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## **Role of Ultrasound Elastography in Differentiating Pancreatic Cancer: Present and Future Directions**

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**ABSTRACT**

**Aim.** To review the diagnostic value of ultrasound elastography in the assessment of focal pancreatic lesions, particularly its role in differentiating benign from malignant lesions during endoscopic ultrasound (EUS) examinations.

**Materials and Methods.** A narrative review of published studies on ultrasound elastography techniques, including strain elastography (SE), acoustic radiation force impulse (ARFI), and shear wave elastography (SWE), was conducted. The analysis focused on elastography parameters such as strain ratio (SR), strain histogram (SH), and shear wave velocity (SWV), as well as their reported diagnostic performance in pancreatic imaging.

**Results.** Ultrasound elastography allows non-invasive assessment of tissue stiffness, with malignant pancreatic lesions generally demonstrating higher stiffness than benign or inflammatory lesions. Studies report high sensitivity of EUS elastography for detecting malignancy (approximately 90–97%) with diagnostic accuracy around 87–89%, although specificity remains moderate. Quantitative techniques such as SWE provide more reproducible

measurements than qualitative strain-based assessment. Emerging approaches combining elastography parameters with artificial intelligence and radiomic analysis show potential to further improve diagnostic accuracy.

**Conclusion.** EUS elastography is a useful complementary technique in the evaluation of focal pancreatic lesions. Although it cannot replace biopsy due to limited specificity, it may improve lesion characterisation and help target the most suspicious areas for tissue sampling. Future integration with artificial intelligence may further enhance diagnostic performance.

**Keywords:** EUS elastography, pancreatic cancer, qualitative and quantitative elastography, fine needle aspiration

## **Introduction**

Ultrasound elastography (USE) is a non-invasive imaging technique that detects changes in the biomechanical properties of soft tissues associated with various pathological processes. It is based on the principle that pathological processes, such as inflammation, fibrosis, or malignancy, often lead to alterations in tissue composition, resulting in increased stiffness. This change is commonly reflected by a higher elastic modulus, which can be measured and analyzed using elastographic techniques (Oglat & Abukhalil, 2024; Prado-Costa et al., 2018; Sigrist et al., 2017)). Elastography enhances the detection of pathological tissue changes and improves diagnostic accuracy in distinguishing normal from abnormal tissues. Elastography has significantly enhanced diagnostic accuracy across multiple medical fields. It is widely applied in the evaluation of breast and thyroid nodules. Similarly, it plays an important role in the assessment of prostate lesions and lymph nodes, aiding in the identification of suspicious areas that may require further diagnostic procedures (Azizi et al., 2013; Bhatia et al., 2012; Bojunga et al., 2010; Brock et al., 2012; Chang et al., 2018; Gao et al., 2022; Woo et al., 2014).

Elastographic techniques in gastroenterology have mainly focused on non-invasive evaluation of liver fibrosis, particularly in patients with suspected chronic liver disease and cirrhosis. (Conti et al., 2016; Feier et al., 2013; Ferraioli et al., 2012; Friedrich-Rust et al., 2012; Y. Li et al., 2016; Ronot et al., 2015). Recent studies suggest elastography may also be a valuable tool for differentiating malignant focal pancreatic lesions during endoscopic ultrasound (EUS) examinations. Differentiating between benign and malignant focal pancreatic lesions remains a diagnostic challenge due to overlapping imaging features. Emerging evidence suggests that elastographic assessment of tissue stiffness may provide additional diagnostic information, helping to distinguish malignant tumors, which are typically stiffer, from benign or inflammatory lesions. As a result, elastography is increasingly recognized as a promising

complementary technique in the diagnostic workup of pancreatic pathology, potentially enhancing the accuracy of EUS-based evaluations and guiding further management.

### **Techniques of Ultrasound Elastography**

Elastography measures tissue elasticity, the ability of tissues to resist deformation from an applied force and return to their original shape. The fundamental principle of elastography is based on the relationship between stress and strain. This relationship is described by Hooke's law, which states that the greater the resistance of a tissue to deformation, the higher its stiffness (Sigrist et al., 2017). Mathematically, this relationship can be expressed as:

$$\sigma = E \cdot \varepsilon,$$

where:

$\sigma$  (stress) – stress, defined as the force applied per unit area,

$\varepsilon$  (strain) – relative strain (the change in length relative to the original length),

E – Young's modulus, which describes the level of external stress required to produce a normal degree of stress perpendicular to the surface.

The strain profile along the compression axis determines the distribution of tissue elastic properties. A higher elastic modulus means greater resistance to deformation and increased stiffness (Oglat & Abukhalil, 2024). The physical principles and measurement methods are described in detail in scientific publications (Gennisson et al., 2013; Oglat & Abukhalil, 2024; Sarvazyan et al., 1998).

Currently available ultrasound elastography (USE) methods are classified into two main categories based on the measured physical parameter: compression-based methods, which rely on internal or external forces to induce tissue deformation, and shear wave-based methods, which utilize shear waves generated by ultrasound to assess tissue stiffness. (Ferraioli et al., 2012; Gennisson et al., 2013; Shiina et al., 2015). Strain elastography (SE) is the most commonly used technique. It can be categorised based on the method of tissue excitation. The first approach induces deformation through manual compression by the operator using the ultrasound transducer. It is effective for superficial structures. The second approach keeps the transducer stationary, with tissue displacement caused by intrinsic physiological movements like cardiac pulsation or respiration. Since it does not rely on external pressure, it better suits assessing deeper anatomical structures. (Sigrist et al., 2017)

SE assesses stiffness by comparing pre- and post-compression images, providing a relative measure of tissue stiffness. Two main parametric approaches are used for result analysis: qualitative assessment based on colour pattern analysis and semi-quantitative assessment using

the strain ratio (SR) or strain histogram (SH). The qualitative technique relies on subjective comparisons of colour patterns and their homogeneity, classified on a five-point colour scale. The strain ratio (SR) is calculated as the ratio of strain values within the lesion (region of interest, ROI) to those from a reference area. Higher SR values indicate greater lesion stiffness compared to reference tissue (Giovannini et al., 2009). Strain histogram (SH) analysis provides a graphical representation of strain distribution within the ROI (C. F. Dietrich et al., 2014; H. H. Okasha et al., 2021; Opačić, 2015).

Acoustic Radiation Force Impulse (ARFI) is a relatively recent dynamic technique that combines tissue elasticity with conventional grayscale images from standard ultrasound (US) systems. ARFI serves as a fundamental excitation mechanism that bridges strain elastography and shear wave elastography, as it generates localized tissue displacement and shear waves that can be analyzed either as relative deformations (strain) or as propagating wave velocities (shear wave elastography). In the ARFI technique, shear waves are generated within a predefined region of interest (ROI) measuring approximately  $1 \times 0.5$  cm, which is positioned by the operator on a standard grayscale ultrasound (US) image. ARFI induces localized shear stresses in tissues, generating shear waves that propagate perpendicular to the ultrasound beam and move outward from the excitation region. ARFI systems therefore enable both qualitative visualization of spatial variations in tissue stiffness and quantitative assessment, most commonly expressed as shear wave velocity (SWV) measured in meters per second (m/s), which serves as an indicator of tissue elasticity (Nightingale, 2011).

Shear wave elastography (SWE), unlike strain imaging, uses short-duration acoustic radiation force impulses to generate shear waves. These waves travel perpendicular to the impulse, and their velocity is directly related to tissue stiffness. This transverse motion enhances the differences between tissues, thereby improving contrast and enabling more accurate elastographic measurements. Measuring shear wave velocity (SWV) within the region of interest (ROI) enables both qualitative and quantitative assessment of tissue elasticity (Cui et al., 2022; Ozturk et al., 2018). Shear wave imaging (SWI) is implemented using three primary technical approaches: one-dimensional transient elastography (1D-TE), point shear wave elastography (pSWE), and two-dimensional shear wave elastography (2D-SWE) (Bamber et al., 2013). Two-dimensional shear wave elastography (2D-SWE) stands out as an innovative advancement in shear wave imaging, using acoustic radiation force to create shear waves. Unlike earlier techniques that focus on a single point, such as acoustic radiation force impulse (ARFI) or point shear wave elastography (pSWE), 2D-SWE rapidly excites several focal zones in sequence (Bamber et al., 2013). This method is more reproducible and less operator-

dependent than strain elastography (C. Dietrich et al., 2017; Taljanovic et al., 2017; L. Zhang et al., 2020). Shear wave elastography (SWE) faces several technical limitations. Its restricted penetration depth makes imaging of deeper structures difficult, even when a thin layer of ultrasound gel is used to improve superficial imaging. Some ultrasound systems also limit the size and geometry of the region of interest (ROI) for analysis. Additionally, short pauses are required between acquisitions, which prevents continuous, real-time evaluation of moving tissues. SWE measurements are further affected by operator-dependent factors, such as transducer pressure and orientation. The calculated shear modulus can also vary with probe alignment to the anatomical structure, reflecting tissue anisotropy (Taljanovic et al., 2017).

### **Pancreatic Cancer**

According to recent studies, pancreatic cancer ranks seventh among all cancers in mortality (Sung et al., 2021; S. Wang et al., 2024). According to GLOBOCAN 2020 data, the number of deaths is estimated to be almost equal to the number of cases (Sung et al., 2021). The 5-year survival rate is 10-11% (Drouillard et al., 2018; Q. Li et al., 2022; Siegel et al., 2022). Early diagnosis of cancer allows patients to be qualified for surgical treatment, which is the only chance for extending 5-year survival rates. Some lesions, especially benign pancreatic tumours, may be difficult to distinguish from PDAC on imaging studies (Perumal, 2013).

Progress in the diagnosis of pancreatic lesions occurred with the introduction of endoscopic ultrasound. Fine-needle aspiration biopsy (FNA) and fine-needle biopsy (FNB) guided by EUS are among the basic, commonly used diagnostic methods, enabling the acquisition of tissue samples for accurate cytological and histopathological assessment of focal pancreatic lesions (Iglesias García et al., 2009; Iglesias-Garcia et al., 2014). Reported sensitivity and specificity for malignancy range from 64% to 85% and 98% to 100%, respectively (Ardengh et al., 2007; Bhutani et al., 1997; Giovannini et al., 1995; Hewitt et al., 2012; Iglesias-Garcia, 2007). The widespread use of EUS-FNA biopsy is due to its relatively low complication rate and its safety (Jacobson et al., 2005; O'Toole et al., 2001; Wiersema et al., 1997). In cases of chronic pancreatitis, the sensitivity of endoscopic ultrasound-guided fine-needle aspiration biopsy (EUS-FNA) for diagnosing neoplastic lesions is significantly reduced, complicating differentiation between inflammatory and neoplastic lesions in the pancreas (Ardengh et al., 2007; Varadarajulu et al., 2005). The performance of EUS-FNA may also be technically limited in certain situations. Key factors hindering accurate sample collection include vessels in the biopsy field, duodenal stenosis, and significant fibrosis, especially with chronic pancreatitis. In

such cases, diagnostic accuracy may be significantly reduced (Bhutani et al., 1997; Varadarajulu et al., 2005).

In response to the limitations of traditional morphological assessment in endoscopic ultrasound and the diagnostic difficulties associated with performing aspiration biopsy, elastographic techniques used during EUS examination are gaining increasing importance. Endoscopic elastography (EUS) enables non-invasive assessment of tissue biomechanical properties by analysing susceptibility to deformation under applied force. This method allows visualisation and semi-quantitative or quantitative assessment of tissue stiffness, which can support the differentiation between benign and malignant pancreatic lesions.

Qualitative assessment of tissue elasticity is performed in real time and displayed as a colour elastographic map. The colour scale reflects tissue stiffness: blue indicates the highest stiffness (often malignant lesions), green represents fibrosis, yellow denotes normal tissue, and red indicates adipose tissue, which is most deformable (Giovannini et al., 2006). Clinical experience led to the development of the 5-point Giovannini scoring system, which assesses colour pattern and lesion heterogeneity. Points 1 and 2 indicate benign lesions, while points 3-5 indicate malignancy. This method has low specificity (21.20%-64%), as benign lesions may not always appear soft and hard tumours often correlate with malignancy (Almasri & Ali, 2021; Itokawa et al., 2011; Puga-Tejada et al., 2022). Studies show that using elastography with strain ratio (SR) analysis during EUS, and comparing results to biopsy findings, gives high sensitivity (90.5–97%) and good accuracy (87-89%). However, its specificity is only moderate (63-77%), so it should not be used alone for diagnosis (Dawwas et al., 2012; Iglesias–Garcia et al., 2010; H. Okasha et al., 2017; H. H. Okasha et al., 2018; F. Wang et al., 2025).

A retrospective study conducted at the First Affiliated Hospital of Xi'an Jiaotong University compared several elastographic parameters- strain ratio (SR), fat-lesion strain ratio (FLR), and mean elongation histogram (MEAN)-in the diagnosis of pancreatic ductal adenocarcinoma (PDAC). The study showed that all three parameters differentiate benign from malignant pancreatic lesions, with SR demonstrating the highest independent diagnostic performance (sensitivity 90.5%, specificity 75%). Combining all three parameters significantly improves diagnostic accuracy, suggesting that multiparameter elastographic analysis may be a more reliable indicator of PDAC than single measurements (F. Wang et al., 2025).

At the same time, a significant limitation of qualitative elastographic assessment based on colour mapping remains the high dependence of results on operator experience. Acquiring the necessary competencies to properly perform EUS examinations requires extensive training and clinical practice. To reduce subjectivity and improve reproducibility, semi-quantitative and

quantitative methods have been introduced and are increasingly used in clinical practice (Cho et al., 2024; Diehl et al., 2025; Mulabecirovic et al., 2016). Research shows that malignant pancreatic tumors have much higher shear wave velocity (SWV) values than benign ones (Alidina et al., 2026; X. Li et al., 2026; Xie et al., 2020; C. Zhang et al., 2025). A study by Xie et al. (2020, Clin Hemorheol Microcirc, 74:179-187) found that at a threshold of 1.77 m/s, the method achieved high sensitivity (90%) and specificity (96%), making it an objective and promising tool for non-invasive differentiation of pancreatic lesions (Xie et al., 2020)

### **Development Prospects and the Role of Artificial Intelligence**

Making ultrasound elastography better for detecting pancreatic issues depends on new computer tools like artificial intelligence and machine learning. AI-based systems can help automate the analysis of elastographic images by giving an objective look at color patterns, strain distribution, and measurements like strain ratio (SR) and shear wave velocity (SWV). Deep learning models trained on large datasets can spot subtle image features that might be hard for people to see, making it easier to tell the difference between benign and malignant lesions (Alidina et al., 2026; Dumitrescu et al., 2022; X. Li et al., 2026). An additional emerging field is radiomics, which involves extracting numerous quantitative features from medical images. Combining elastographic parameters with radiomic features from ultrasound, computed tomography (CT), or magnetic resonance imaging (MRI) allows for the development of multiparametric diagnostic models with higher accuracy than single imaging modalities (Huang et al., 2024; Tong et al., 2022). Even with these advances, there are still important challenges. The lack of standard examination protocols, differences between ultrasound systems, and limited access to large, well-labelled datasets make it hard to widely use AI-based methods (Urooj et al., 2025; H. Zhang et al., 2023). Prospective, multicenter studies are needed to validate these technologies before they can be used routinely in clinics (Han et al., 2025).

### **Conclusions**

Strain elastography gives information about how tissues respond to force, but it is limited because it depends on the operator and is mostly qualitative. Shear wave elastography measures tissue stiffness with numbers, making it more repeatable and less dependent on who does the test. Studies show that EUS elastography is very sensitive for finding malignant pancreatic lesions, but its specificity is still limited. Therefore, this method should not be considered a standalone diagnostic tool in daily clinical practice, but rather as a complement to conventional

techniques, supporting more precise targeting of aspiration biopsy and potentially improving diagnostic accuracy the most suspicious areas within a lesion. This improves sampling accuracy, increases diagnostic yield, and may reduce the number of needle passes and related complications. Using artificial intelligence together with radiomics makes it possible to automate image analysis and more accurately tell apart benign from malignant lesions earlier. Although there are still problems like non-standard protocols and small databases, AI-based models that use different types of data could improve ultrasound diagnostics and lead to better patient outcomes.

### **Disclosure**

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The authors deny any conflict of interest.

## **Declaration of the use of generative AI and AI-assisted technologies in the writing process**

In preparing this work, the authors used ChatGPT for the purpose of grammar checking and improving the readability of the text. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication

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