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RESEARCH ARTICLE

ELASTOGRAPHY IN OVARIAN IMAGING: EMERGING APPLICATIONS IN PCOS AND PCOM

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Abstract

Polycystic ovary syndrome (PCOS) is one of the most common endocrine and metabolic disorders affecting women of reproductive age and is frequently associated with infertility, menstrual irregularities, hyperandrogenism, obesity, and insulin resistance. Polycystic ovarian morphology (PCOM), characterized by increased follicle number and enlarged ovarian volume, represents the characteristic imaging appearance of the disorder. Conventional ultrasonography remains the primary imaging modality for ovarian evaluation; however, it provides limited information regarding stromal tissue composition, fibrosis, and biomechanical properties. In recent years, elastography has emerged as an advanced ultrasound-based technique capable of assessing tissue stiffness and elasticity in real time,thereby offering additional functional information beyond routine morphological assessment.Both strain elastography and shear wave elastography (SWE) have demonstrated promising applications in ovarian imaging. Studies have shown that ovaries affected by PCOS and PCOM exhibit increased stromal stiffness due to stromal hypertrophy, collagen deposition, fibrosis, hyperthecosis, and chronic low grade inflammation. Elastographic findings have also shown correlation with hormonal abnormalities such as elevated androgen levels, increased anti-Müllerian hormone (AMH), insulin resistance, and metabolic syndrome. Furthermore, elastography may aid in differentiating PCOM from multifollicular ovaries, evaluating infertility, predicting ovarian response during assisted reproductive therapy,and monitoring treatment outcomes.This review highlights the principles and techniques of ovarian elastography, pathophysiological basis of altered ovarian stiffness,imaging findings in PCOS and PCOM, clinical applications, current evidence, advantages, limitations, and future directions including artificial intelligence integration and multiparametric ultrasound approaches in reproductive imaging.

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Introduction:-

Polycystic ovary syndrome (pcos) is one of the most common endocrine and metabolic disorders affecting women of reproductive age worldwide, with a reported prevalence ranging from 6% to 20% depending on the diagnostic criteria used.[1,7] it is a heterogeneous disorder characterized by chronic anovulation, hyperandrogenism, menstrual irregularities, infertility, obesity, insulin resistance, and metabolic dysfunction.[6,8] in addition to reproductive abnormalities, pcos is associated with long-term complications such as type 2 diabetes mellitus, cardiovascular disease, dyslipidemia, and psychological disorders, making it a major public health concern.[3,17]polycystic ovarian morphology (pcom) represents the characteristic ovarian appearance seen on imaging in many women with pcos. According to the revised rotterdam criteria, pcom is defined by the presence of 20 or more follicles measuring 2–9 mm in diameter in at least one ovary and/or an ovarian volume greater than 10 ml when assessed using high-resolution transvaginal ultrasonography.[1,4] ultrasound examination plays a central role in the diagnosis and evaluation of ovarian morphology because it is non-invasive, widely available, cost-effective, and capable of assessing follicular distribution and stromal echogenicity.[5,20]conventional grayscale and doppler ultrasonography are routinely used to evaluate ovarian size, follicle number, and vascularity. However, these imaging modalities provide limited information regarding tissue biomechanics, stromal fibrosis, and ovarian stiffness.[10,11] increasing evidence suggests that stromal hypertrophy, collagen deposition, fibrosis, and hyperthecosis contribute significantly to the pathophysiology of pcos and may correlate with endocrine and metabolic abnormalities.[8,19]

Elastography is an advanced ultrasound-based imaging technique that evaluates tissue stiffness and elasticity by measuring tissue displacement or shear-wave propagation following mechanical stress.[10,11] Initially developed for the assessment of liver fibrosis, elastography has rapidly expanded into various clinical applications including breast, thyroid, prostate, musculoskeletal, and gynaecologic imaging.[12] Recent advances in strain elastography and shear-wave elastography (SWE) have enabled non-invasive quantitative assessment of ovarian stromal stiffness in women with PCOS and PCOM.[13,14]Emerging evidence indicates that ovaries affected by PCOS demonstrate significantly increased stiffness compared with normal ovaries due to stromal fibrosis, increased connective tissue, and hormonal alterations.[13,15] Elastography may therefore serve as a valuable adjunct to conventional ultrasound by improving diagnostic accuracy, differentiating PCOM from multi-follicular ovaries, assessing disease severity, correlating with hormonal and metabolic parameters, and monitoring therapeutic response.[14,15] This review aims to discuss the principles of ovarian elastography, imaging techniques, pathophysiological basis of altered ovarian stiffness in PCOS and PCOM, current clinical applications, research evidence, limitations, and future perspectives in reproductive imaging.

Figure 1: Transvaginal ultrasound images showing polycystic ovarian morphology with multiple peripherally arranged follicles in the right ovary.

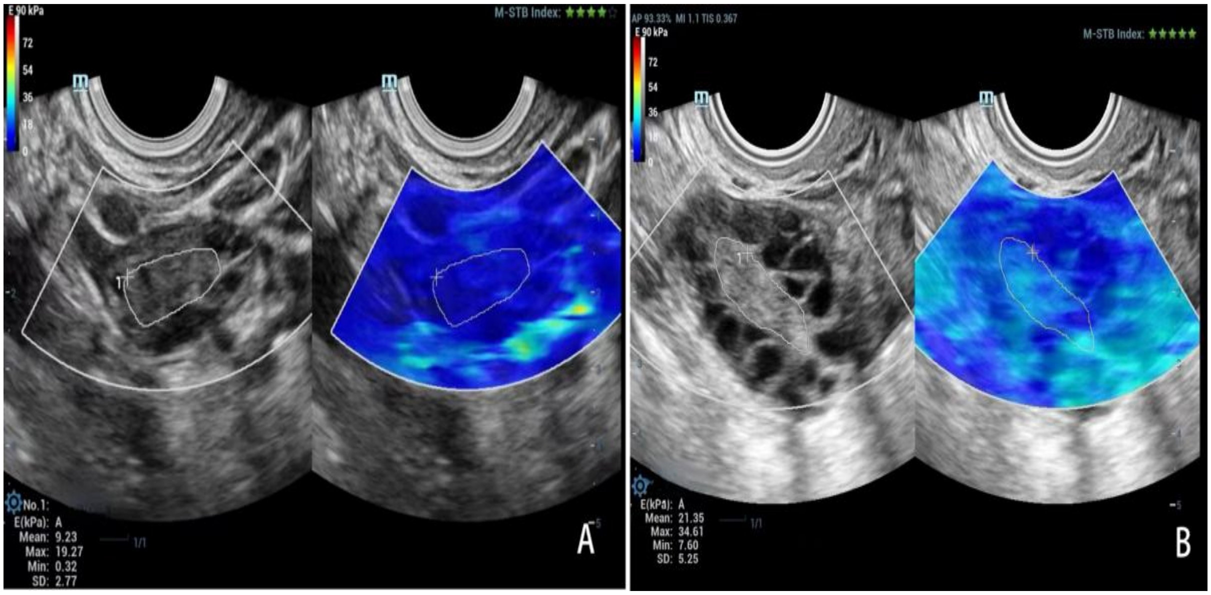


Figure 2: Ovarian elastography images demonstrating increased stromal stiffness in polycystic ovaries, with elasticity measurements expressed in kilopascals (kPa).

Anatomy and Physiology of the Ovary: The ovaries are paired female reproductive organs responsible for oocyte production and secretion of hormones such as estrogen, progesterone, and androgens.[21,22] Structurally, the ovary consists of an outer cortex containing developing follicles and stromal tissue, and an inner medulla containing blood vessels, lymphatics, nerves, and connective tissue.[21,23] The ovarian stroma is composed of fibroblasts, collagen fibers, and extracellular matrix that provide structural and hormonal support.[22,23]

Folliculogenesis is the process of follicular maturation and includes:[23,24]
- Primordial follicle recruitment
- Primary follicle development
- Secondary follicle formation
- Graafian follicle maturation
- Ovulation

These processes are regulated by the hypothalamic-pituitary-ovarian axis through hormones such as FSH and LH.[23] During ovulation, the mature Graafian follicle ruptures and releases the oocyte, followed by formation of the corpus luteum.[21,23]In polycystic ovary syndrome (PCOS), normal follicular maturation is disrupted due to hyperandrogenism, insulin resistance, and hormonal imbalance.[1,6] This leads to follicular arrest, accumulation of immature follicles, stromal hypertrophy, fibrosis, and enlarged ovaries.[8,19] These pathological stromal changes increase ovarian stiffness, which can be assessed using elastography in ovarian imaging.[11, 10,13]

Pathophysiology: Polycystic ovary syndrome (PCOS) is a complex endocrine and metabolic disorder characterized by hormonal imbalance, insulin resistance, abnormal follicular development, and structural ovarian changes.[2,6]The disorder develops due to interactions between genetic, environmental, metabolic, and endocrine factors that alter the normal hypothalamic-pituitary-ovarian axis.[6,8]One of the hallmark abnormalities in PCOS is hyperandrogenism, which may be clinical or biochemical. Clinical manifestations include hirsutism, acne, alopecia, seborrhea, and menstrual irregularities.[2,17] Increased luteinizing hormone (LH) secretion stimulates ovarian theca cells to produce excess androgens, while insulin further enhances androgen synthesis.[6,8] Elevated androgen levels disrupt follicular maturation and inhibit ovulation, resulting in chronic anovulation.[6,3] Insulin resistance is another major feature of PCOS and occurs in both obese and lean women.[8,3] Peripheral tissues such as skeletal muscle, adipose tissue, and liver become less responsive to insulin, leading to compensatory hyperinsulinemia.[8,27] Hyperinsulinemia increases ovarian androgen production and decreases hepatic synthesis of sex hormone-binding globulin (SHBG), thereby increasing free circulating androgen levels.[2,19] These hormonal abnormalities impair dominant follicle selection and lead to accumulation of immature follicles within enlarged ovaries.[6,19]

Abnormal folliculogenesis in PCOS is characterized by arrest of follicular development at the small antral stage.[6,8] Multiple immature follicles accumulate peripherally within the ovary, producing the classic “string of pearls” appearance on ultrasound.[1,26] Chronic anovulation contributes to infertility and menstrual dysfunction.[19,03]The ovarian stroma undergoes significant structural remodelling in PCOS. Stromal hypertrophy, stromal hyperplasia, increased connective tissue deposition, collagen accumulation, and fibrosis contribute to increased ovarian volume and stromal echogenicity.[8,19] Thickening of the tunica albuginea further impairs follicular rupture and ovulation.[6,28] Hyperthecosis and chronic low-grade inflammation additionally contribute to stromal rigidity and fibrosis.[8,18]

Doppler ultrasonography demonstrates increased ovarian vascularity, stromal blood flow, and angiogenesis in women with PCOS.[26,28] These vascular and stromal alterations form the biological basis for elastographic imaging, which evaluates ovarian tissue stiffness and fibrosis.[19,11] Elastography has therefore emerged as a promising imaging modality for assessing ovarian stromal changes in PCOS and polycystic ovarian morphology (PCOM).[11]

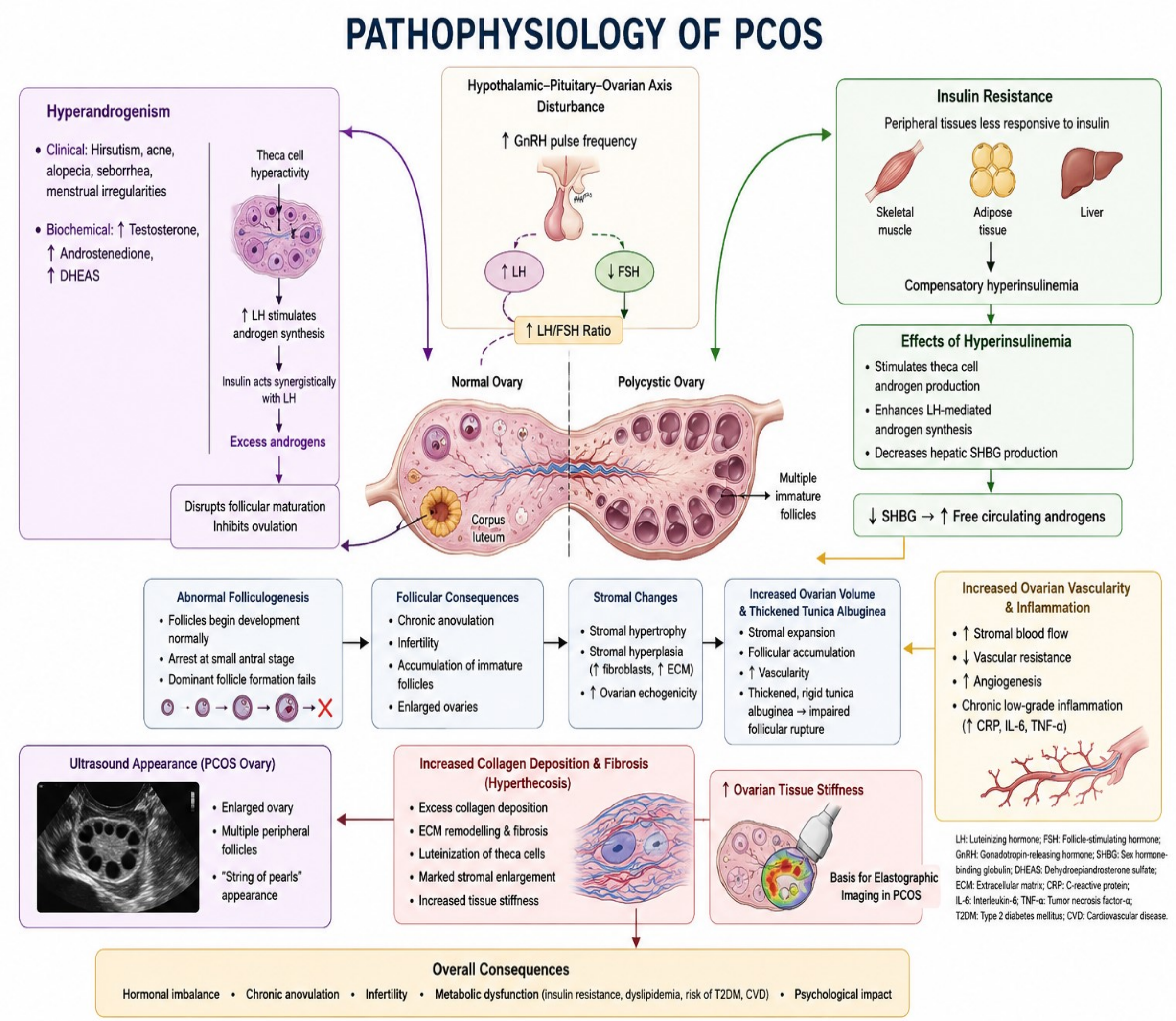


Figure 03: This diagram effectively demonstrates how endocrine dysfunction, insulin resistance, inflammation, and ovarian structural remodelling together contribute to the development and progression of PCOS.

Introduction to Elastography in Ovarian Imaging: Elastography is an advanced ultrasound imaging technique that assesses tissue stiffness and elasticity. Unlike conventional ultrasonography, which mainly depicts anatomical structures, elastography provides additional functional and biomechanical information about tissue composition, fibrosis, and stromal architecture. This technique has emerged as a valuable tool in gynaecologic imaging, particularly in the assessment of ovarian disorders such as Polycystic Ovary Syndrome (PCOS) and polycystic ovarian morphology (PCOM).[10,29]In PCOS and PCOM, ovarian stromal hypertrophy, fibrosis, and increased collagen deposition lead to alterations in tissue elasticity, resulting in increased ovarian stiffness.[30,31] Elastography enables non-invasive evaluation of these stromal changes, thereby improving diagnostic accuracy and enhancing understanding of ovarian pathophysiology.[32]

Currently, two major elastographic techniques are widely used in gynaecologic and ovarian imaging:-

1. Strain Elastography: Strain elastography is a qualitative or semi-quantitative technique that evaluates tissue deformation after external compression is applied using the ultrasound transducer. Softer tissues deform more easily, whereas stiffer tissues show less deformation. The resulting elastogram provides a color-coded representation of tissue stiffness, helping assess ovarian stromal consistency.[33]

2. Shear-Wave Elastography (SWE): Shear-wave elastography is a quantitative imaging modality that uses acoustic radiation force impulses to generate shear waves within tissues. The velocity of these shear waves is measured to calculate tissue stiffness objectively, usually expressed in kilopascals (kPa) or meters per second (m/s). SWE offers greater reproducibility and reduced operator dependency compared with strain elastography.[34,11] Both elastographic methods contribute significantly to the evaluation of ovarian stromal abnormalities in PCOS and PCOM. By detecting increased ovarian stiffness associated with stromal fibrosis and hypertrophy, elastography may serve as a promising adjunctive tool in the diagnosis, characterization, and monitoring of ovarian disorders.[29,32,11]

Types of Elastography in Ovarian Imaging

Aspect	Strain Elastography (SE)	Shear-Wave Elastography (SWE)
Definition	A qualitative or semi-quantitative elastographic technique that evaluates tissue deformation after external compression.[35]	A quantitative elastographic technique that measures tissue stiffness using acoustic radiation force impulses.[34,11]
Basic Principle	Tissue deformation occurs when manual pressure is applied; softer tissues deform more than hard tissues.	Acoustic pulses generate shear waves inside tissue; wave velocity reflects tissue stiffness.[34]
Physical Basis	Based on tissue strain under compression.[35]	Based on shear-wave propagation velocity and Young's modulus.[11]
Key Formula	$\sigma = E\varepsilon^2$	$E = 3\rho c_s^{24}$
Method of Compression	Manual compression using transvaginal probe.	No manual compression required.[36]
Imaging Technique	Compression–decompression cycles create elastograms.[35]	Focused ultrasound pulses create transverse shear waves.[34]
Type of Assessment	Qualitative or semi-quantitative.	Fully quantitative.[11]
Output	Relative tissue stiffness shown by colour patterns.	Numerical stiffness values in kPa or m/s.[4]
Color Mapping	Red/green = softer tissue; blue = harder tissue.	Color-coded quantitative stiffness map.[34]
Quantitative Parameters	Strain ratio, elasticity score.[35]	Shear-wave velocity and elasticity modulus.[11]
Operator Dependency	High.	Low.[4]
Reproducibility	Moderate.	High.[4,6]
Accuracy	Moderate diagnostic accuracy.[37]	Higher diagnostic accuracy.[37]
Real-Time Imaging	Yes.	Yes.[34]
Transvaginal Application	Commonly used with transvaginal ultrasound.[29]	Commonly used with transvaginal ultrasound.[29]
Advanced Imaging Features	Real-time elastographic mapping, dual-display imaging, 3D	2D-SWE, 3D-SWE, ultra-fast imaging, AI-assisted elastography.[37]

	strainelastography, Doppler fusion imaging.[36]	
3DImaging Capability	Available in advanced systems.[36]	More advanced volumetric stiffness mapping available.[37]
Doppler Integration	Can combine with Doppler for vascular assessment.[29]	Can combine with Doppler and multiparametric imaging.[37]
Artificial Intelligence Integration	Limited.[36]	Increasingly integrated for automated analysis.[37]
Applications in PCOS/PCOM	Detects increased stromal stiffness due to fibrosis and hypertrophy.[29.30]	Quantifies ovarian stromal stiffness objectively in PCOS and PCOM.[30]
Applications in Ovarian Tumours	Helps differentiate benign and malignant lesions.[38]	Better characterization of tumour stiffness and heterogeneity.[38]
Applications in Endometriosis	Detects fibrotic lesions with increased stiffness.	Quantifies stiffness in fibrotic ovarian lesions.[39]
Advantages	Simple, inexpensive, real-time imaging, easily integrated into ultrasound.[36]	Objective, quantitative, reproducible, less operator dependent.[11,37]
Limitations	Operator variability, poor standardization, compression inconsistency.[36]	Expensive equipment, motion artifacts, limited availability.[37]
Clinical Utility	Useful screening adjunct tool.[29]	Preferred advanced quantitative assessment tool.[37]
Diagnostic Reliability	Variable between operators.[36]	Better interobserver agreement.[37]
Equipment Requirement	Standard elastography-enabled ultrasound system.	Advanced SWE-capable ultrasound platform.[34]
Cost	Relatively lower.[36]	Higher.[37]
Role in Advanced Imaging	Useful for qualitative stromal mapping.[29]	Considered the future standard for quantitative ovarian stiffness analysis.[37,30]

Advanced Elastographic Imaging Modalities in Ovarian Imaging

Advanced Imaging Technique	**Description**	**Clinical Importance**
3D Elastography	Provides volumetric assessment of ovarian tissue stiffness.[40,41]	Better visualization of stromal heterogeneity and follicular distribution.[41]
2D Shear-Wave Elastography	Produces large-area quantitative stiffness maps.[42,11]	Improves assessment of diffuse ovarian stromal fibrosis.[11]
Ultra-Fast Imaging	Captures rapid shear-wave propagation with high temporal resolution.[42]	Enhances measurement accuracy and image quality.[42,38]
Doppler-Elastography Fusion	Combines vascularity assessment with tissue stiffness imaging.[29]	Useful in evaluating stromal hypervascularity in PCOS.[30]
Contrast-Enhanced Elastography	Combines contrast ultrasound with elastographic evaluation.[38,39]	Improves ovarian lesion characterization and vascular assessment.[39]
AI-Assisted Elastography	Uses machine learning for automated stiffness analysis.[43]	Reduces operator dependency and improves diagnostic precision.[43,44]
Multiparametric Ultrasound Imaging	Integrates B-mode, Doppler, elastography, and contrast imaging.[38, 39]	Provides comprehensive ovarian tissue evaluation.[39]
Radiomics-Based Elastography	Extracts advanced imaging biomarkers from stiffness maps.[44]	Potential future role in early diagnosis and prognostic prediction.[44]

Strain Elastography in Ovarian Imaging

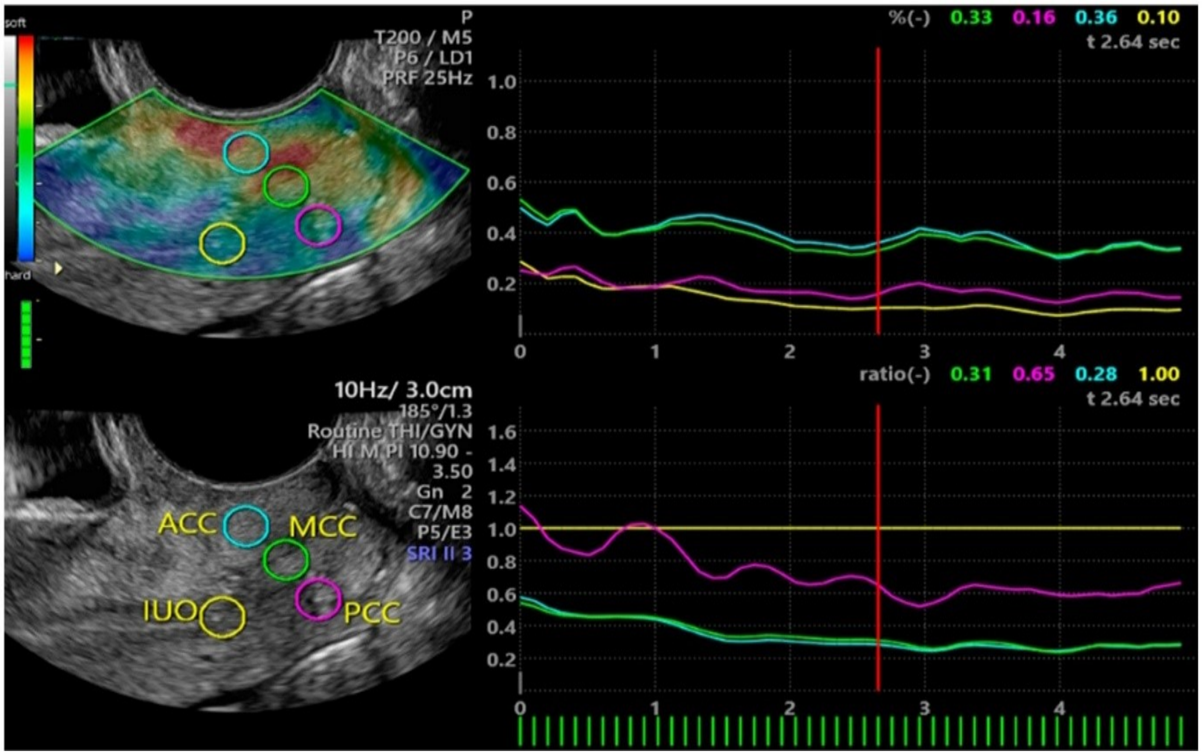


Figure 04: Ultrasound elastography image of the ovary demonstrating regional assessment of ovarian tissue stiffness in PCOS. Color elastogram and elasticity ratio curves indicate increased stromal rigidity and altered ovarian elasticity associated with fibrotic and hyperplastic stromal changes.

Shear-Wave Elastography (SWE) in Ovarian Imaging

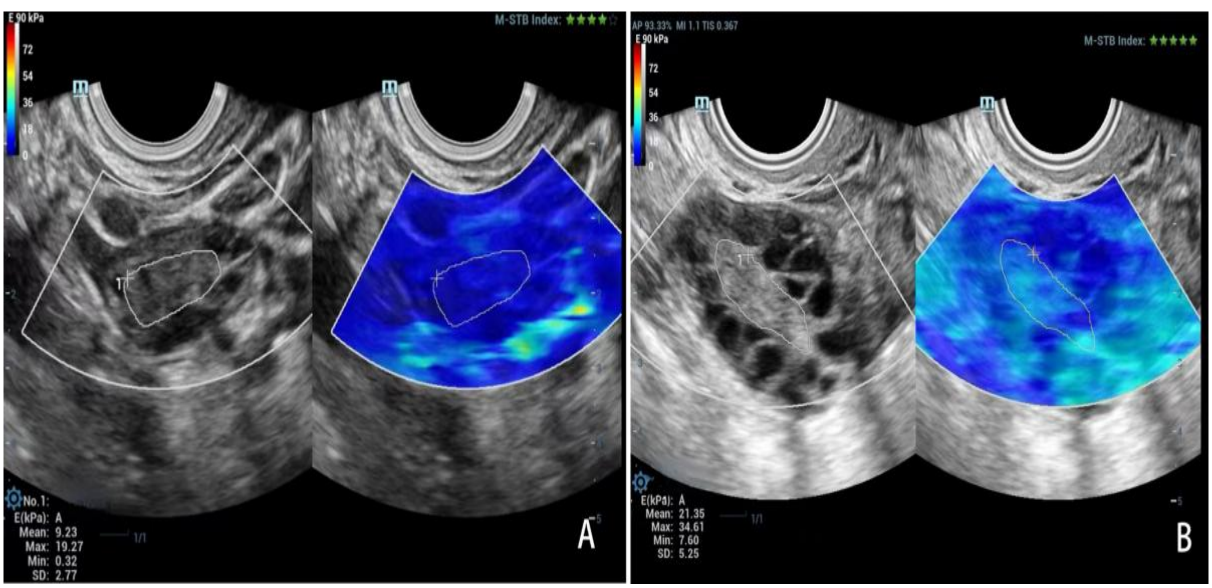


Figure 5: Transvaginal shear-wave elastography images comparing ovarian tissue stiffness. (A) Normal ovary demonstrating relatively softer stromal elasticity. (B) Polycystic ovary showing increased stromal stiffness with characteristic multiple peripheral follicles and altered elastographic pattern suggestive of stromal fibrosis and hyperplasia in PCOS.

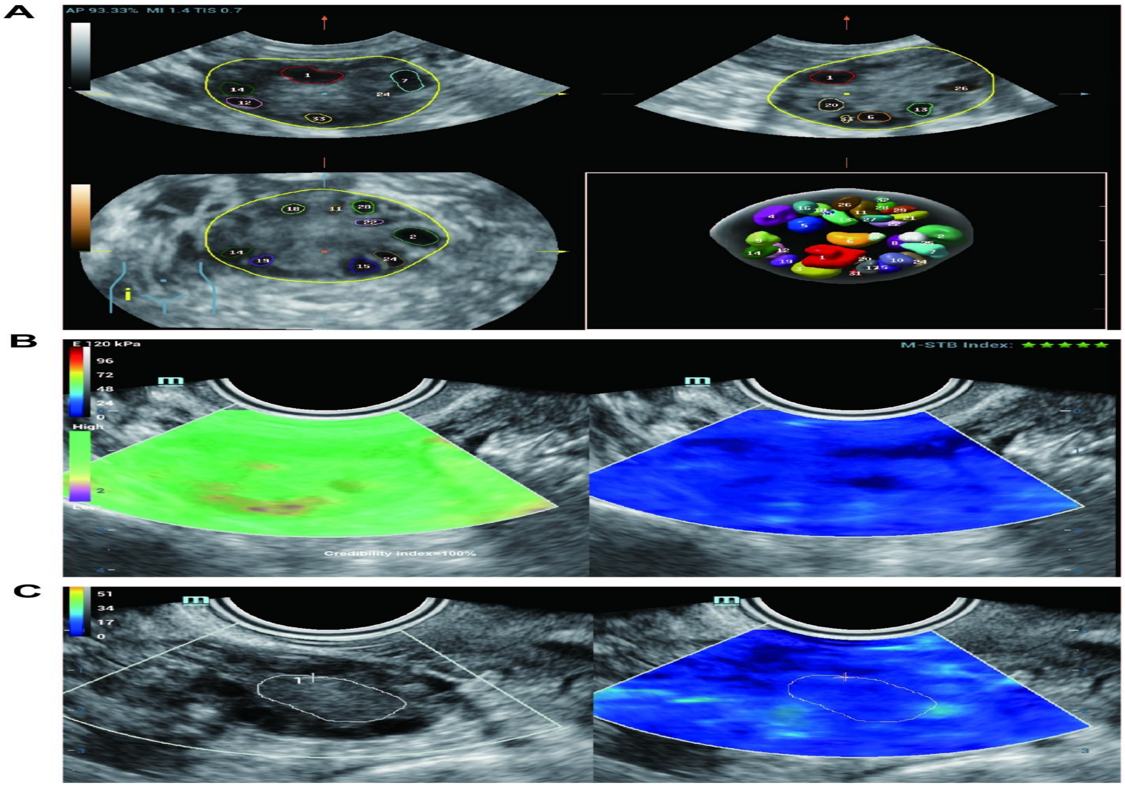


Figure 6: Multimodal transvaginal ultrasound elastography assessment of ovarian tissue in PCOS. (A) Three-dimensional ovarian reconstruction demonstrating spatial distribution of follicles and stromal regions. (B) Color-coded elastography maps showing variations in ovarian tissue stiffness, with blue areas representing increased stromal rigidity. (C) Quantitative shear-wave elastography analysis of ovarian stroma illustrating elevated tissue stiffness associated with stromal hypertrophy and fibrosis in polycystic ovaries.

Advanced 3D Elastography and Quantitative Imaging

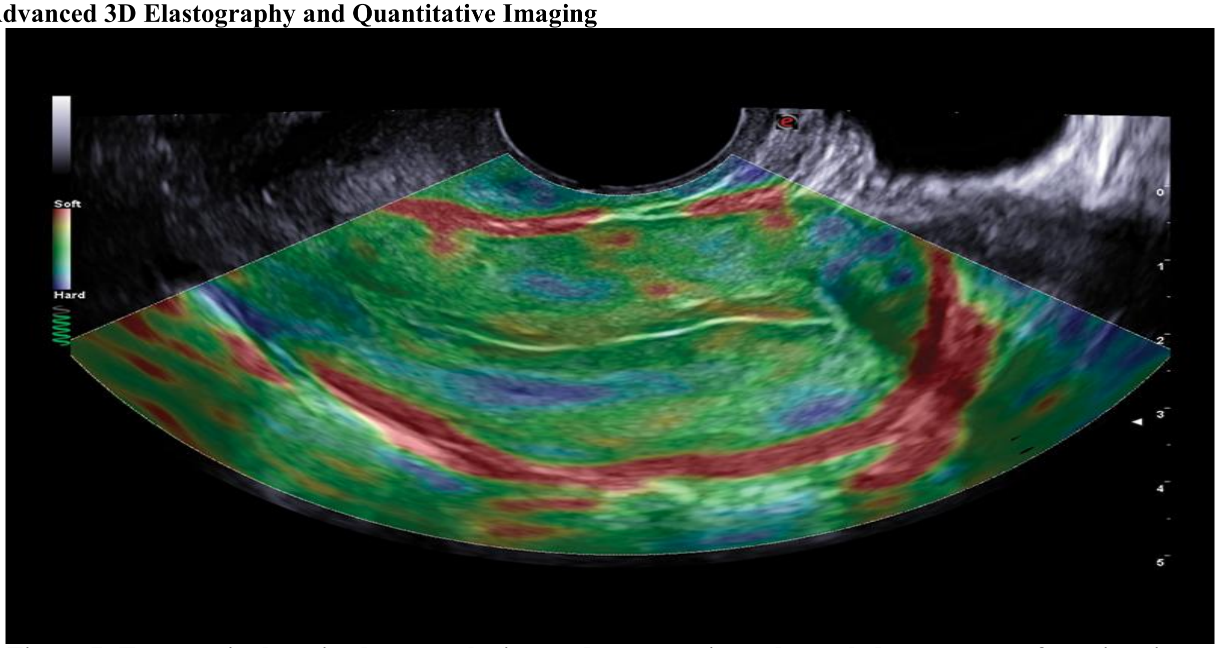


Figure 7: Transvaginal strain elastography image demonstrating color-coded assessment of ovarian tissue elasticity. Areas of varying colors represent differences in tissue stiffness, with harder stromal regions indicating increased fibrosis and stromal hypertrophy associated with PCOS.

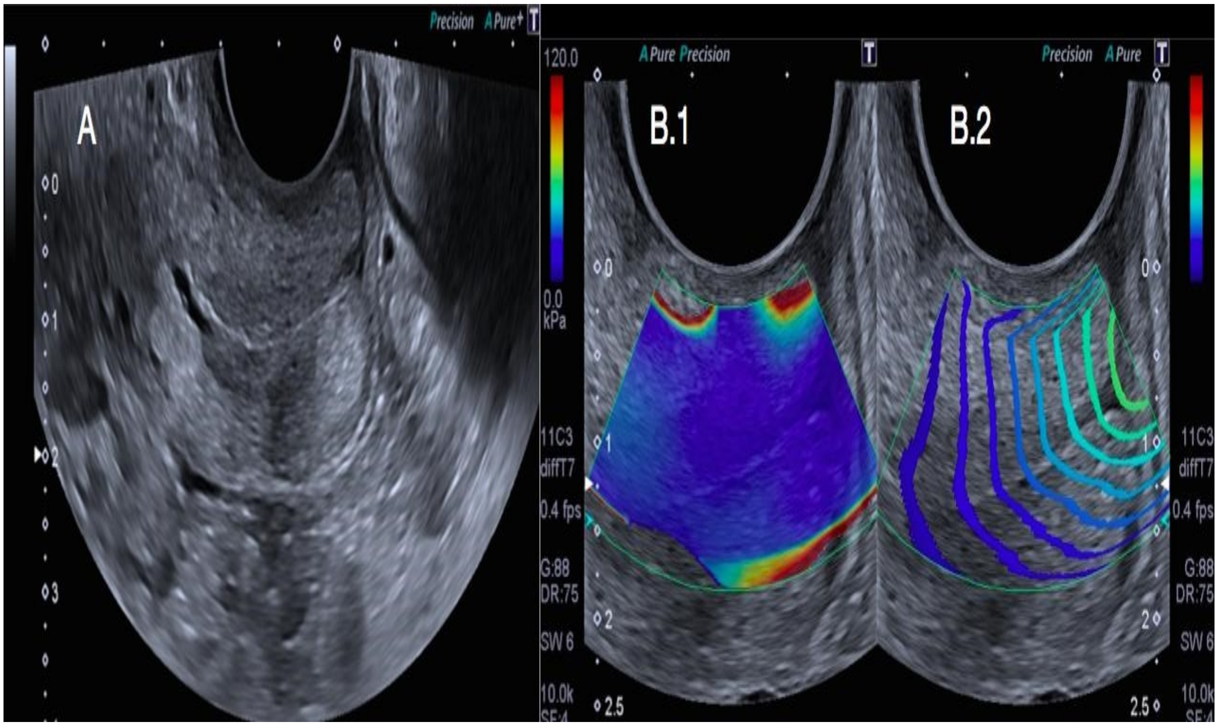


Figure 8: Transvaginal ultrasound and elastography evaluation of ovarian tissue. (A) Conventional grayscale ultrasound image of the ovary. (B1) Shear-wave elastography color map demonstrating tissue stiffness distribution. (B2) Propagation map illustrating shear-wave transmission and elasticity pattern within the ovarian stroma.

Doppler and Multiparametric Elastography Imaging

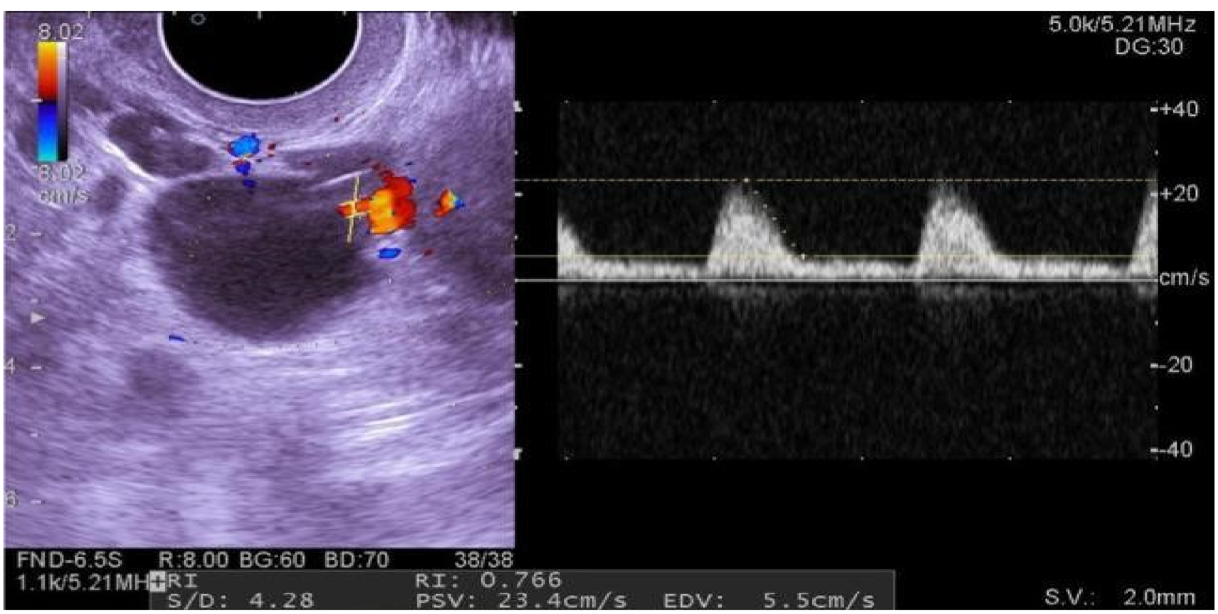


Figure 9: Transvaginal color Doppler ultrasound demonstrating ovarian stromal vascularity with corresponding spectral Doppler waveform analysis. Increased stromal blood flow and reduced vascular resistance are characteristic Doppler findings associated with polycystic ovary syndrome (PCOS).

Detailed Overview of Elastography in Ovarian Imaging: Elastography is an advanced ultrasound-based imaging modality that evaluates tissue stiffness, elasticity, and biomechanical properties. Unlike conventional ultrasonography, which primarily assesses anatomical morphology, elastography provides additional functional information regarding tissue consistency, fibrosis, stromal architecture, and connective tissue remodeling.[45,11] In gynaecologic imaging, ovarian elastography has emerged as a promising technique for evaluating ovarian disorders, particularly Polycystic Ovary Syndrome (PCOS) and polycystic ovarian morphology (PCOM).[29] These conditions are associated with stromal hypertrophy, fibrosis, collagen deposition, and altered ovarian biomechanics, all of which contribute to increased ovarian stiffness detectable by elastography.[30,32]

Aspect	Details
Ovarian Elastography Technique	Proper examination technique is essential for obtaining reliable and reproducible elastographic measurements.[45,41]
Patient Preparation	Appropriate patient preparation improves image quality and measurement accuracy.[41]
Empty Bladder Requirement	Patients are generally instructed to empty the bladder before examination.[46]
Reasons for Empty Bladder	• Improves pelvic visualization • Reduces patient discomfort • Minimizes motion and compression artifacts • Facilitates easier transvaginal probe positioning.[46]
Patient Positioning	Patient is placed in the supine lithotomy position.[46]
Advantages of Positioning	• Allows optimal transvaginal probe access • Improves ovarian visualization • Enhances image stability.[46]
Preferred Timing of Examination	Early follicular phase of the menstrual cycle is preferred.[46]
Importance of Early Follicular Phase	• Hormonal activity remains relatively stable • Stromal edema is minimal • Physiological vascular changes are reduced • Ovarian elasticity measurements become more reproducible.[9,47]
Effect of Menstrual Cycle on Elastography	Physiological changes during ovulation and luteal phases may alter stromal stiffness and affect elastographic interpretation.[47]

Transvaginal Elastography in Ovarian Imaging

Aspect	Details
Transvaginal Elastography	Preferred imaging approach for ovarian elastographic evaluation.[33,29]
Preferred Imaging Technique	Transvaginal elastography is preferred because it provides superior image quality and accurate ovarian assessment.[33]
Advantages of Transvaginal Approach	• Higher spatial resolution • Better stromal visualization • Improved follicular assessment • Accurate stiffness quantification.[29,46]
Probe Positioning	The transvaginal probe is positioned close to the ovaries, minimizing signal attenuation and improving image quality.[29]
Superior Ovarian Visualization	Allows clear visualization of: • Ovarian cortex • Follicles • Stromal echogenicity • Stromal fibrosis.[46]
Improved Sensitivity	Detects subtle ovarian abnormalities such as: • Stromal rigidity • Fibrotic changes • Tissue heterogeneity.[32]
Better Quantification	Provides more accurate assessment of: • Shear-wave velocity • Young's modulus • Stromal stiffness patterns.[11]

Transabdominal Elastography in Ovarian Imaging

Aspect	Details
Transabdominal Elastography	Alternative ovarian elastographic imaging approach used when transvaginal examination is not feasible.[46]
Indications	Transabdominal elastography is useful in: • Adolescents • Virginal women • Large pelvic masses • Patients unable to tolerate transvaginal examination.[46]
Advantages	Provides a non-invasive pelvic assessment when transvaginal imaging is contraindicated or not acceptable.[46]
Limitations	Image quality may be reduced because of: • Increased tissue depth • Abdominal wall attenuation • Lower-frequency probes • Reduced spatial resolution.[37]
Image Quality Considerations	Greater distance between the probe and ovaries may decrease visualization of stromal details and stiffness measurements.[37]

Clinical Importance	Despite limitations, transabdominal elastography remains valuable for ovarian assessment in selected patient populations where transvaginal imaging cannot be performed.[46,37]

Elastographic Appearance of the Normal Ovary

Aspect	**Details**
Elastographic Appearance of Normal Ovary	Normal ovaries generally demonstrate healthy and balanced tissue elasticity.
Typical Elastographic Features	• Homogeneous elasticity • Balanced stromal stiffness • Uniform vascularity • Symmetrical stromal architecture.
Overall Tissue Characteristics	Healthy ovarian tissue usually exhibits: • Moderate elasticity • Absence of marked rigidity • Uniform stromal distribution.[39]
Normal Elastographic Findings	Normal ovarian tissue shows stable and uniform elasticity patterns on elastographic imaging.[46]
Strain Elastography Findings	• Uniform color distribution • Minimal focal stiffness.[33]
Shear-Wave Elastography Findings	• Normal shear-wave velocity • Lower Young's modulus values.[11]
Menstrual Cycle Influence on Ovarian Elasticity	Ovarian elasticity changes physiologically during different phases of the menstrual cycle.[48]
Hormonal Fluctuations	Estrogen and progesterone influence: • Stromal hydration • Tissue vascularity • Connective tissue consistency.[48]
Ovulation	Follicular rupture causes: • Temporary biomechanical alterations • Local tissue edema • Vascular changes.
Corpus Luteum Formation	Associated with: • Increased vascularity • Stromal edema • Temporary increase in ovarian stiffness.[49]
Stromal Fluid Changes	Interstitial fluid accumulation modifies: • Elasticity measurements • Tissue compressibility.
Clinical Importance	Physiological variations during the menstrual cycle must be considered during, interpretation of ovarian elastography findings to avoid false-positive results.[48,49]

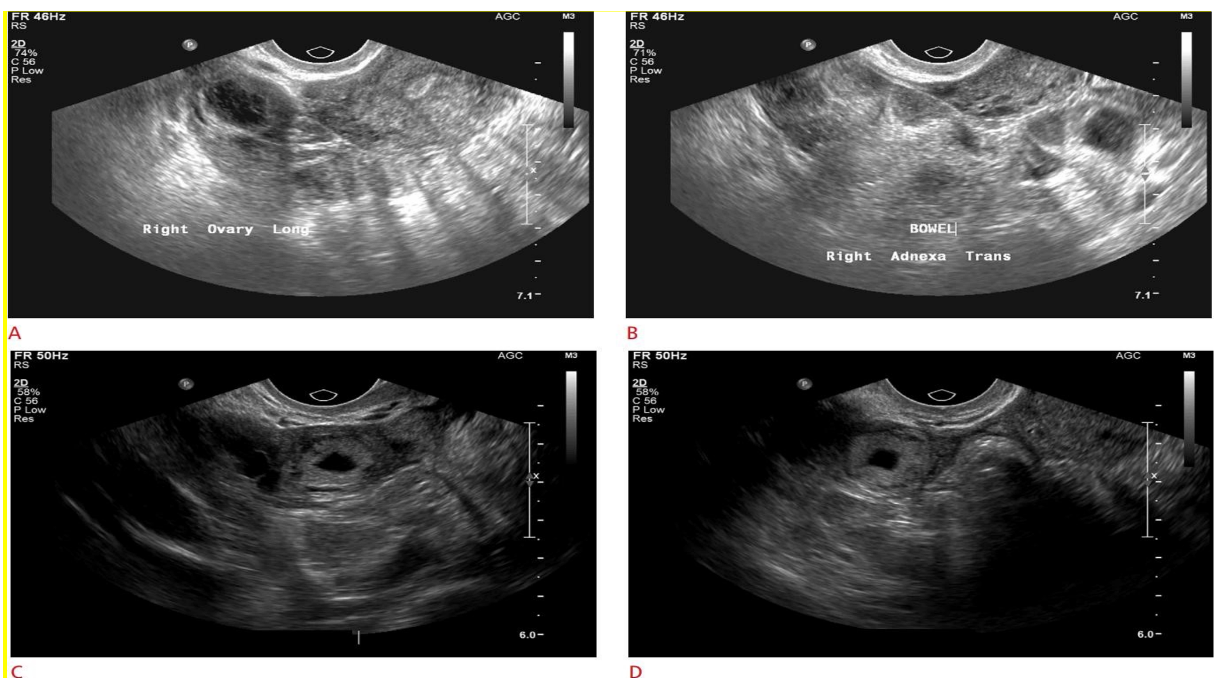


Figure 10: Transvaginal ultrasound images demonstrating ovarian morphology and adnexal findings. (A–D) Grayscale ultrasound views showing ovarian follicles, stromal echogenicity, and adnexal anatomy commonly evaluated in polycystic ovary syndrome (PCOS).

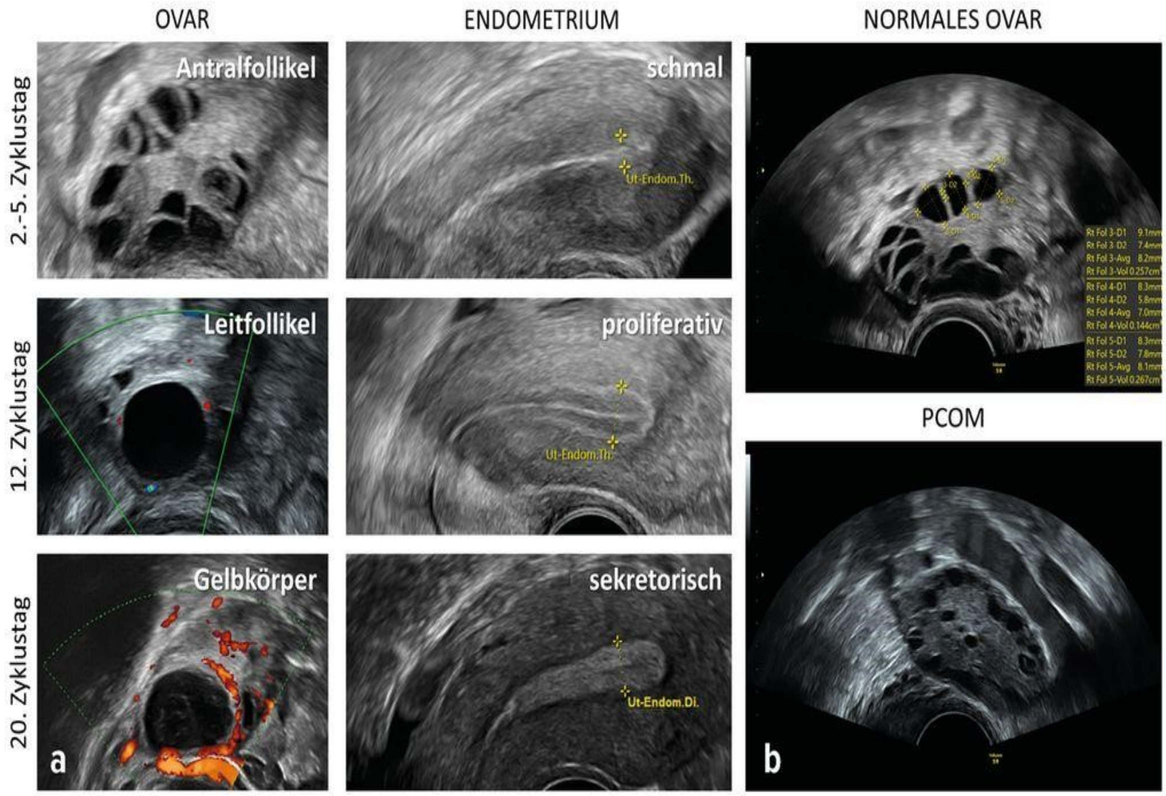


Figure 11: Ultrasound appearance of normal ovarian physiology and polycystic ovarian morphology (PCOM). Left panel shows follicular and endometrial changes during different phases of the menstrual cycle, including antral follicle, dominant follicle, and corpus luteum formation. Right panel compares a normal ovary with polycystic ovarian morphology characterized by multiple peripheral follicles and increased stromal tissue.

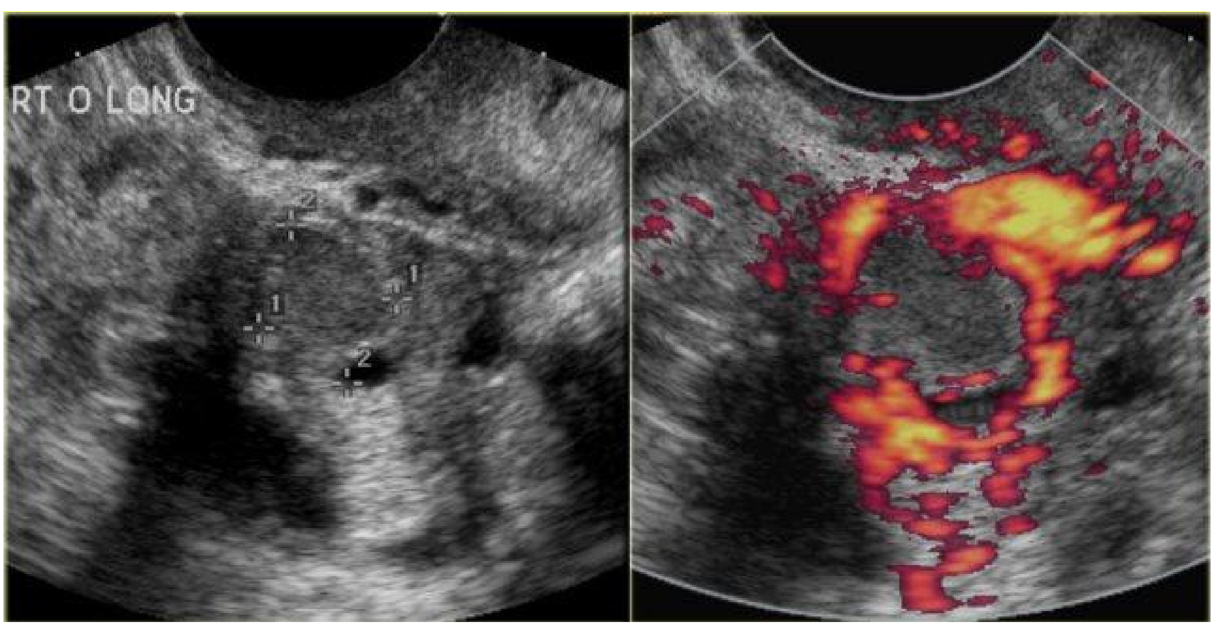


Figure 12: Transvaginal grayscale and color Doppler ultrasound images of the ovary demonstrating increased stromal vascularity and perifollicular blood flow, findings commonly associated with polycystic ovary syndrome (PCOS).

Menstrual Cycle Influence and Elastography Findings in PCOS and PCOM

Aspect	Details
Menstrual Cycle Influence on Ovarian Elasticity	Ovarian elasticity changes physiologically throughout the menstrual cycle.
Influencing Factors	Hormonal Fluctuations: Estrogen and progesterone alter stromal hydration. Ovulation: Follicular rupture temporarily changes tissue biomechanics. Corpus Luteum Formation: Increases vascularity and stromal edema.Stromal Fluid Changes: Interstitial fluid alters elasticity measurements.
Clinical Importance	Physiological variations during the menstrual cycle must be considered during interpretation of elastography findings.
Elastography Findings in PCOS and PCOM	Studies demonstrate significantly increased ovarian stiffness in women with PCOS compared with healthy ovaries.[29,32]
Causes of Increased Ovarian Stiffness	Stromal Fibrosis: Excess connective tissue deposition increases rigidity.[32] Collagen Accumulation: Dense collagen fibers reduce tissue elasticity.[30]Hyperthecosis: Luteinized theca cells enlarge the stroma.[49] Stromal Edema: Fluid accumulation alters tissue mechanics.[32]Increased Connective Tissue: Causes dense stromal architecture.Chronic Inflammation: Promotes fibrosis and extracellular matrix remodelling
Result of Structural Abnormalities	These abnormalities produce measurable increases in ovarian stiffness detected by elastography.
Histopathological Correlation	Microscopic examination demonstrates: • Increased stromal cellularity • Fibrotic stromal tissue • Thickened ovarian capsule • Enlarged theca-interstitial cells • Increased vascularity.
Significance of Histopathological Findings	Structural abnormalities explain the increased elastographic stiffness seen in PCOS ovaries.[48]
Correlation with Hormonal Parameters	Ovarian stiffness positively correlates with: • Serum testosterone levels • Free androgen index • LH/FSH ratio • Anti-Müllerian hormone (AMH).
Effects of Elevated Androgen and AMH Levels	Associated with: • Stromal hypertrophy • Follicular excess • Increased ovarian rigidity.
Correlation with Metabolic Syndrome	Women with PCOS frequently exhibit: • Obesity • Dyslipidemia • Hypertension • Insulin resistance.
Clinical Relevance	Research suggests ovarian stiffness increases with worsening metabolic dysfunction, indicating potential use of elastography as a biomarker for disease severity.[50]

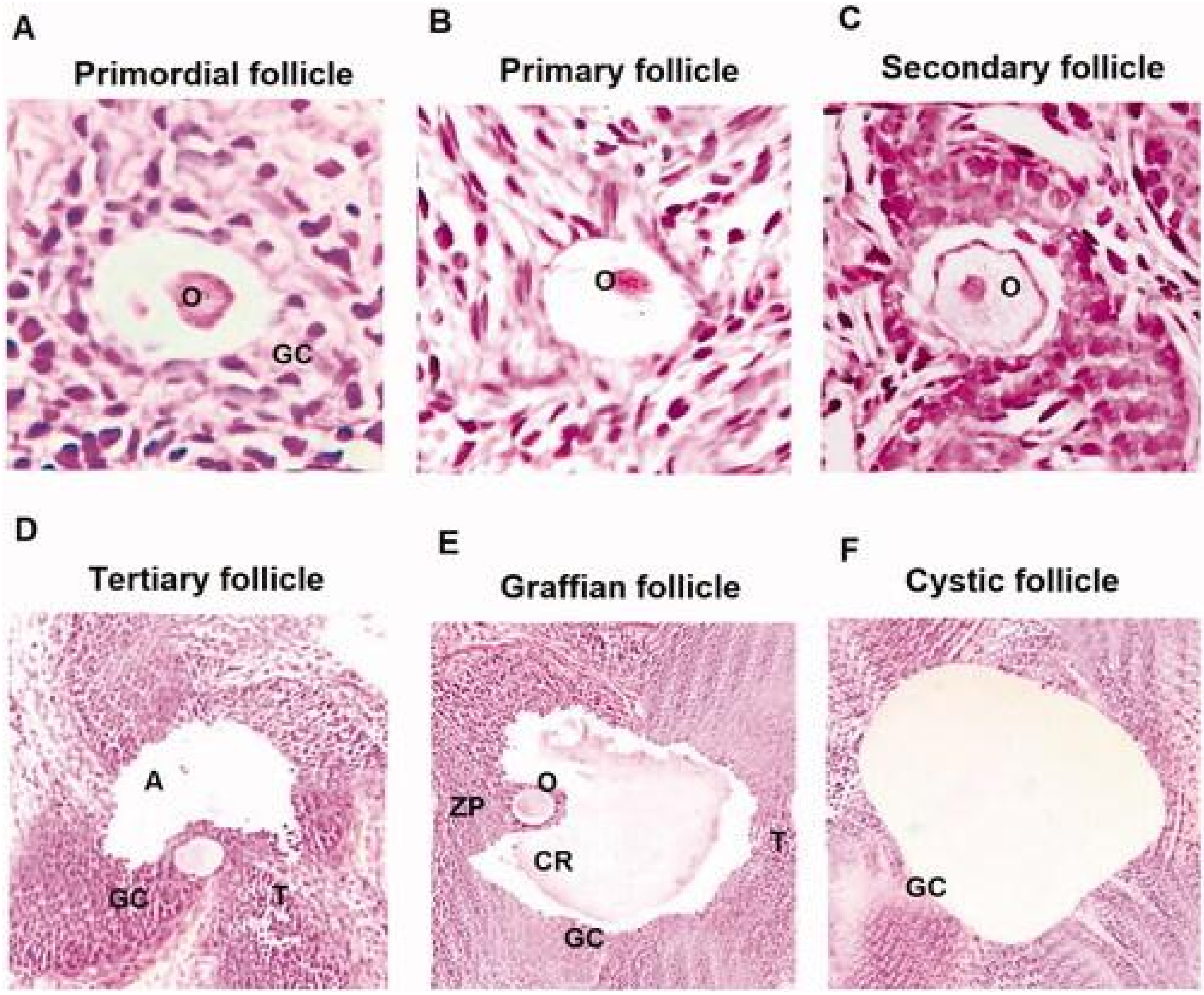


Figure 13: Histological stages of ovarian follicular development. (A) Primordial follicle, (B) Primary follicle, (C) Secondary follicle, (D) Tertiary follicle, (E) Graafian follicle, and (F) Cystic follicle demonstrating progressive maturation of ovarian follicles and structural changes within the ovarian cortex.

Role in Infertility Assessment

Aspect	**Details**
Role of PCOS in Infertility	PCOS is one of the leading causes of anovulatory infertility.[51]
Role of Elastography in Fertility Assessment	Ovarian elastography may assist in multiple aspects of infertility evaluation and reproductive imaging.[29,32]
Evaluating Ovarian Reserve	Assesses stromal activity and follicular density.[48]
Predicting Ovulation Induction Response	Higher stromal stiffness may correlate with poor ovulatory response.[32,30]
Identifying Severe Stromal Disease	Detects advanced fibrosis and stromal hypertrophy.[50]
Assessing IVF Response	May help predict ovarian responsiveness during assisted reproductive therapy.[30,53]
Predicting Ovarian Hyperstimulation Syndrome (OHSS)	Altered stromal characteristics may identify patients at increased OHSS risk.[53,54]
Clinical Significance	Ovarian elastography represents a promising adjunct in fertility assessment and reproductive imaging.[29,32]

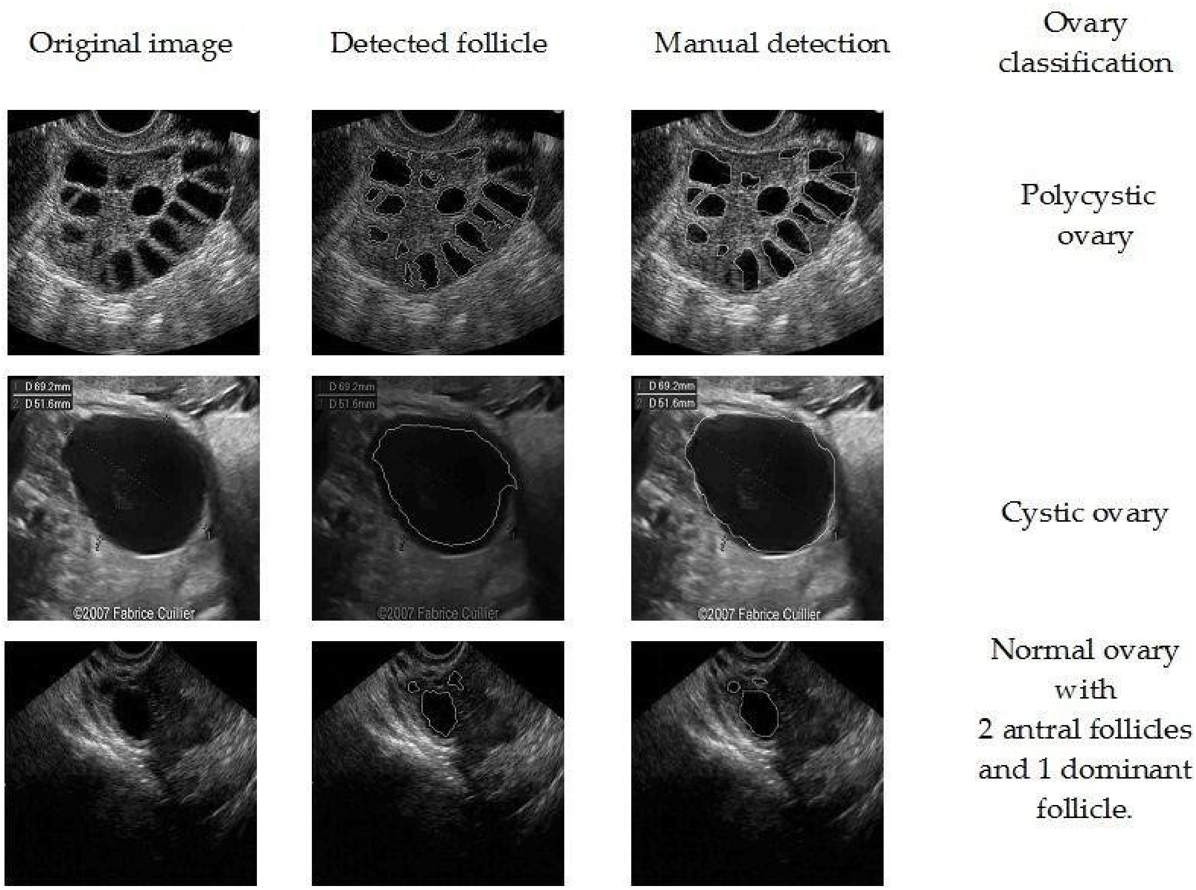


Figure 14: Automated and manual ultrasound follicle detection for ovarian classification. The figure compares original transvaginal ultrasound images, computer-detected follicles, and manual follicular segmentation used to classify ovaries as polycystic ovary, cystic ovary, and normal ovary with antral and dominant follicles.

Differentiation of PCOM from Multifollicular Ovaries

Feature	**Multifollicular Ovaries**	**Polycystic Ovarian Morphology (PCOM)**
Definition	Contain multiple developing follicles without stromal abnormalities characteristic of PCOS.[55]	Demonstrate characteristic ovarian structural abnormalities associated with PCOS.[1]
Underlying Nature	Often considered a physiological variant, especially in adolescents and young women.[55,48]	Frequently associated with endocrine dysfunction, infertility, and metabolic abnormalities.[56]
Ovarian Volume	Usually normal.	Increased ovarian volume.
Follicle Characteristics	Multiple follicles of varying size.	Multiple small follicles arranged peripherally.[1]
Follicle Arrangement	No characteristic peripheral arrangement.	Classic peripheral "string of pearls" appearance.[1]
Stromal Enlargement	Absent or minimal.	Significant stromal hypertrophy present.[30]
Stromal Echogenicity	Minimal stromal echogenicity.[48]	Increased stromal echogenicity.[30]
Stromal Fibrosis	Usually absent.[55]	Commonly present.
Ovarian Capsule	Normal ovarian capsule.[48]	Thickened ovarian capsule.[50]
Ovulatory	Usually maintains normal ovulation.[55]	Frequently associated with chronic

Function		anovulation.[56]
Hormonal Profile	Typically normal hormonal status.[48]	Often associated with hyperandrogenism and elevated LH/FSH ratio.[56,53]
Clinical Significance	Usually benign physiological finding.[55]	Associated with PCOS, infertility, and metabolic syndrome.[4,8]
Elastography Findings	Normal or mildly altered ovarian stiffness.	Increased ovarian stiffness due to fibrosis and stromal hypertrophy.[29,32]

Comparison with Doppler Ultrasound

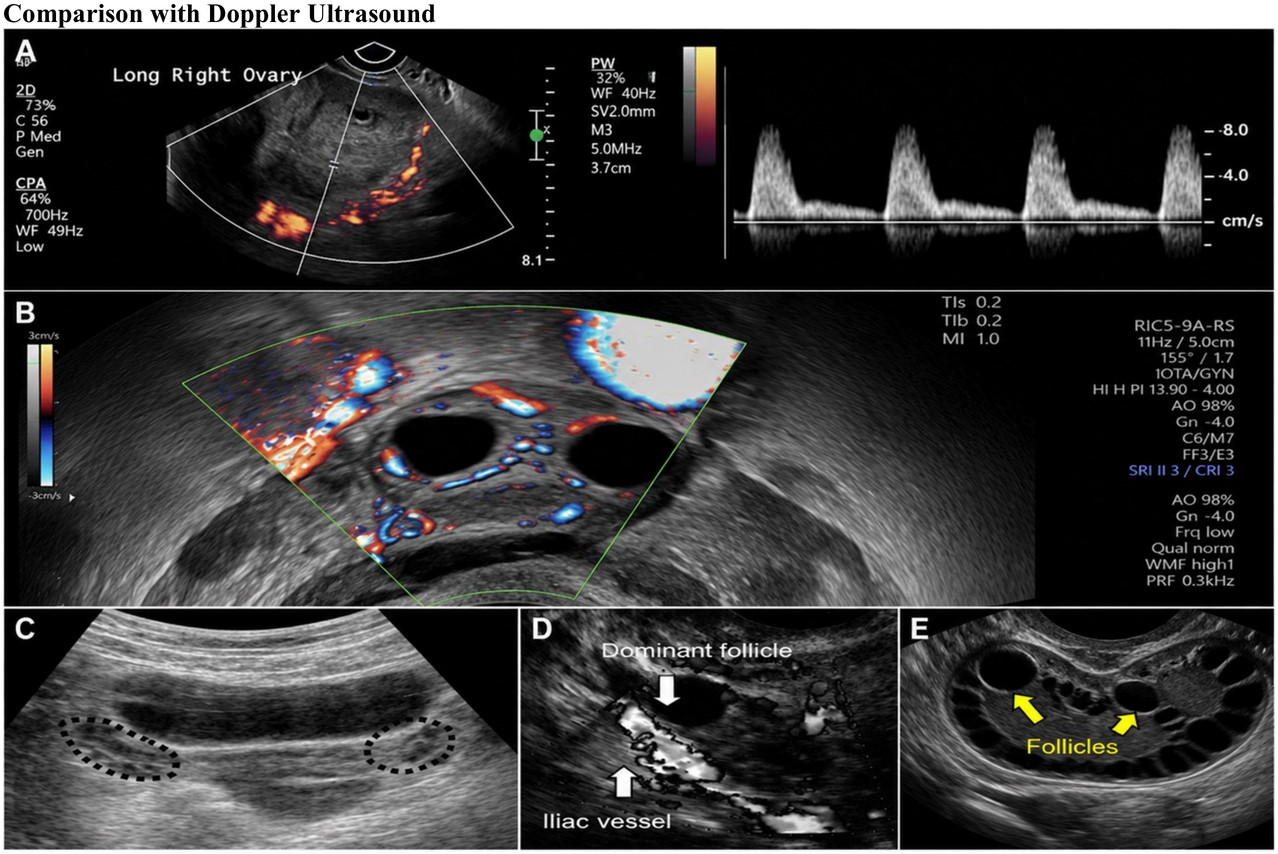


Figure: Ultrasound evaluation of polycystic ovary morphology (PCOM) and stromal vascularity.
(A) Transvaginal color Doppler with spectral waveform showing increased stromal blood flow and low-resistance pattern.
(B) Color Doppler demonstrating perifollicular and stromal vascularity.
with multiple antral follicles peripherally (dotted circles). **(D)** Dominant follicle with adjacent iliac vessel on color Doppler.
(E) Multiple peripheral follicles (arrows) producing a "string of pearls" appearance, characteristic of PCOM.

Doppler Ultrasonography and Elastography in PCOS Evaluation

Aspect	Details
Role of Doppler Ultrasonography	Evaluates ovarian vascularity and blood flow characteristics.[47,49]
Doppler Findings in PCOS	• Increased stromal vascularity • Reduced vascular resistance • Increased ovarian blood flow • Increased stromal perfusion.[49,30]
Significance of Doppler Changes	Reflect increased stromal metabolic activity and angiogenesis.[30,]
Advantages of Elastography Over Doppler	Elastography uniquely evaluates: • Tissue fibrosis • Stromal rigidity • Mechanical properties • Connective tissue remodeling • Biomechanical alterations.[11,29]
Difference Between Doppler and Elastography	Doppler assesses vascularity, whereas elastography assesses tissue stiffness and biomechanical properties.[11]
Clinical Relationship	Doppler and elastography provide complementary information.[29,32]

Benefits of Combined Approach	Combined use may improve: • Diagnostic accuracy • Disease severity assessment • Fertility evaluation • Treatment monitoring.[32,54]

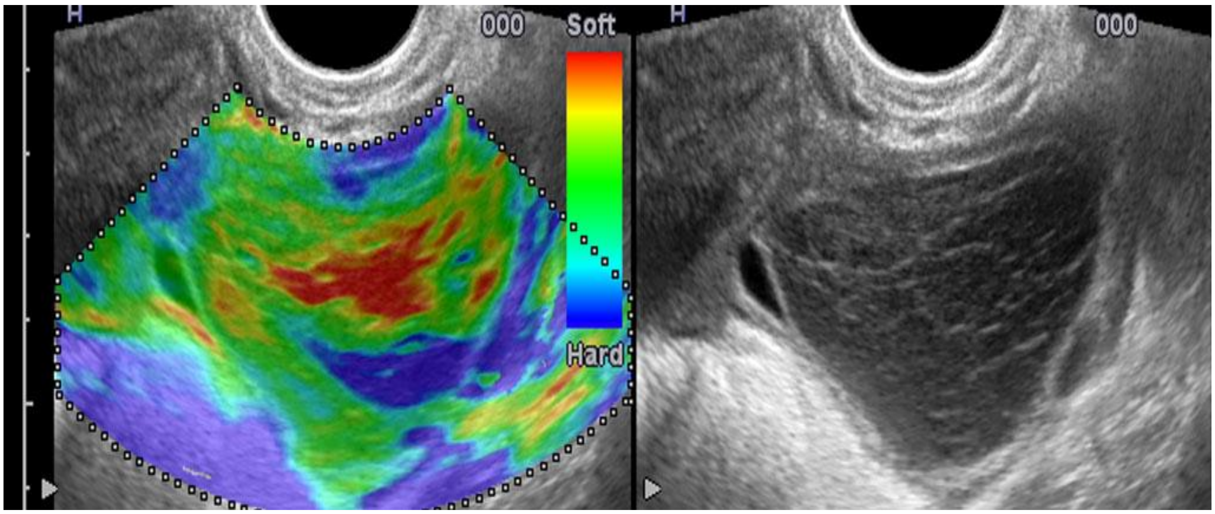
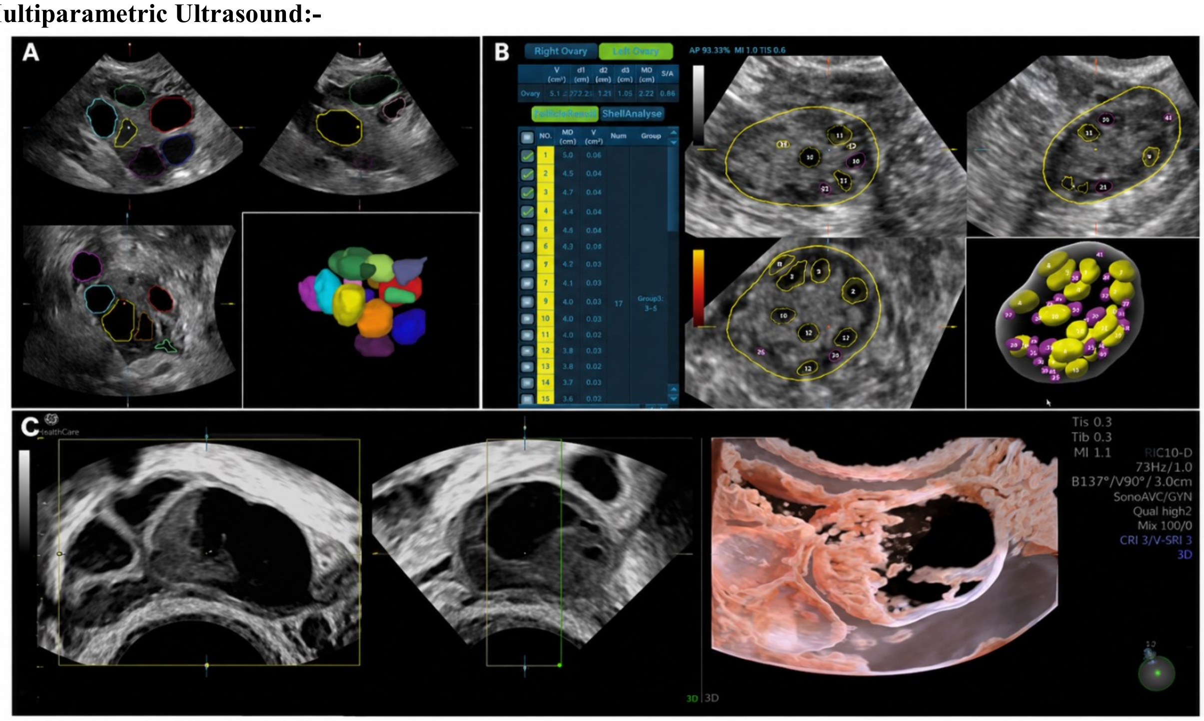


Figure 16: Transvaginal ultrasound elastography image demonstrating color-coded assessment of ovarian tissue stiffness alongside conventional grayscale ultrasound imaging. The elastogram shows heterogeneous stromal elasticity, with harder regions indicating increased tissue stiffness associated with stromal fibrosis and structural remodeling in polycystic ovary syndrome (PCOS).

Emerging Applications of Ovarian Elastography:-

Multiparametric Ultrasound:-



Automated follicle detection and three-dimensional (3D) evaluation of the ovary using transvaginal ultrasound. (A) Multiplanar views with color-coded segmentation of individual follicles and corresponding 3D reconstruction. (B) Automated follicle analysis with measured diameters and volumes, follicle counting, and 3D mapping for quantitative assessment. (C) Orthogonal ultrasound planes with 3D surface-rendered image demonstrating ovarian morphology and multiple antral follicles.

Future ovarian imaging may integrate:-

- B-mode ultrasonography
- Doppler imaging
- 3D ultrasound
- Elastography
- Artificial intelligence (AI)-based analysis

This combined multiparametric approach may improve:-

- Ovarian tissue characterization
- PCOS diagnosis
- Fertility prediction
- Reproducibility of imaging findings

Artificial Intelligence in Ovarian Elastography

Category	Description / Application	Clinical Significance / Benefit
Artificial Intelligence in Ovarian Imaging	AI is expected to play a major role in future ovarian imaging and elastography analysis.[44,45]	Enhances diagnostic precision and workflow efficiency.[44]
Automated Stiffness Quantification	AI algorithms may automatically calculate ovarian stiffness values from elastographic images.[49,51]	Reduces manual errors and improves objectivity.[45]
Reduced Observer Variability	Machine learning may improve consistency and reduce operator dependence.[57]	Increases reproducibility of imaging findings.[57]
Diagnostic Standardization	AI may establish standardized diagnostic thresholds for ovarian stiffness and morphology.[45]	Enables uniform PCOS diagnosis across institutions.[45]
Prediction of Fertility Outcomes	AI-assisted elastography may predict fertility-related outcomes.[57]	Supports personalized reproductive management.[57]
Ovulation Induction Response Prediction	AI may estimate ovarian response to ovulation induction therapy.[57,]	Helps optimize fertility treatment protocols.[56]
IVF Success Rate Prediction	AI models may correlate elastographic findings with IVF outcomes.	Assists in counseling and prognosis.[58]
Ovarian Reserve Assessment	Combines elastographic and hormonal parameters to evaluate ovarian reserve.[48]	Useful in fertility assessment.[48]
OHSS Risk Prediction	AI may identify women at risk for ovarian hyperstimulation syndrome (OHSS).[57]	Improves safety during assisted reproduction.
Severity Classification	Machine learning models may classify PCOS severity based on elastographic patterns and hormonal parameters.[45,54]	Enables individualized treatment planning.[54]
Noninvasive Technique	Elastography involves no radiation exposure and is safe for repeated examinations.[42]	Suitable for reproductive-aged women and long-term follow-up.
Real-Time Assessment	Provides immediate evaluation of ovarian stiffness, stromal architecture, and fibrosis severity.	Enables rapid clinical decision-making.[42]
Quantitative Analysis	Shear-wave elastography provides objective numerical stiffness measurements.[11]	Improves reproducibility and monitoring capability.[11]
Early Detection	May identify stromal abnormalities before visible morphologic changes appear on conventional ultrasound.[29]	Facilitates earlier diagnosis of ovarian pathology.[11]
Better Tissue Characterization	Provides information on stromal fibrosis, connective tissue remodelling, ovarian rigidity, and tissue biomechanics.[11,29]	Improves understanding of ovarian pathology.[29]
Improved Monitoring Capability	Numerical stiffness values can be followed over time.	Useful for monitoring treatment response and disease progression.[11]
Enhanced Diagnostic Accuracy	Elastography complements conventional ultrasound findings.	Supports more precise ovarian evaluation and PCOS diagnosis.[29]

Limitations of Ovarian Elastography

Category	Details	Clinical Implications / Challenges
Lack of Standardization	Different ultrasound systems and manufacturers use different measurement techniques, elastographic algorithms, and reference ranges.[38]	Limits comparability and reproducibility between studies and institutions.[38]
Operator Dependency	Particularly significant in strain elastography where probe pressure and examiner expertise influence results.[37]	May reduce consistency and accuracy of measurements.[37]
Motion Artifacts	Image quality may be affected by bowel peristalsis, respiratory motion, and patient movement.[38]	Can interfere with accurate stiffness assessment.[38]
Physiological Variability	Ovarian stiffness varies during the menstrual cycle, ovulation, and corpus luteum formation.[49]	Interpretation must consider menstrual phase and hormonal status.[49]
Limited Large-Scale Studies	Current research is limited by small sample sizes, lack of longitudinal studies, and absence of standardized cutoff values.[29,38]	Prevents widespread routine clinical implementation.[38]
Need for Further Validation	More evidence is required to establish diagnostic reliability and clinical utility.[38]	Essential before adoption into standard gynecologic practice.[38]

Future Perspectives of Ovarian Elastography

Category	Details	Clinical Significance / Future Role
Standardized Ovarian Stiffness Reference Values	Future studies aim to establish normal and pathological ovarian stiffness ranges.	May improve diagnostic consistency.
Large Multicenter Clinical Trials	Large-scale collaborative research is needed to validate findings.	Strengthens scientific evidence and clinical acceptance.[38]
AI-Integrated Elastographic Analysis	Artificial intelligence may assist in automated image interpretation and stiffness quantification.[44,45]	Enhances diagnostic precision and reduces observer variability
Longitudinal Monitoring Studies	Future research may evaluate ovarian stiffness changes over time.	Useful for disease progression and treatment monitoring.[11]
Fertility Prediction Models	Elastography may be integrated into predictive reproductive models.	Supports individualized fertility assessment.[57]
Pediatric and Adolescent Applications	Potential use in younger populations with ovarian disorders.[32]	Expands clinical applicability.
Integration with Hormonal Biomarkers	Combining elastography with endocrine markers may improve diagnostic accuracy.	Enables comprehensive ovarian evaluation.[54]
Personalized Reproductive Imaging Approaches	Imaging findings may guide individualized reproductive management strategies.[57]	Supports precision medicine in reproductive endocrinology.[57]
Future Role of Elastography	Elastography may become an important component of precision medicine in reproductive endocrinology.[29,32]	May improve diagnosis, monitoring, and fertility care in the future.[32]

Conclusion:-

Elastography has emerged as a highly promising and innovative imaging modality in the evaluation of ovarian disorders, particularly polycystic ovary syndrome (PCOS) and polycystic ovarian morphology (PCOM). Unlike conventional ultrasonography, which primarily provides structural and morphological information, elastography offers additional functional assessment of ovarian tissue biomechanics by evaluating tissue stiffness and elasticity. This ability to assess stromal architecture noninvasively represents a significant advancement in reproductive imaging and gynaecologic ultrasound.

The pathophysiological basis of increased ovarian stiffness in PCOS is strongly associated with stromal hypertrophy, stromal hyperplasia, collagen deposition, fibrosis, hyperthecosis, chronic low-grade inflammation, and increased connective tissue remodelling. These histopathological alterations contribute to the characteristic increase in stromal rigidity observed on elastographic imaging. Both strain elastography and shear-wave elastography (SWE) have demonstrated the capability to detect these biomechanical changes and provide valuable information regarding ovarian tissue composition.

Shear-wave elastography, in particular, offers quantitative and reproducible measurements of ovarian stiffness using shear-wave velocity and Young's modulus values. Increased stiffness values in women with PCOS have shown correlation with several clinical and biochemical parameters, including elevated serum testosterone, increased LH/FSH ratio, anti-Müllerian hormone (AMH) levels, insulin resistance, obesity, and metabolic syndrome. These correlations suggest that elastography may serve not only as a diagnostic adjunct but also as a potential biomarker for endocrine and metabolic severity in PCOS.

One of the most clinically valuable applications of elastography is its ability to differentiate polycystic ovarian morphology from multifollicular ovaries. Conventional grayscale ultrasound may demonstrate multiple follicles in both conditions, making differentiation difficult in certain patients, especially adolescents and young women. However, elastography evaluates stromal biomechanics and tissue rigidity, thereby improving diagnostic specificity by identifying the increased stromal stiffness characteristic of PCOM and PCOS.Elastography also has significant potential applications in infertility assessment and reproductive medicine. Since PCOS is one of the leading causes of anovulatory infertility, evaluation of ovarian stromal stiffness may help predict ovulation induction response, assess ovarian reserve, evaluate IVF outcomes, and identify patients at increased risk of ovarian hyperstimulation syndrome (OHSS). Furthermore, elastography may prove useful for monitoring treatment response following lifestyle modification, hormonal therapy, insulin-sensitizing agents, or assisted reproductive interventions.The integration of elastography with other imaging modalities such as Doppler ultrasonography, three-dimensional ultrasound, and multiparametric imaging techniques may further improve diagnostic accuracy and comprehensive ovarian evaluation. Doppler imaging provides vascular information, whereas elastography assesses tissue fibrosis and rigidity, making these techniques complementary rather than competitive. Additionally, the incorporation of artificial intelligence (AI) and machine learning algorithms into ovarian elastography may revolutionize reproductive imaging by enabling automated stiffness quantification, reduction of observer variability, predictive fertility modelling, and improved standardization of imaging interpretation.

Despite its promising applications, ovarian elastography still faces several limitations that currently restrict widespread clinical implementation. These include lack of standardized imaging protocols, variability among ultrasound systems, operator dependency (especially in strain elastography), motion artifacts, physiological variability during the menstrual cycle, and limited availability of large multicenter studies. Moreover, universally accepted cutoff values for ovarian stiffness have not yet been established. Therefore, additional prospective studies with larger patient populations are required to validate current findings and develop standardized diagnostic criteria.Future research should focus on establishing normative ovarian stiffness reference values across different age groups and menstrual phases, improving reproducibility of measurements, integrating AI-assisted image analysis, and evaluating long-term clinical outcomes. Further exploration of paediatric and adolescent applications may also improve early diagnosis and management of PCOS.

In conclusion, elastography represents an important advancement in ovarian imaging and reproductive medicine. By providing real-time evaluation of tissue stiffness and stromal architecture, elastography offers functional information beyond conventional ultrasound morphology. Its ability to assess fibrosis, stromal remodelling, endocrine dysfunction, and metabolic abnormalities makes it a valuable emerging tool in the diagnosis and management of PCOS and PCOM. With continued technological refinement, multicentre validation, and integration with artificial intelligence and multiparametric imaging, elastography has the potential to become an essential component of personalized reproductive healthcare and future gynaecologic imaging practice.

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