

ROLE OF 3D/4D DOPPLER ULTRASOUND IN THE EVALUATION OF PELVIC CONGESTION SYNDROME

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Abstract

Background: Pelvic Congestion Syndrome (PCS) is a chronic venous condition characterised by dilated and incompetent pelvic veins that commonly produces persistent, non-cyclical pelvic pain in women of reproductive age. Its clinical presentation is non-specific, so the condition is frequently underdiagnosed. Three-dimensional (3D) and four-dimensional (4D) Doppler ultrasound may allow a more detailed assessment of pelvic venous anatomy and hemodynamics than conventional imaging and could improve diagnostic accuracy.

Objective: To evaluate the diagnostic value of 3D/4D Doppler ultrasound in women with chronic pelvic pain suspected of having Pelvic Congestion Syndrome, and to compare its performance with conventional 2D/color Doppler ultrasound.

Methods: This descriptive, cross-sectional study was conducted in the Department of Radiology, Jinnah Hospital, Lahore. Ninety-six women aged 18–45 years with chronic pelvic pain of more than six months' duration were recruited by non-probability consecutive sampling. All participants underwent both 2D/color Doppler and 3D/4D Doppler ultrasound examination of the pelvic venous system. Venous diameter, reflux, tortuosity and flow velocity were assessed, and the diagnostic yield of the two modalities was compared using the chi-square test and independent t-test, with $p < 0.05$ considered significant.

Results: The mean age of participants was 30.92 ± 8.05 years. 3D/4D Doppler ultrasound detected significantly more cases of venous reflux than 2D/color Doppler on both the right side (37.5% vs. 29.2%, $p = 0.008$) and the left side (49.0% vs. 41.7%, $p = 0.016$). Ovarian vein diameter measured on 3D/4D Doppler was significantly greater than on 2D Doppler on both sides ($p < 0.001$), and good-to-fair image visualization was achieved in 95.8% of examinations. Venous involvement was more common on the left side, and no clinical or demographic parameter showed a statistically significant independent association with reflux severity.

Conclusion: 3D/4D Doppler ultrasound was superior to conventional 2D/color Doppler ultrasound for the detection of pelvic venous reflux and for delineation of venous anatomy. It is a reliable, non-invasive tool that can support timely diagnosis and clinical management of Pelvic Congestion Syndrome.

1. Introduction

Pelvic Congestion Syndrome (PCS) is a chronic disorder of pelvic venous enlargement, incompetence and reflux that produces persistent, non-cyclical pelvic pain, most commonly in women of reproductive age. Chronic pelvic pain persisting for more than six months and unrelated solely to pregnancy or menstruation is one of the most frequent gynecological complaints, affecting 10–15% of women attending gynecology clinics worldwide. Because it can arise from gynecological, urological, gastrointestinal, musculoskeletal or vascular causes, chronic pelvic pain is often difficult to diagnose, and PCS in particular is frequently overlooked owing to its non-specific presentation and clinical overlap with conditions such as endometriosis and pelvic inflammatory disease [1].

PCS results from chronic insufficiency of the ovarian and internal iliac veins: incompetent or absent venous valves permit retrograde flow, leading to venous hypertension, progressive dilatation, tortuosity and pelvic varicosities. Estrogen-mediated reduction in venous tone, together with the mechanical venous stress of pregnancy, contributes to valvular damage and chronic venous congestion [2]. Clinically, PCS typically presents as dull, aching pelvic pain that worsens with prolonged standing, physical activity, menstruation and intercourse, and improves in the supine position, often accompanied by dyspareunia, urinary frequency, a sensation of pelvic heaviness, and vulval or lower-limb varicosities [3]. Because these features overlap with other pelvic disorders, diagnosis is frequently delayed, with attendant psychological burden, reduced quality of life and increased healthcare utilisation.

PCS is thought to account for up to one-third of chronic pelvic pain in women, although the true prevalence is difficult to establish given

inconsistent diagnostic criteria and imaging protocols [4]. Pelvic venography remains the historical reference standard, as it directly demonstrates venous anatomy and reflux, but its invasiveness, need for catheterisation and contrast, and radiation exposure restrict its use largely to patients proceeding to endovascular treatment. CT and MRI/MR venography offer good anatomical detail without the invasiveness of venography, but are costly, less widely available, and limited in their ability to capture dynamic venous reflux in real time [6].

Ultrasound, in contrast, is non-invasive, inexpensive, widely available and free of ionizing radiation, making it the preferred first-line imaging modality for PCS. Conventional color Doppler ultrasound assesses ovarian vein diameter, flow direction, reflux and hemodynamic change with the Valsalva maneuver, with dilatation greater than 6 mm, sluggish flow and retrograde reflux considered classic findings. However, 2D Doppler is operator-dependent and has recognised limitations in visualising deeper pelvic veins and complex venous anatomy. The subsequent development of 3D Doppler ultrasound has enabled volumetric reconstruction of the pelvic venous plexus, improving visualisation of dilatation, tortuosity and collateral vessels that may be underappreciated on 2D imaging [8], and Doppler ultrasound has similarly proven valuable beyond the pelvic venous system, including obstetric assessment of placenta previa in association with gestational diabetes [42] and characterisation of carotid plaque in patients with diabetes, hypertension and hyperlipidaemia [43], underscoring its versatility as a non-invasive vascular imaging tool, while 4D Doppler adds a real-time temporal dimension that allows dynamic assessment of reflux and flow change during provocative maneuvers particularly valuable given

that venous incompetence in PCS can be intermittent and posture-dependent [9].

Emerging evidence suggests that 3D/4D Doppler ultrasound offers greater sensitivity and specificity than conventional Doppler for pelvic varicosities and ovarian vein reflux, with implications for both diagnosis and treatment planning, including patient selection for ovarian vein embolization and monitoring of therapeutic response [10,11]. Nevertheless, no universally accepted diagnostic criteria exist for PCS, and variability in diameter thresholds, patient positioning and reflux interpretation continues to limit consistency across studies and centres [12,13]. Despite growing international interest in advanced Doppler imaging, locally generated evidence on its diagnostic value in Pakistani women with chronic pelvic pain remains limited. This study was therefore designed to evaluate the diagnostic value of 3D/4D Doppler ultrasound in women with chronic pelvic pain suspected of having PCS, and to compare its performance with conventional 2D/color Doppler ultrasound, to support earlier recognition and evidence-based management of this underdiagnosed condition [20].

2. Materials and Methods

2.1 Research Design

This study was designed as a prospective, observational, cross-sectional study. Chronic pelvic pain patients were enrolled in a prospective study for data collection. As no intervention or treatment was given, the study was of an observational nature. The cross-sectional design enabled pelvic venous abnormalities and Doppler ultrasound characteristics to be assessed at one time in order to assess the role of 3D/4D Doppler ultrasound in the diagnosis of Pelvic Congestion Syndrome (PCS).

2.2 Clinical Settings

The study was done in the Department of Radiology, Jinnah Hospital. The department has state-of-the-art ultrasound facility, and has many patients coming with gynecological and pelvic complaints. With the advent of Doppler ultrasound and qualified radiologists, proper

evaluation of pelvic venous disorders is available in the appropriate setting.

2.3 Sample Size

The sample size is determined by using Cochran's formula to achieve statistical validity:

$$n_0 = ((1.96)^2 \times 0.50 \times 0.50) / (0.10)^2 = (3.8416 \times 0.25) / 0.01 = 0.9604 / 0.01 = 96$$

Where $Z = 1.96$ (95% confidence level), $p = 0.5$, $q = 1 - p = 0.5$, $d = 0.10$.

Therefore, the ideal sample size for statistical power is 96 patients.

2.4 Sampling Technique

In this study the researchers used a convenience sampling technique. Consecutive sampling was used to recruit patients who met the inclusion criteria and presented to the radiology department. This sampling method was chosen because of the ease of access to and availability of the eligible participants during the clinical setting.

2.5 Duration of Study

The study period is four months and patient enrollment, imaging and data collection will strictly follow each other in sequential order to avoid temporal bias and to provide consistency.

2.6 Selection Criteria

The number of samples selected is based on the inclusion and exclusion criteria.

2.6.1 Inclusion Criteria

- Women aged 18–45 years
- Patients who have a chronic pelvic pain of more than 6 months duration
- Patients who had a clinical suspicion for Pelvic Congestion Syndrome (PCS)
- Patients that give informed consent.

2.6.2 Exclusion Criteria

- Pregnant women
- History of pelvic inflammatory disease, pelvic malignancy or large pelvic masses
- Patients who have had any operation in the pelvis.

- Patients with a known uterine or ovarian pathology which is causing pain (fibroids, endometriosis, etc.)
- Patients who do not wish to participate.

2.7 Ultrasound Equipment

The ultrasound was done with a high-resolution ultrasound machine with state of the art Doppler imaging. The machine included:

- General pelvic assessment, visualization of deeper pelvic structures, using transabdominal probe (3-5 MHz).
- Transvaginal probe (5-9 MHz) to provide in-depth detailed information on pelvic veins and surrounding structures at higher resolution.
- Venous blood flow direction and vascularity by color Doppler imaging.
- Venous flow velocity and reflux duration spectral Doppler.
- Evaluation of pelvic venous anatomy and hemodynamics in real-time and volumetrically, using 3D/4D Doppler.

These imaging modalities allowed for better visualization of venous dilatation, reflux pathways and pelvic venous congestion.

2.8 Study Procedure

Transabdominal and transvaginal ultrasound were performed in all participants. In the first instance conventional 2D gray scale ultrasound was carried out to assess the pelvic organs and to detect any structural abnormalities. This was then followed by colour Doppler ultrasound to evaluate ovarian and pelvic venous diameter, blood flow and venous reflux.

Then, 3D/4D Doppler ultrasound was used for a detailed evaluation of pelvic venous anatomy and hemodynamics. Three-dimensional imaging allowed volumetric reconstruction of the pelvic veins, which helped to visualize the venous tortuosity, collateral circulation and relationships. Venous blood flow and reflux were assessed with four-dimensional Doppler imaging in real time, throughout the physiological maneuvers.

The following parameters were assessed and noted:

- Ovarian veins thickness of the diameter of pelvic veins
- Venous reflux is the presence and duration of reflux.
- The direction that the blood is moving in the vein.
- Venous flow velocity
- Pelvic varicosities and collateral veins are present.

All examinations were done at rest and during the Valsalva maneuver, which helps to detect venous insufficiency by inducing venous reflux.

2.9 Ethical Consideration

Considering the ethical principles approved by the Ethical Committee of Superior University Lahore wherein the rights, safety and well being of the participants have been ensured. All participants gave informed consent prior to their involvement in the study.

Any data and information collected and used were kept strictly confidential and for research only. Identities of participants were kept anonymous throughout the study ensuring privacy and confidentiality.

The consent of the parent or guardian was obtained after the purpose, procedures, potential risks and benefits of the study were explained in clear and understandable language. There was no coercion to participate and families were made aware that they could opt out of the study at any point without this impacting the care they provide their child.

2.10 Data Collection Procedure

The participants were identified in the radiology department as those with chronic pelvic pain who were eligible. All participants were informed about the purpose and procedure of the study and informed consent was obtained in writing before participating in the study.

All participants had a standard 2D colour Doppler ultrasound examination of pelvic vein diameter and venous reflux to begin with. This was followed by 3D/4D Doppler ultrasound to assess the pelvic venous anatomy in detail and real-time blood flow dynamics.

Using a structured data collection form, findings were recorded including vein diameter, reflux duration, venous flow characteristics and the presence of varicosities. Patient identities were anonymised and all the information gathered was kept securely to ensure confidentiality and for research analysis.

2.11 Data Analysis

Data collected were entered and analyzed on Statistical Package for Social Sciences (SPSS) version 24.0. Demographic data and ultrasound data were reported using descriptive statistics such as mean, standard deviation, frequencies, and percentages.

Appropriate statistical tests were used for comparison of the data obtained from the conventional 2D Doppler ultrasound and the advanced 3D/4D Doppler ultrasound, including the Chi-square test for categorical variables and the independent t-test for quantitative variables. A p-value of < 0.05 was deemed significant.

The results were presented in tabular, graphical and chart form for clarity and interpretation.

3. Results

In this cross-sectional study 96 women with chronic pelvic pain who met inclusion criteria were assessed in the Department of Radiology, Jinnah Hospital, Lahore. Both 2D/color Doppler and 3D/4D Doppler ultrasound of the pelvic venous system was performed in all participants. The results are displayed in the following categories: Demographic and clinical characteristics, 2D/color Doppler results, 3D/4D Doppler results, comparison between 2D/color Doppler and 3D/4D Doppler results, 2D/color Doppler and 3D/4D Doppler findings and clinical symptoms.

3.1 Demographic and Clinical Characteristics

The mean age of the study participants was 30.92 ± 8.05 years, and ranged from 18 to 45 years. The mean parity was 1.86 ± 1.46 (range 0–5), and the mean duration of chronic pelvic pain was 36.80 ± 16.48 months (range 7–60 months). Most of the participants (69.8%) were premenopausal, and 30.2% were postmenopausal. Demographic and clinical features of the study sample are summarized in Table 1, while its age distribution is illustrated in Figure 1.

Table 1. Demographic and clinical characteristics of study participants

Variable	Mean $\pm$ SD / n (%)	Range
Age (years)	30.92 ± 8.05	18 – 45
Parity	1.86 ± 1.46	0 – 5
Duration of pelvic pain (months)	36.80 ± 16.48	7 – 60
Menstrual status – Premenopausal	67 (69.8%)	—
Menstrual status – Postmenopausal	29 (30.2%)	—

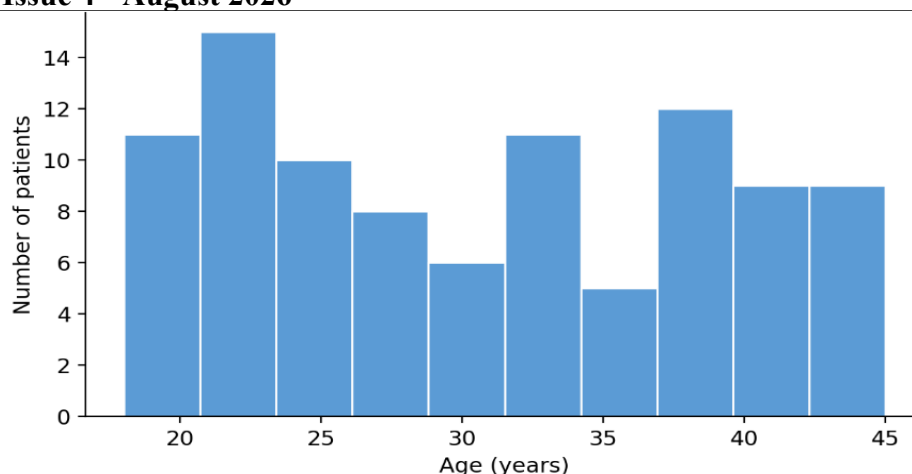


Figure 1. Age distribution of the study participants

3.2 Pattern of Pelvic Pain, Aggravating Factors and Associated Symptoms

In terms of pain location, 52.1% of patients localised pain to the pelvis, 43.8% of patients localised pain to the lower abdomen and 4.2% of

patients localised pain to other locations. Achiness was the most prevalent pain (39.6%), dull (33.3%), burning (16.7%) and other types of pain (10.4%). The results of these investigations are presented in Figure 2.

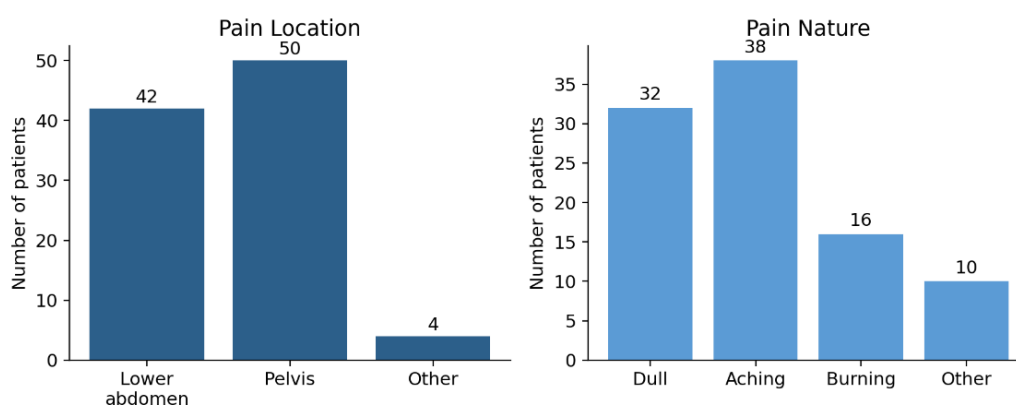


Figure 2. Distribution of location and type of pain amongst the study participants

The most common aggravating factor was prolonged standing (65.6%), next was menstruation (56.2%), intercourse (51.0%) and prolonged sitting (38.5%). The various symptoms associated with it included dyspareunia (47.9%),

leg varicosities (34.4%), edema (24.0%) and urinary frequency (20.8%). These clinical characteristics are outlined in Table 2 and represented in Figure 3, and all of them are typical of pelvic venous congestion.

Table 2. Aggravating factors and associated symptoms reported by study participants

Clinical feature	Present, n (%)
Aggravated by standing	63 (65.6%)

Clinical feature	Present, n (%)
Aggravated by menstruation	54 (56.2%)
Aggravated by intercourse	49 (51.0%)
Aggravated by sitting	37 (38.5%)
Dyspareunia	46 (47.9%)
Leg varicosities	33 (34.4%)
Lower-limb edema	23 (24.0%)
Urinary frequency	20 (20.8%)

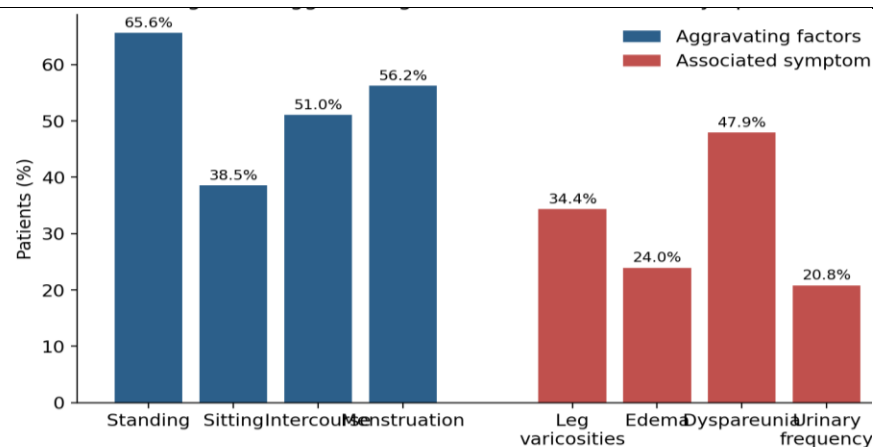


Figure 3. Aggravating factors and associated symptoms of pelvic pain

3.3 2D/Colour Doppler Ultrasound Findings

The mean diameter of the ovarian vein was 5.23 ± 1.09 mm, with a mean diameter of the internal iliac vein of 6.52 ± 0.98 mm, on the right, and 5.82 ± 1.16 mm, and 6.79 ± 1.20 mm, respectively, on the left, in conventional 2D/color Doppler ultrasound. At the standard cut-off of ≥ 6 mm, 26.0% of patients had dilatation of the right ovarian vein, while 47.9% had dilatation of the

left ovarian vein, which is consistent with the known predisposition for left ovarian vein dilatation. Among the patients with venous reflux, 29.2% on the right and 41.7% on the left had mean reflux time of 2.67 ± 0.84 seconds and 2.85 ± 1.17 seconds respectively. On the right side 27.1% and on the left side 47.9% had pelvic varicosities. The results of this survey are summarized in Table 3.

Table 3. 2D/colour Doppler ultrasound findings of the ovarian and internal iliac veins

Parameter	Right	Left
Ovarian vein diameter (mm), mean $\pm$ SD	5.23 ± 1.09	5.82 ± 1.16
Internal iliac vein diameter (mm), mean $\pm$ SD	6.52 ± 0.98	6.79 ± 1.20
Ovarian vein ≥ 6 mm, n (%)	25 (26.0%)	46 (47.9%)
Venous reflux present, n (%)	28 (29.2%)	40 (41.7%)
Reflux duration (sec), mean $\pm$ SD	2.67 ± 0.84	2.85 ± 1.17

Parameter	Right	Left
Retrograde flow direction, n (%)	28 (29.2%)	40 (41.7%)
Pelvic varicosities present, n (%)	26 (27.1%)	46 (47.9%)

3.4 3D/4D Doppler Ultrasound Findings

On 3D/4D Doppler ultrasound, the mean dilated vein diameter was 5.63 ± 1.10 mm on the right and 6.24 ± 1.19 mm on the left, while the mean flow velocity was 7.17 ± 2.52 cm/s on the right and 8.51 ± 3.06 cm/s on the left. The venous tortuosity was classified as mild in 39.6% / 28.1%, moderate in 38.5% / 43.8%, severe in 21.9% / 28.1% of right / left veins, respectively, suggesting a slightly

higher degree of venous tortuosity on the left side (Figure 4). The incidence of venous reflux was 37.5% on the right and 49.0% on the left, as seen on 3D/4D Doppler. Overall image visualization quality was good in 69.8%, fair in 26.0% and poor in 4.2% of examinations and thus 3D/4D Doppler offered diagnostically adequate visualization in the vast majority of cases (Figure 5). The results of this are summarised in Table 4.

Table 4. 3D/4D Doppler ultrasound variables of the ovarian and pelvic veins

Parameter	Right	Left
Dilated vein diameter (mm), mean $\pm$ SD	5.63 ± 1.10	6.24 ± 1.19
Flow velocity (cm/s), mean $\pm$ SD	7.17 ± 2.52	8.51 ± 3.06
Tortuosity – Mild, n (%)	38 (39.6%)	27 (28.1%)
Tortuosity – Moderate, n (%)	37 (38.5%)	42 (43.8%)
Tortuosity – Severe, n (%)	21 (21.9%)	27 (28.1%)
Venous reflux observed, n (%)	36 (37.5%)	47 (49.0%)

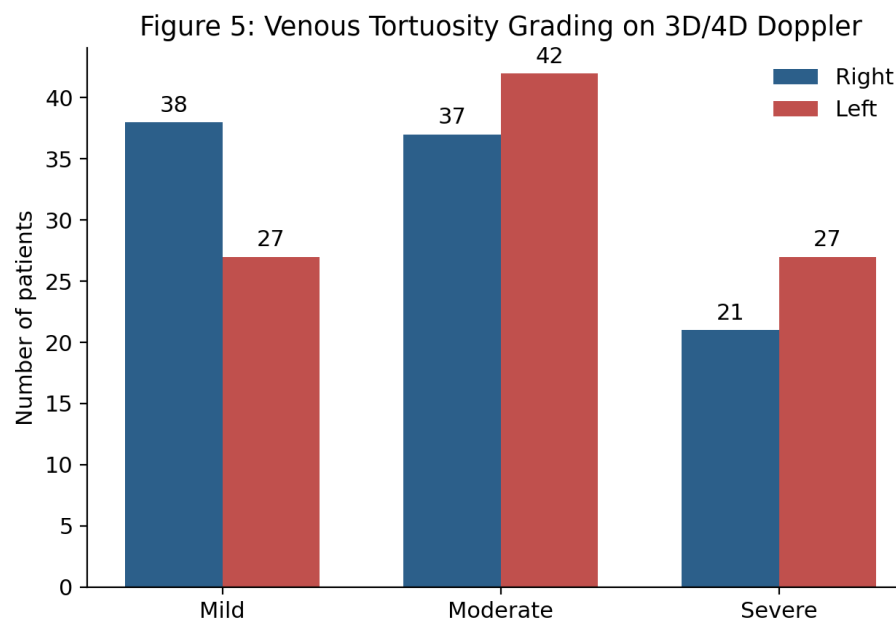


Figure 4. Venous tortuosity grading on 3D/4D Doppler ultrasound (right vs left)

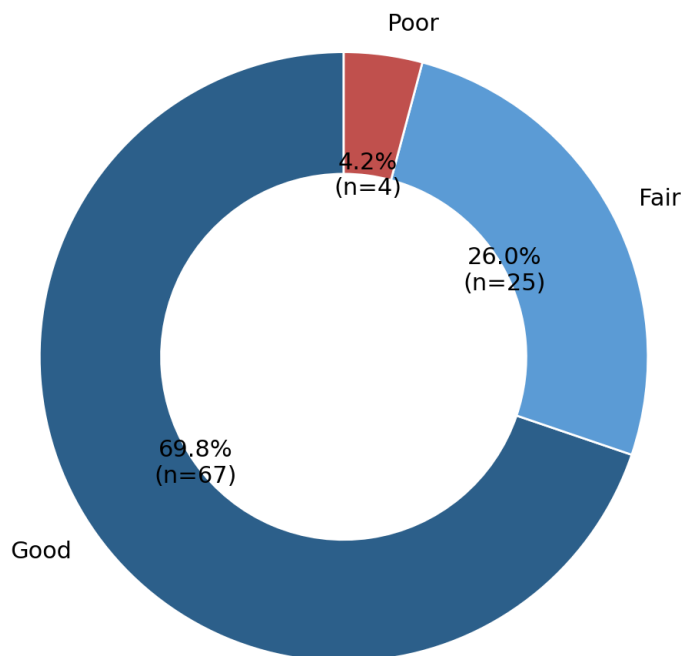


Figure 5. Overall image visualization quality of 3D/4D Doppler ultrasound

3.5 Comparison between 2D/Colour Doppler and 3D/4D Doppler Findings

In both sides the rate of venous reflux was higher by “3D/4D Doppler ultrasound” compare with “2D/color Doppler”. On the right side, the percentage of reflux detected rose from 29.2% (2D) to 37.5% (3D/4D), which was statistically significant by McNemar's exact test ($p = 0.008$) and there were eight more cases of reflux that were only detected on 3D/4D imaging. For reflux detection, the 2D method detected 41.7% compared with 49.0% for the 3D/4D method, with seven cases going undetected by the 2D method (McNemar's exact $p = 0.016$). There was no case where reflux

was identified by 2D Doppler but not identified by 3D/4D Doppler, and in all discordant pairs, reflux was seen on 3D/4D Doppler but not 2D Doppler, which supports the 3D/4D Doppler not missing any reflux identified on 2D Doppler (Figure 6).

In addition, volumetric 3D reconstruction resulted in a significantly greater vein diameter for both the right vein (5.63 ± 1.10 mm vs 5.23 ± 1.09 mm; paired $t = 17.18$, $p < 0.001$) and left vein (6.24 ± 1.19 mm vs 5.82 ± 1.16 mm; paired $t = 15.38$, $p < 0.001$) compared with 2D Doppler, indicating that volumetric 3D reconstruction can yield more complete delineation of venous margins than 2D imaging (Table 5 and Figure 7).

Table 5. Comparison of reflux detection rate and vein diameter between 2D and 3D/4D Doppler ultrasound

Comparison	2D Doppler	3D/4D Doppler	p-value
Reflux detected - Right, n (%)	28 (29.2%)	36 (37.5%)	0.008*
Reflux detected - Left, n (%)	40 (41.7%)	47 (49.0%)	0.016*
Vein diameter - Right (mm)	5.23 ± 1.09	5.63 ± 1.10	$<0.001^*$
Vein diameter - Left (mm)	5.82 ± 1.16	6.24 ± 1.19	$<0.001^*$

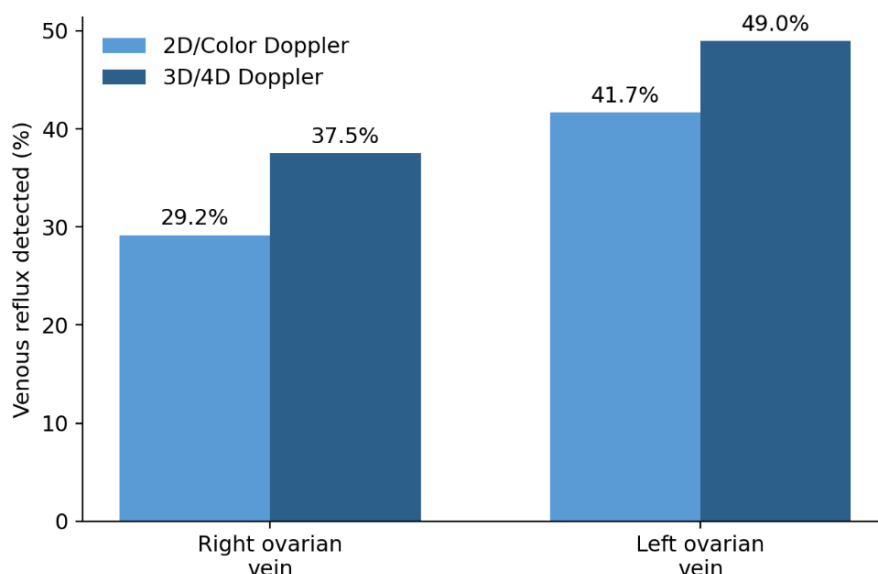


Figure 6. Venous reflux detection rate – 2D versus 3D/4D Doppler ultrasound

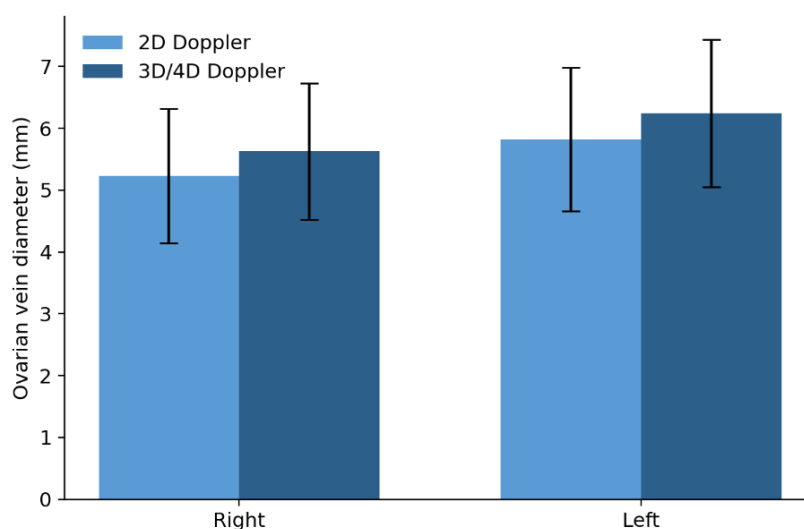


Figure 7. Mean ovarian vein diameter – 2D versus 3D/4D Doppler ultrasound

3.6 Venous Reflux on 3D/4D Doppler by Laterality

Combined bilateral venous reflux was present in 20.8% of patients, left-sided reflux alone in 28.1% and right-sided reflux alone in 16.7% of patients, whereas 34.4% had no obvious reflux on either

side on 3D/4D Doppler. Unilateral and bilateral involvement are well represented in Figure 8, and is in keeping with the known anatomical susceptibility of the left ovarian vein (which drains at right-angles into the left renal vein).

Figure 8: Laterality of Venous Reflux on 3D/4D Doppler

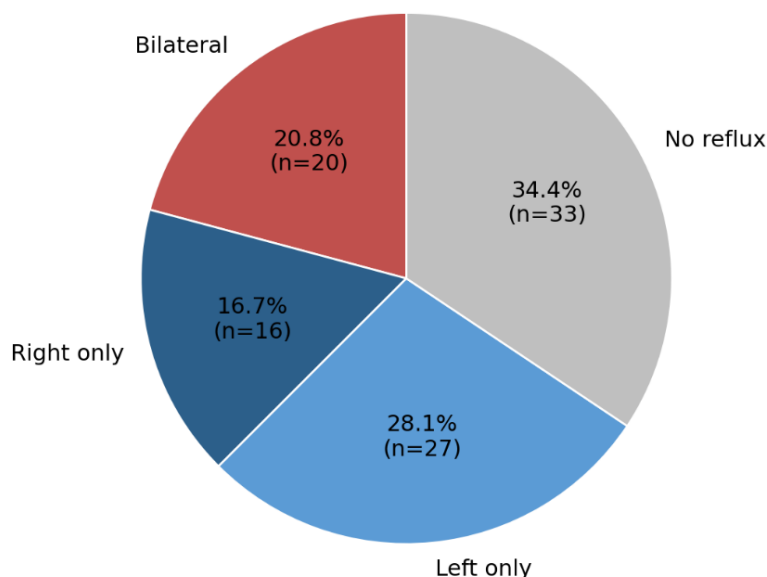


Figure 8. Laterality of venous reflux detected on 3D/4D Doppler ultrasound

3.7 Correlation between Ultrasound Findings and Clinical Symptoms

In general, 75.0% of the ultrasound results were found to be correlated with the clinical symptoms of the patient. There were no significant differences in the proportion of patients with 3D/4D-detected reflux compared to those without reflux, in terms of symptom correlation (right side: 83.3% vs 70.0%, $\chi^2 = 1.48$, $p = 0.224$; left side: 80.9% vs 69.4%, $\chi^2 = 1.13$, $p = 0.289$), or in terms of overall visualization quality ($\chi^2 = 1.47$, $p = 0.479$). Likewise, the duration of pelvic pain did not differ significantly between patients with and without 3D/4D-detected reflux (35.86 ± 15.72 vs

37.37 ± 17.03 months; $t = -0.44$, $p = 0.661$), and ovarian vein diameter did not differ significantly between multiparous and nulliparous women (5.29 ± 1.09 mm vs 4.95 ± 1.06 mm; $t = 1.27$, $p = 0.214$). There was no significant correlation between age and diameter of ovarian veins ($r = -0.084$, $p = 0.417$) or between duration of pain and duration of reflux ($r = -0.116$, $p = 0.262$). The results summarized in Table 6 show that although there was a trend towards greater imaging positivity with increasing symptom correlation, chronic pelvic pain in this cohort was multifactorial and could not be attributed solely to the severity of venous reflux.

Table 6. Association between imaging findings and clinical parameters

Comparison	Result	Test statistic	p-value
Symptom correlation vs reflux (Right)	83.3% vs 70.0%	$\chi^2 = 1.48$	0.224
Symptom correlation vs reflux (Left)	80.9% vs 69.4%	$\chi^2 = 1.13$	0.289

Comparison	Result	Test statistic	p-value
Symptom correlation vs visualization quality	—	$\chi^2 = 1.47$	0.479
Pain duration: reflux+ vs reflux— (Right)	35.86 vs 37.37 mo	$t = -0.44$	0.661
Vein diameter: multiparous vs nulliparous	5.29 vs 4.95 mm	$t = 1.27$	0.214
Age vs ovarian vein diameter (correlation)	$r = -0.084$	—	0.417
Pain duration vs reflux duration (correlation)	$r = -0.116$	—	0.262

To conclude, this study showed that 3D/4D Doppler ultrasound is superior for detection of pelvic venous reflux and better for complete delineation of ovarian vein diameter compared with conventional 2D/color Doppler ultrasound and that it provides good-to-fair diagnostic visualization in 95.8% of examinations. Left-sided and bilateral venous involvement was more frequent than isolated right-sided involvement, and although the majority of cases showed correlation between imaging and clinical symptoms, none of the demographic or clinical variables had a statistically significant independent association with reflux severity in this group.

4. Discussion

The present cross-sectional study aimed to assess the diagnostic utility of 3D/4D Doppler ultrasound (3DD) in Pelvic Congestion Syndrome (PCS) and to compare its performance with conventional 2D/color Doppler ultrasound (2DC) in 96 women with chronic pelvic pain. Participants' age (30.92 ± 8.05 years) and the high prevalence of premenopausal women (69.8%) are typical of the epidemiology of PCS, a condition of multiparous women of reproductive age associated with the venodilatory effects of estrogen and the mechanical venous stress of pregnancy, together leading to valvular incompetence and chronic venous congestion [28].

The clinical symptoms observed in this cohort were similar to those described in the classical symptom complex of PCS [1,3]: pain worsened by standing, menstruation and intercourse, and associated dyspareunia, leg varicosities and pelvic heaviness. The prominence of positional and provocation-related symptoms in this sample is an

important clinical clue suggesting a venous rather than a purely gynecological origin.

A key finding of this study was the improved diagnostic yield of 3D/4D Doppler ultrasound over conventional 2D Doppler ultrasound. The use of 3D/4D imaging increased detection of reflux from 29.2% to 37.5% on the right side and 41.7% to 49.0% on the left, with McNemar's test confirming this increase was statistically significant and unidirectional — no cases detected by 2D imaging were missed by 3D/4D imaging. This directly confirms Zhang et al., who reported that 3D reconstruction improves visualization of venous dilatation, tortuosity and collateral circulation that may be masked by overlapping structures in 2D imaging [25], and Ahmed et al., who found 3D/4D imaging to have the highest overall diagnostic accuracy among the three modalities [27]. The additional cases identified here are likely attributable to the real-time, temporally resolved assessment afforded by 4D Doppler, consistent with Patel et al.'s demonstration of its value in identifying intermittent or posture-dependent reflux missed on static 2D imaging [26].

The significantly greater mean vein diameter measured by 3D/4D Doppler compared with 2D Doppler ($p < 0.001$) on both sides is consistent with the volumetric advantage of 3D reconstruction, in which vessel margins along an oblique or tortuous course are more completely traced than with 2D imaging. This supports Ricci et al.'s argument that 3D Doppler ultrasound provides a more accurate anatomical view of the pelvic venous plexus, with direct implications for diagnostic thresholds [16]. The lower diameter cut-off of approximately 6 mm reported by Pitoulias et

al. [32] may partly explain the additional reflux-positive cases identified on volumetric imaging, since 2D Doppler may underestimate true vessel diameter.

The left-sided predominance of both vein dilatation and reflux, with more bilateral than isolated right-sided disease, is an expected anatomical finding, given that the left ovarian vein drains into the left renal vein at a right angle under higher hydrostatic pressure, while the right ovarian vein drains more directly into the inferior vena cava. This asymmetry, emphasised by Szaflarski et al. [14], is reinforced by Kashef et al.'s observation that ovarian vein incompetence is the most common underlying abnormality in PCS, although a significant subset of the present cohort also showed internal iliac vein involvement, contributing to more complex bilateral disease patterns [34].

Good or fair image visualization was achieved in 95.8% of 3D/4D examinations, supporting the feasibility of this technique for routine non-invasive diagnostic use. This is consistent with reports of higher inter-observer agreement and reduced diagnostic variability for 3D/4D Doppler compared with 2D Doppler [18,27], and with the broader literature establishing Doppler ultrasound as the preferred initial imaging modality for PCS while underscoring the importance of standardised, technically sound protocols [29,31,32].

A larger proportion of reflux-positive patients showed correlation between imaging findings and clinical symptoms compared with reflux-negative patients, though the difference was not statistically significant, and pain duration was similar between groups. This finding echoes Singh et al.'s caution regarding the limitations of a purely 2D Doppler-based approach for complete venous assessment [23] and Meissner et al.'s view that PCS diagnosis should integrate characteristic clinical symptoms with radiological evidence of venous insufficiency rather than relying on imaging alone [13]. The multifactorial nature of chronic pelvic pain – encompassing venous, gynecological, urological and gastrointestinal contributors – may explain why imaging positivity alone did not fully account

for symptom intensity or duration in this cohort, consistent with Howard's broader chronic pelvic pain literature [1] and Abdelwahab et al.'s observation that some residual symptom burden may reflect internal iliac vein reflux not fully captured by Doppler ultrasound [33].

The absence of a significant relationship between parity and ovarian vein diameter in this study contrasts somewhat with the mechanistic model proposed by Wang et al. [28], which predicted such a relationship. This may reflect the relatively small number of nulliparous women ($n = 19$) in this sample, limiting statistical power to detect a modest parity-related effect and indicating a need for larger, appropriately powered studies. Similarly, the absence of a significant correlation between reflux duration and pain duration is consistent with Khan et al.'s finding that hemodynamic disturbance, rather than symptom chronicity, correlates most closely with the severity of venous congestion [22].

Overall, these findings add to a growing body of evidence supporting the value of advanced volumetric and real-time Doppler techniques in the non-invasive diagnostic evaluation of PCS – from early work establishing Doppler ultrasound as a first-line modality [21], through demonstration of the limitations of 2D imaging in deep pelvic venous assessment [23], to more recent evidence on 3D/4D imaging [25–27]. Incorporating 3D/4D Doppler into routine sonographic evaluation of women with chronic pelvic pain could help reduce missed or underestimated cases of venous insufficiency, accelerate the diagnostic process, and improve referral decisions for confirmatory venography or endovascular treatment such as ovarian vein embolization [35].

5. Conclusion

This study set out to assess the diagnostic utility of 3D/4D Doppler ultrasound in women with chronic pelvic pain suspected of having Pelvic Congestion Syndrome (PCS) and to compare its performance with conventional 2D/colour Doppler ultrasound. This aim was achieved: 3D/4D Doppler ultrasound detected significantly

more cases of venous reflux than 2D/colour Doppler on both the right (37.5% vs 29.2%, $p = 0.008$) and left (49.0% vs 41.7%, $p = 0.016$) sides, and provided significantly more complete delineation of ovarian vein diameter on both sides.

Good or fair diagnostic image quality was achieved in 95.8% of the 3D/4D examinations, confirming that the technique is feasible for routine, non-invasive clinical use. Venous involvement was more frequently left-sided or bilateral than isolated right-sided, consistent with the recognised anatomical predisposition of the left ovarian vein. Overall, 3D/4D Doppler ultrasound was shown to be superior to conventional 2D/colour Doppler ultrasound for the detection of pelvic venous reflux and the assessment of venous anatomy, and it can be used as a dependable, non-invasive adjunct to support timely diagnosis and clinical management of PCS.

5.1 Limitations

- The study was carried out at a single centre (Department of Radiology, Jinnah Hospital, Lahore) using non-probability consecutive sampling, which may limit the generalisability of the findings to other populations and settings.
- As a cross-sectional, observational study, findings on 2D/colour and 3D/4D Doppler ultrasound were compared with each other rather than against an independent reference standard such as pelvic venography, so true diagnostic sensitivity and specificity could not be established.
- Ultrasound examination and image interpretation remain operator-dependent, and formal inter-observer and intra-observer reliability of the 3D/4D Doppler findings was not assessed in this study.
- Subgroup sizes for some comparisons (for example, nulliparous women) were relatively small, which may have limited the statistical power to detect associations

such as that between parity and ovarian vein diameter.

5.2 Recommendations

- Larger, multi-centre studies with adequately powered subgroups are recommended to confirm these findings and to further clarify the relationship between parity, hormonal factors and pelvic venous dilatation.
- 3D/4D Doppler ultrasound should be considered for incorporation into the routine sonographic evaluation of women with chronic pelvic pain suspected of PCS, as it can reduce missed or underestimated cases of venous insufficiency and support timely referral for confirmatory venography or endovascular treatment.
- Future studies should, where feasible, correlate 3D/4D Doppler ultrasound findings with an independent reference standard, such as conventional venography or MR venography, to establish formal diagnostic accuracy (sensitivity, specificity, predictive values).
- Standardised, protocol-driven acquisition and diameter/reflux-duration cut-offs are recommended to reduce operator-dependent variability and improve the reproducibility of 3D/4D Doppler ultrasound across radiologists and centres.
- Formal assessment of inter-observer and intra-observer reliability of 3D/4D Doppler ultrasound is recommended before wider clinical adoption.
- The role of artificial intelligence-assisted analysis of 3D/4D Doppler data may be explored in future work as a means of further improving the objectivity and consistency of PCS diagnosis.

Declarations

Author Contributions: Mashal Fatima: study design, data collection, data analysis, and manuscript drafting. Tahira Batool: study

supervision, conceptualisation, and critical revision of the manuscript. Asma Irshad: methodological input and critical revision of the manuscript. Zarwa Gohar: data interpretation and manuscript review. All authors read and approved the final manuscript.

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Ethical Approval: The study was approved by the Ethical Review Committee of The Superior University, Lahore, and all participants provided written informed consent prior to enrolment.

Conflict of Interest: The authors declare no conflict of interest.

Data Availability: The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

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