ULJASH
المجلد 1، العدد2، 2025
Vol: 1, No: 2, (2025)
مجلة جامعة لحج للعلوم التطبيقية والإنسانية
University of Lahej Journal of Applied Sciences and Humanities
ISSN: 3105-000X
OPEN ACCESS

Use of Issue Doppler Effect Technology in Clinical Applications for the Diagnosis of Ischemic Heart Disease

Nabil Saleh Abdullah Nasser & Alaa Khaled Ahmed Saleh

Physics Department, Faculty of Education, Aden University

Received	Accepted	Published
28/02/2025	18/05/2025	21/12/2025

Cite: Nasser, N.S. A. &. Saleh, A. K.A. (2025). Use of tissue Doppler Effect technology. *University of Lahej Journal of Applied Sciences and Humanities*, *1* (2), 295-301.

Abstract

Tissue Doppler Echocardiography (TDI) is a recent advancement in medical ultrasound imaging, offering a non-invasive and precise method for assessing cardiac tissue velocities with high spatial and temporal resolution. In this study, a Mindray DC-60Exp diagnostic ultrasound system was employed to evaluate a 64-year-old male patient with ischemic heart disease using a tissue Doppler echocardiography protocol. The primary objective of the examination was to measure tissue velocities associated with both axial and lateral mitral annulus motion and to analyze differences between healthy and diseased tissue velocities. TDI operates on the principle of the Doppler effect, wherein cardiac tissue velocity is determined by analyzing frequency shifts in reflected ultrasound waves. These frequency changes are then used to calculate tissue velocity via the Doppler equation, enabling the identification of pathologically altered myocardial regions. Key parameters derived from this equation include the maximum systolic velocity(S'), representing peak tissue motion during systole; the early diastolic velocity (e'), reflecting myocardial relaxation velocity during early diastole; and the late diastolic velocity (a'), corresponding to tissue relaxation during late diastole. The results demonstrated a significant reduction in (S') and (e') values in ischemic regions compared to healthy myocardial tissue, indicating impaired cardiac tissue motion secondary to ischemia. These findings underscore the efficacy of TDI in detecting early functional myocardial changes, thereby enhancing diagnostic accuracy and guiding therapeutic strategies for ischemic heart disease. Furthermore, this application highlights the critical role of physics-based innovations in medical imaging, which improve the quality of diagnostic data and facilitate timely clinical decision-making.

Keywords: Ultrasound (US), Echocardiography (ECG), Doppler effect (DE), ischemic heart disease (IHD).

Introduction

Physics is the cornerstone of many modern medical technologies, playing a pivotal role in their development. Echocardiography techniques rely on ultrasound, which consists of mechanical waves with frequencies above the human hearing range (>20 kHz). Medical applications typically use frequencies ranging from 1 MHz to 100 MHz (Cho, 2017; Solomon, Wu, & Gillam, 2017). These waves penetrate soft tissues, enabling the acquisition of accurate images of target organs. Ultrasound imaging operates on the principle of acoustic impedance, where wave propagation speed depends on tissue density. When density differences exist between tissues, sound waves reflect at boundaries, generating images that delineate anatomical structures and facilitate cardiac functional assessment (Oates, 2023; Taylor & Holland, 1990). However, imaging through bony or gas-filled tissues remains challenging due to wave scattering and reduced image quality (Abdulla & Clarke, 2020). He deals with the problem in the form of one question only, and the hypothesis (s) on which it is based (the possible outcome of the solution), in addition to previous research and studies that dealt with the topic of direct relevance, and it is written in a scientific, serial and brief way through which the researchers shows similarities and differences in terms of the goal, the sample, the study variables, the method and tools used, and the conclusions reached. Piezoelectric crystals generate ultrasound waves, and image quality depends on the relationship between wave frequency and imaging depth. Reflection depth is calculated using the equation:

$$d = \frac{v.t}{2} \qquad (1)$$

where v is the ultrasound velocity in tissue (1540 m/s), t is the round-trip travel time, and d is the tissue depth. Multiple pulse waves are transmitted, and returning echoes are converted to digital signals for dynamic imaging (Dons et al., 2015). The Doppler effect measures frequency shifts between transmitted and reflected waves, enabling blood velocity or tissue motion calculation via:

$$v = \Delta f \times \frac{c}{2f_0 \cos\theta} \qquad (2)$$

where f_0 is the transmitted frequency (typically 4 MHz), Δf is the frequency shift, c is the sound speed in tissue (1540 m/s), and $\cos\theta$ is the angle between the ultrasound beam and motion direction.

Tissue Doppler Imaging (TDI), an advanced ultrasound technique, measures myocardial motion velocities rather than blood flow. This provides precise cardiac functional assessment, enhancing clinical understanding of cardiac performance (Soilemezi et al., 2020; Mittal, 2017). At $\theta = 0^0$, maximum frequency shift is calculated as:

$$\Delta f = \frac{2f_0\, v}{c} \qquad (3)$$

Motion toward the probe increases reflected frequency, while motion away decreases it. Results are visualized as color-coded images (red: toward probe, blue: away) or velocity-time curves. TDI quantifies myocardial velocities (6–24 cm/s), which are 8–10 times lower than blood flow velocities and 40 dB higher in signal amplitude (Bushberg & Boone, 2011; Terslev et al., 2017). To capture low-velocity tissue signals, high-pass filters are disabled, and pulse repetition frequency (PRF) is reduced to 8–16 kHz to minimize artifacts (Jarman, 2017). Signal processing employs Fourier transform:

$$X(f) = \int_{-\infty}^{\infty} x\,(t) e^{-j2\pi f}\, dt \qquad (4)$$

where $X(f)$represents the frequency signal in k-space, and $x(t)$is the spatial signal. This separates tissue motion frequencies, enabling precise velocity extraction and suppression of noise (Hidayat, Suhendi, Wibawa, & Tumbelaka, 2018).

TDI achieves high temporal resolution (up to 90 frames/sec), improvable via parallel processing, enhancing diagnostic accuracy. It is particularly valuable for diagnosing ischemic heart disease by detecting regional myocardial velocity differences. For example, reduced septal and lateral mitral annulus velocities indicate diastolic dysfunction (Bjaerum & Kristoffersen, 2002; Mousa, 2015). TDI's physics-based analysis enables early, objective detection of left ventricular impairment, surpassing traditional subjective methods. This underscores the critical role of medical physics in advancing diagnostic technologies and improving healthcare outcomes.

2. Materials and Method

2.1 Materials:

The diagnostic ultrasound device {Mindray DC-60Exp} was used as the main tool in this research as shown in **Fig. 1.**

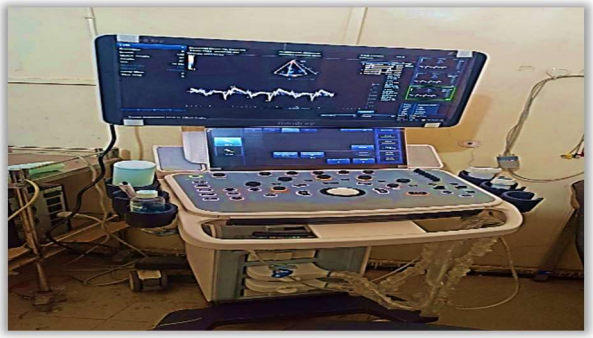

Fig. 1. *Diagnostic Ultrasound Device {Mindray DC-60 Exp}*

Table 1:

The Components of the {Mindray DC-60 Exp} Device.

Component	Function
Monitor	21.5-inch Full HD LED display with a 178-degree viewing angle for displaying the images and parameters during scanning.
Speakers	Sound output.
Touch screen panel	13.3-inch ultra-thin touchscreen for Operator-system interface or control
Ultrasound gel holder	Used for placing the ultrasound gel.
Probe holder	Used for placing the general probe (not including pencil probe or intra-cavity probe).
Pencil probe holder	Used for placing the pencil probe.
Probe cable hook	Used for fixing the probe cable.
Control panel adjusting lever	Used for lifting or swiveling the control panel.
Keyboard	Used for typing characters or entering some functions
Main control panel	Operator-system interface or control
USB_MIC port	USB/MIC port.
Hanger	/
Intracavitary probe holder	Used for fixing the intracavitary probe.
Ultrasound gel holder/gel warmer	Used for placing the ultrasound gel or installing the gel warmer.
Physio panel	Used for connecting the ECG leads and external ECG device
Compartment	Used for securing or moving the system.
Probe port	Sockets connects transducers and the main unit.
Caster	Used for securing or moving the system.
Monitor supporting arm	Supports the monitor, for adjusting the height and position of the monitor.
Control panel supporting arm	Supports the control panel, for adjusting the height of the panel.
Rear handle	Used for pushing and moving the system.
Cooling vent	/
I/O Panel	Interface panel used for inputting and outputting signals.
Caster brake	Used for locking/unlocking the caster
Power supply panel	Electrical port panel.
DVD-RW	DVD-RW drive

Fig. 2. Power Converter {Phased Array-Mindray P4-2}.

The components of the Device {Mindray DC-60 Exp} are shown in table 1 as follows:

The device is equipped with a dedicated examination table to enhance patient comfort and facilitate procedures. Ultrasound gel was applied to improve wave transmission and reduce interference.

2.2 Methods:

The patient was positioned in the left lateral decubitus position on an examination table to optimize image acquisition during the cardiac evaluation. Imaging was performed using a Mindray DC-60 Exp. ultrasound system equipped with Tissue Doppler Imaging (TDI) technology. Standard echocardiography and color TDI were conducted with a phased array transducer (2-5 MHz frequency range) to accommodate varying imaging requirements. Ultrasound gel was applied to ensure adequate acoustic coupling. All recordings were acquired during normal respiration to minimize motion artifacts. Standard echocardiographic measurements included left ventricular dimensions and ejection fraction (EF), were calculated via the modified Simpson's biplane method. Mitral inflow velocities were assessed using pulsed-wave Doppler, with the sample volume positioned at the tips of the mitral valve leaflets. Early (E) and late (A) diastolic filling velocities were recorded, and the E/A ratio and E deceleration time (EDT) were derived.

For TDI, pulsed-wave Doppler was utilized to measure myocardial longitudinal velocities. The sample volume (≤5 mm) was placed at the lateral and septal mitral annulus, adhering to American Society of Echocardiography (ASE) guidelines. The septal annulus measurement was standardized 10 mm below the leaflet base. The ultrasound beam was aligned parallel to mitral annulus motion, and system settings were optimized to reduce noise: frame rate >121 Hz, pulse repetition frequency 1.9 kHz, and gain adjusted to 50. Filters and dynamic range (145 dB) were configured to maintain signal clarity.

Peak systolic (S'), early diastolic (e'), late diastolic (a'), and myocardial velocities were recorded, along with the e'/a' ratio. The E/e' ratio, reflecting the relationship between mitral inflow and annular diastolic velocities, was calculated. All measurements were obtained during normal expiration, and TDI tracings were recorded at a sweep speed of 100 mm/s.

2.3 Properties of tissue Doppler imaging system:

Table 2 shows the properties of tissue Doppler imaging system and the values used in studying the pathological condition of the patient's heart.

Table 2

Properties of Tissue Doppler Imaging System (TDI).

Body Part Examined	Heart
Transducer Frequency	4 MHz
Wall Filter (WF)	28 Hz
Gain	50
SVD	96
SV	2.5
Frame Rate (FR)	121 Hz
Pulse Frequency (PRF)	1.9 kHz
Angle	0°
Dynamic Range	145 dB

3. Results and Calculations

Tissue Doppler imaging (TDI) procedures were performed using a standardized cardiac ultrasound protocol for a 46-year-old male patient presenting with abnormal cardiac symptoms. Tissue Doppler images were acquired and analyzed (**See Fig. 3 and 4**).

This measurement is primarily used to assess systolic and diastolic cardiac function. The upper panel (color-coded Doppler) depicts tissue movement direction: blue indicates motion away from the probe, and red indicates motion toward the probe, corresponding to myocardial motion during systole and diastole. The lower panel (spectral waveform) displays tissue velocity over time. The positive systolic wave (S') reflects myocardial velocity during left ventricular contraction. The two negative diastolic waves represent early diastolic velocity (e', corresponding to ventricular relaxation) and late diastolic velocity (a', associated with left atrial contraction.

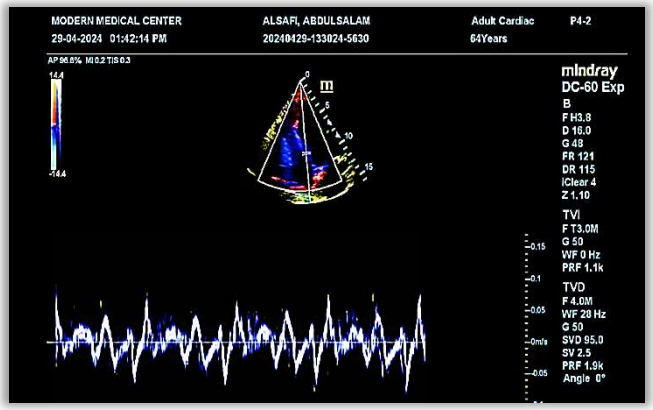

Fig. 3. *A TDI Waveform Recorded at the Lateral Mitral Annulus of the Left Ventricular Wall in a Patient with Ischemic Heart Disease*

The color coding indicates tissue movement direction: red corresponds to motion toward the transducer, and blue represents motion away from the transducer. The spectral Doppler profile exhibits a single positive systolic wave (S')above the baseline and two negative diastolic waveforms below the baseline: early diastolic (e') and late diastolic (a').

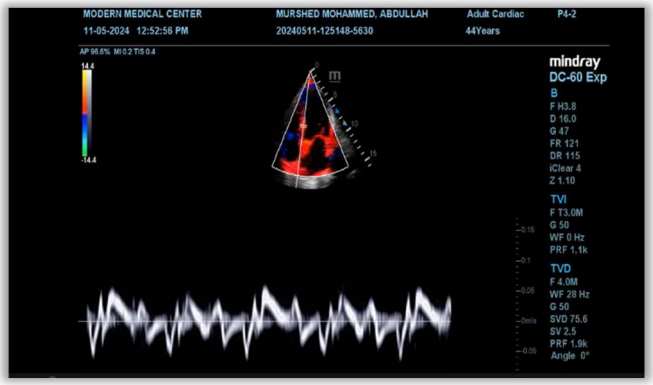

Fig. 4 *TDI Measurements of Myocardial Motion at the Basal (Septal) Mitral annulus of the Left Ventricle*

Calculations:

The velocity values (**See table 4**) were obtained using Equation (2) with input parameters from **Table 3**. The frequency difference was calculated using Equation (3), and the received frequency (f_r) was determined according to the equation:

$$f_r = \Delta f + f_0 \qquad (4)$$

where (f_0) represents the transmitted ultrasound Frey, and (Δf) denotes the frequency shift.

Table 3

Velocity & Frequency

Item	Velocity (cm/s)	Transmitted Frequency (Hz)	Received Frequency (Hz)	Frequency Shift (Hz)
Axial Velocity (s')	4.4	4000000	4000228.57	228.57
Axial Velocity (e')	4.73	4000000	4000245.71	245.71
Axial Velocity (a')	6.52	4000000	4000338.70	338.70
Lateral Velocity (s')	5.5	4000000	4000285.71	285.71
Lateral Velocity (e')	9	4000000	4000467.53	467.53
Lateral Velocity (a')	6.5	4000000	4000337.66	337.66

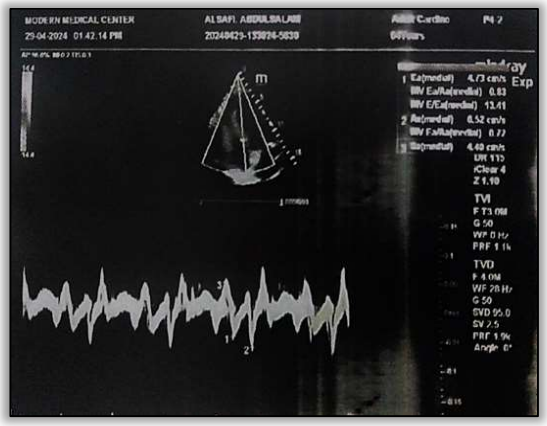

Fig. 5. *Velocity Values Derived from Tissue Doppler Measurements of Myocardial Motion in the Left Ventricle, Specifically at The Basal (Septal) Mitral Annulus.*

Table 4

Normal Reference Range of TDI Values in Healthy Adults (Mean ± SD) and TDI Values of the Patients.

Item	S'(cm/s)		e' (cm/s)		a' (cm/s)		E/e'		e'/a'	
	Normal	Abnormal	Normal	Abnormal	Normal	Abnormal	Normal	Abnormal	Normal	Abnormal
Septal velocity	8.1± 1.5	4. 4	8.6 ± 1.9	4. 73	9.5 ± 2.4	6. 52	8.7 ± 2.2	13. 41	1 ± 0.7	0. 73
Lateral velocity	10.2 ± 2.4	5.5	12.2 ± 3	9	11.3 ± 2.9	6.5	6.3 ± 1.9	11	1.5 ± 0.6	1.1
Average Septal &lateral Velocity	9.2 ± 1.7	4.95	10.4 ± 2.2	6.865	10.4 ± 2.7	6.51	7.5 ± 1.9	12.205	1.3 ± 0.7	0.915

4. Discussions

Tissue diastolic velocity values are critical tools for evaluating cardiac function, as they reflect the systolic and diastolic movement speeds of the myocardial tissue. By comparing the patient's results (Table 4, Figures 3 and 4) with normal reference values, the following observations were made:

1. Tissue diastolic velocity (***S'***)*:*

A significant reduction in systolic velocity was observed in the patient compared to normal values. This decrease reflects impaired myocardial contractility, consistent with compromised blood pumping efficiency due to ischemic heart disease. Coronary artery obstruction in such cases limits oxygen and nutrient supply to cardiac tissue, leading to diminished systolic performance.

2. Tissue diastolic velocity (e'):

Early diastolic velocity, which measures left ventricular compliance during relaxation post-systole, was markedly reduced in the patient. In ischemic heart disease, reduced perfusion diminishes the myocardium's ability to relax rapidly and elastically, resulting in slower left ventricular filling.

3. Late diastolic tissue velocity (a'):

The late diastolic velocity, indicative of left ventricular filling following atrial contraction, was significantly lower in the patient. This suggests impaired late diastolic function,

likely due to chronic ischemia weakening myocardial relaxation capacity.

4. E/e' ratio:

An elevated E/e' ratio indicates abnormal left ventricular relaxation. A higher ratio signifies increased resistance to diastolic blood flow, reflecting poor compliance and diastolic dysfunction.

5. e'/a' ratio:

A reduced e'/a' ratio highlights diminished early diastolic filling relative to late diastolic filling. This decline correlates with reduced myocardial elasticity and compromised ventricular relaxation

5. Conclusion

Comparison of the patient's values with normal ranges reveals significant cardiac dysfunction attributable to ischemic heart disease. Reduced tissue velocities, decreased e'/a' ratios, and elevated E/e' ratios collectively demonstrate impaired myocardial contraction and relaxation.These findings align with the pathophysiology of ischemic heart disease, where atherosclerosis and hypertension disrupt coronary blood flow, reducing tissue oxygenation and myocardial compliance.

This study employed physical principles to analyze tissue Doppler ultrasound (TDI) images. By extracting and processing frequency shifts via the Doppler effect, myocardial motion was quantified. Fourier transform techniques enabled precise analysis of tissue movement frequencies, generating velocity profiles for comparison with normative data.

Tissue Doppler Imaging (TDI) exemplifies the integration of physics in diagnostic medicine. Its ability to track low-velocity myocardial movements—distinct from high-velocity blood flow—provides critical insights into pathological changes. The methodology underscores the utility of ultrasound in diagnosing diastolic dysfunction, emphasizing its role in advancing cardiovascular diagnostics.

References

Abdulla, S., & Clarke, C. (2020). FRCR physics notes: Medical imaging physics for the first FRCR examination. Radiology Café Publishing.

Bjaerum, S., Torp, H., & Kristoffersen, K. (2002). Clutter filter design for ultrasound color flow imaging. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* 49 (2), 204-216. https://doi.org/10.1109/58.985705.

Bushberg, J. T., & Boone, J. M. (2011). *The essential physics of medical imaging. Lippincott Williams & Wilkins.*

Cho, K. I. (2017). Role of echocardiography in diagnosing myocardial ischemia at emergency department. *Journal of Cardiovascular Ultrasound, 25* (1), 3-4. https://doi.org/10.4250/jcu.2017.25.1.3.

Dons, M., Biering-Sørensen, T., Jensen, J. S., Fritz-Hansen, T., Bech, J., de Knegt, M. C., ... & Mogelvang, R. (2015). *Systolic and diastolic function by tissue Doppler imaging predicts mortality in patients with atrial fibrillation.* 8 (1), 1241. https://doi.org/10.4022/jafib.1241.

Hidayat, D., Suhendi, N., Wibawa, B., & Tumbelaka, B. (2018). Fourier transform of high frequency ultrasonic waves propagated with a transmission mode. *Journal of Physics: Conference Series*, 1080 (1), 012034. https://doi.org/10.1088/1742-6596/1080/1/012034.

Jarman, B. (2017). Emergency point-of-care ultrasound. *Wiley*.

Mittal, S. R. (2017). Basics of tissue Doppler revisited. *Journal of the Indian Academy of Echocardiography & Cardiovascular Imaging*, 1(2),126-132. https://doi.org/10.4103/jiae.jiae_34_17.

Mousa, H. K. (2015). Tissue Doppler imaging. *Journal of Cardiology and Current Research*, 3 (4), 00113.

Oates, C. (2023). Principles of colour Doppler ultrasound. In C. Oates (Ed.), Ultrasound technology for clinical,practitioners.Wiley. https://doi.org/10.1002/9781119891581.ch9.

Soilemezi, E., Savvidou, S., Sotiriou, P., Smyrniotis, D., Tsagourias, M., & Matamis, D. (2020). Tissue Doppler imaging of the diaphragm in healthy subjects and critically ill patients. *American Journal of Respiratory and Critical Care Medicine,* 202 (7), 1005-1012.

Solomon, S. D., Wu, J., & Gillam, L. D. (2017). *Essential echocardiography:A companion to Braunwald's heart disease*. e-book. Elsevier

Taylor, K. J., & Holland, S. (1990). Doppler US. Part I. Basic principles, instrumentation, and pitfalls. *Radiology,*174(2),297-307. https://doi.org/10.1148/radiology.174.2.2404309.

Terslev, L., Diamantopoulos, A. P., Døhn, U. M., Schmidt, W. A., & Torp-Pedersen, S. (2017). Settings and artefacts relevant for Doppler ultrasound in large-vascular vasculitis. *Arthritis Research & Therapy*,19(1),167. https://doi.org/10.1186/s13075-017-1374-1.

استخدام تقنية تأثير دوبلر الأنسجة في التطبيقات السريرية لتشخيص أمراض القلب الإقفارية

نبيل صالح عبد الله ناصر وآلاء خالد أحمد صالح

قسم الفيزياء، كلية التربية، جامعة عدن

تاريخ الاستلام	تاريخ القبول	تاريخ النشر
2025/02/28	2025/05/18	2025/12/21

للاقتباس: ناصر، نبيل وصالح، آلاء. (2025). استخدام تقنية تأثير دوبلر الأنسجة في التطبيقات السريرية لتشخيص أمراض القلب الإقفارية. *مجلة جامعة لحج للعلوم التطبيقية والإنسانية، 1* (2)، 295-301.

ملخص

تخطيط صدى القلب باستخدام دوبلر الأنسجة (TDI) هو تطور حديث في مجال التصوير الطبي بالموجات فوق الصوتية، ويوفر طريقة دقيقة وغير جراحية لقياس سرعات أنسجة القلب بدقة مكانية وزمنية عالية. في هذه الدراسة، تم استخدام جهاز Mindray DC-60Expلفحص مريض ذكر (64 عامًا) مصاب بمرض القلب الإقفاري وفق بروتوكول تخطيط صدى القلب بدوبلر الأنسجة. كان الهدف الرئيسي للفحص قياس سرعات الأنسجة المرتبطة بحركة الحلقة التاجية (المِترالية) المحورية والجانبية، وتحليل الفروق بين سرعات الأنسجة السليمة والمريضة. يعتمد TDI على مبدأ تأثير دوبلر، حيث تُقاس سرعة أنسجة القلب من خلال تحليل التغير في تردد الموجات فوق الصوتية المنعكسة، ثم حساب سرعة النسيج باستخدام معادلة دوبلر، مما يساعد في تحديد المناطق المتأثرة بالمرض .

من خلال معادلة دوبلر، تم حساب المعلمات الرئيسية، بما في ذلك السرعة الإنقباضية القصوى (s') ، التي تمثل ذروة سرعة الأنسجة أثناء الانقباض؛ السرعة الانبساطية المبكرة (e') ، التي تعكس سرعة استرخاء النسيج في المرحلة المبكرة من الانبساط؛ والسرعة الانبساطية المتأخرة (a') ، التي تشير إلى سرعة استرخاء النسيج في المرحلة المتأخرة من الانبساط.

أظهرت النتائج انخفاضًا واضحًا في قيم (S') و (e') في المناطق المصابة مقارنة بالمناطق السليمة، مما يشير إلى ضعف في حركة أنسجة القلب نتيجة الإقفار. تؤكد هذه النتائج فعالية تقنية TDI في الكشف المبكر عن التغيرات الوظيفية في عضلة القلب، مما يسهم في تحسين تشخيص وعلاج مرضى القلب الإقفاري. كما يبرز دور تطبيقات الفيزياء في التصوير الطبي في تعزيز جودة البيانات التشخيصية، مما ينعكس إيجابًا على كفاءة وسرعة اتخاذ القرارات الطبية.

الكلمات المفتاحية: الموجات فوق الصوتية (US)، تخطيط صدى القلب (ECG)، تأثير دوبلر (DE)، مرض القلب الإقفاري (IHD).