higher collagen content in the abdominal aorta, and a gradient of increasing stiffness from proximal to distal aorta serving as a vital mechanism in mitigating pulsatile flow from the heart and safeguarding microcirculation.[15-17]

Furthermore, the choice of ultrasound transducer is critical for optimizing the accuracy and feasibility of elastography measurements. Various factors, including probe frequency, footprint, size, design, and placement, can significantly influence elastography outcomes. Differences in shear wave elastography technologies across systems from different manufacturers can result in varying measurements due to variations in frequencies and the algorithms used to determine tissue properties.[18,19] Consistency and reproducibility in measurements are best achieved by using the same ultrasound elastography system.[20] In this study, aortic wall elasticity for each patient was determined by averaging five 2D-SWE measurements, with an IQR/median ratio of ≤30%. This approach could lower reproducibility. Future studies with a lower IQR/median ratio could increase the agreement within and between observers. Despite moderate intra- and inter-observer agreement, we found no significant differences in aortic 2D-SWE measurements within or between operators. The reproducibility of 2D-SWE in measuring AS can be affected by the anatomical segment used for measurement, with higher stiffness values and greater variance observed in the posterior wall than in the anterior wall.[21] The higher variance in the posterior wall may be due to lower signal quality caused by the larger distance from the transducer, which induces more attenuation and presumably more reflections and reverberations from the overlying soft tissue.[19,22] Together, these factors suggest that age differences, cardiovascular risk factors, assessment locations, and ultrasound imaging systems contribute to the observed variations in AS measurements and their reproducibility. Therefore, while SWE shows promise for assessing AS, continued research and technological improvements are essential for optimizing its reproducibility and clinical application.

The current study has limitations that should be acknowledged. The inclusion criteria were restricted to young healthy adults. This limitation may limit the generalizability of the findings to older populations and those with underlying medical conditions. Patients with various comorbidities, such as hypertension, diabetes, or other chronic conditions, might exhibit different levels of AS. In this study, AS was assessed using the Philips 2D-SWE system. Therefore, the findings may not be directly comparable to those obtained using other ultrasound imaging systems. These factors should be considered when interpreting the results and their potential implications for clinical practice. Further research involving diverse populations and multiple ultrasound systems is needed to enhance the generalizability and comparability of AS measurements.

Conclusion

This study demonstrated that 2D-SWE is a promising non-invasive technique for assessing the stiffness of the abdominal aortic wall, showing moderate intra- and inter-observer reproducibility in healthy subjects, with no significant differences observed within or between observers. Further research is needed to enhance the reproducibility of this technique, particularly in clinical settings involving larger and more diverse populations, including patients with cardiovascular conditions such as abdominal aortic aneurysms.

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Conflicts of Interest

The authors declare that they have no competing interests.

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