

The Accuracy of 2D versus 3D Ultrasound in Bladder Volume Measurement during Urodynamic Studies: A Literature Review

Amal Abdullah Alsolai

Department of Radiological Sciences, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

Abstract

Accurate assessment of bladder volume plays a significant role in diagnosing and managing lower urinary tract dysfunctions, particularly during urodynamic (UD) evaluations. Although catheter-based UD studies are widely accepted as the gold standard, they are invasive, operator-dependent, and often uncomfortable for patients. This has led to increased interest in non-invasive alternatives such as two-dimensional (2D) and three-dimensional (3D) ultrasound (US) imaging. This review compares the diagnostic performance, accuracy, and clinical feasibility of 2D and 3D US technologies in the context of bladder volume measurement during or alongside UD assessments. A structured literature search was conducted across PubMed, Google Scholar, and Web of Science for studies published between 1998 and 2024. Inclusion criteria focused on peer-reviewed articles reporting bladder volume estimation using 2D or 3D US, particularly those providing direct or indirect comparisons to reference standards such as catheterization or post-void residual volume. Findings suggest that 3D US offers improved spatial accuracy, reduced operator dependency, and greater potential for automation and wearable integration compared to 2D US. However, methodological heterogeneity and the limited number of direct head-to-head comparison studies remain key limitations. These findings underscore the need for large-scale comparative trials and standardized imaging protocols to validate 3D US as a primary diagnostic tool in UDs. With further refinement, 3D US holds strong potential as a non-invasive, patient-centered solution for bladder function assessment.

Key words: 2D ultrasound, 3D ultrasound, bladder volume, non-invasive imaging, ultrasound automation, urodynamics

INTRODUCTION

The urinary bladder is a highly compliant and elastic organ capable of storing urine at low pressures. This property, known as detrusor compliance, depends on the physiological balance between the detrusor muscle and the fibrous connective tissue within the bladder wall, and it reflects the bladder's ability to expand in volume without substantial increases in intravesical pressure. In clinical practice, the ability to accurately assess bladder volume is essential for evaluating bladder function and diagnosing urinary disorders.

Urodynamic studies (UDS) remain the gold standard for assessing bladder function and are routinely used to investigate voiding dysfunction, overactive bladder (OAB), urinary retention, and detrusor overactivity. A typical UDS procedure lasts approximately 45 min and involves the insertion of catheters into the

bladder and rectum (or vagina), followed by fluid infusion at a controlled rate (Nenadic *et al.*, 2016).^[1] These studies provide real-time measurements of pressure and volume, offering detailed insights into bladder physiology during filling and voiding cycles.

However, despite their diagnostic value, UDS procedures are invasive, uncomfortable, and resource intensive. Patients frequently report pain or discomfort due to catheterization, and the procedure is associated with complications such as urinary tract infections, hematuria, urethral trauma, and scarring (McCormack *et al.*, 2024).^[2] These risks can reduce

Address for correspondence:

Amal Abdullah Alsolai, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia. E-mail: Amalsolai@ksu.edu.sa

Received: 18-02-2026

Revised: 21-03-2026

Accepted: 29-03-2026

patient compliance and limit routine use, particularly in pediatric, geriatric, or postpartum populations. Furthermore, UDS has been criticized for limited repeatability, procedural artifacts, and its inability to consistently capture functional bladder dynamics outside of the clinical environment.

As a result, there is increasing interest in the development of non-invasive, reliable methods for estimating bladder volume. Ultrasound (US) imaging, which is fast, safe, and free from ionizing radiation, has emerged as a viable alternative. Within this domain, two-dimensional (2D) and three-dimensional (3D) US modalities are the most explored. These technologies offer the potential to measure bladder volume without catheterization and are increasingly being used in clinical and research settings.

While 2D US is widely available and cost-effective, it has limitations in terms of volume estimation accuracy, especially when the bladder shape is irregular. It generally requires the application of geometric formulas (such as ellipsoid assumptions) based on linear dimensions, which introduces variability. On the other hand, 3D US technologies capture volumetric data directly, enabling more accurate and consistent reconstructions of the bladder's shape. Studies have shown that 2D US tends to overestimate actual bladder volume, whereas 3D US often slightly underestimates it (Chang *et al.*, 2021).^[3] Nonetheless, both methods demonstrate clinical reliability and can serve as non-invasive tools for bladder volume assessment.

In recent years, innovations in imaging and signal processing have further enhanced these modalities. A study by Akkus *et al.* (2020) introduced a fully automated segmentation algorithm for transabdominal US images, capable of accurately measuring detrusor wall thickness and delineating the bladder sac. These advances minimize inter-operator variability and pave the way for reproducible, real-time assessments.^[4] Similarly, studies have investigated bladder shape's impact on estimation accuracy, leading to novel 3D bladder reconstruction models that improve volumetric fidelity during both low and high bladder fill states. Additional research has explored specialized applications. For instance, a study by Nusee *et al.* (2014) evaluated portable 3D US systems for postpartum patients, finding a strong correlation with catheterized volumes.^[5] Veterinary applications also support the generalizability of these methods, with canine models used to compare 2D and 3D US bladder measurements. Furthermore, wearable solutions are emerging. A forward-looking US scanner that continuously measures bladder volume in real time has been developed by Jo *et al.* (2021), which offers significant promise for patients requiring frequent or ambulatory bladder tracking.^[6]

Emerging reviews and scoping analyses have highlighted the integration of artificial intelligence (AI)-driven diagnostic tools in urology. In pediatric populations, AI-enhanced bladder imaging has demonstrated potential

in detecting lower urinary tract dysfunction and optimizing bladder management protocols (Chowdhury *et al.*, 2024).^[7] Automated segmentation tools, real-time 3D modeling, and portable devices all contribute to a rapidly evolving ecosystem of non-invasive urodynamic (UD) technologies.^[7]

Given these developments, it is essential to evaluate the comparative performance of 2D and 3D US in bladder volume estimation. This review synthesizes findings from a range of clinical, technical, and experimental studies to assess their diagnostic accuracy, reproducibility, and real-world applicability. Special focus is placed on technological innovation, integration with AI, and the suitability of these methods in specific populations such as postpartum patients, pediatric cases, and those with impaired compliance. The ultimate goal is to determine whether modern US technologies can serve as practical and precise alternatives to invasive UD assessments in routine clinical practice.

MATERIALS AND METHODS

The purpose of this review is to evaluate the comparative accuracy of 2D and 3D US technologies in measuring bladder volume during UD assessments. The study is based on a structured review of secondary data, focusing on published literature that investigates US-based bladder volume estimation in clinical or research settings involving UD.

To ensure a comprehensive evidence-based review, a targeted literature search was conducted using scholarly databases including PubMed/MEDLINE, Web of Science, and Google Scholar. The search strategy employed combinations of medical subject headings and free-text keywords such as “2D ultrasound,” “3D ultrasound,” “bladder volume estimation,” “non-invasive bladder assessment,” “urodynamics,” “automated bladder segmentation,” and “residual urine estimation.” Boolean operators (AND/OR) were used to maximize the retrieval of relevant peer-reviewed articles.

Inclusion criteria encompassed original research articles and relevant review papers published in English between 2008 and 2024, with the exception of one earlier study from 1998, included for its early insight into how bladder shape affects ultrasonic volume estimation. While informative, its methodology predates modern imaging standards. This study introduced early evidence that geometrical irregularities of the bladder can significantly impact the accuracy of 2D US measurement – a concept still relevant in modern 3D modeling and AI-assisted segmentation.

Articles were included if they provided quantitative comparisons between 2D and 3D US modalities or highlighted the advantages of either technology in UD or bladder volume monitoring contexts. Studies were evaluated based on design methodology, sample size, US imaging protocols, reference standards (e.g., catheterization, UD), and reported outcomes

such as accuracy, reliability, reproducibility, or clinical feasibility. Emphasis was placed on studies that incorporated modern applications, including automated segmentation, machine learning, and wearable or portable US systems.

The goal of this review is to synthesize the findings from these studies and provide a balanced comparison of 2D and 3D US technologies, assessing their diagnostic performance and practical value as non-invasive alternatives to catheter-based bladder volume measurements during UD evaluations.

DISCUSSION

Comparative evaluation of 2D and 3D US modalities

Accurate bladder volume estimation is critical during UD evaluations, particularly in diagnosing conditions such as urinary retention or OAB. Across multiple studies, 3D US consistently outperforms 2D US in volumetric accuracy, especially at moderate to high bladder filling levels. Chang *et al.* (2021) demonstrated that a 3D reconstruction model yielded near-identical volume measurements to catheterization when model complexity reached $n = 4$, with a low error margin of ± 5 mL.^[17] In contrast, 2D US often relies on geometric assumptions such as ellipsoidal or cuboidal formulas, which can result in volume overestimation ranging from 10% to 20% depending on bladder shape and orientation. In a comparative study involving portable scanners, Nusee *et al.* (2014) found that 3D US had a mean difference of 15.7 mL from catheterized measurements, with strong correlation ($r = 0.819$), while 2D estimations showed wider variability, particularly at bladder volumes below 100 mL.^[5] Additional findings by Jo *et al.* (2021) using wearable US systems confirmed that real-time 3D imaging demonstrated greater consistency during dynamic bladder filling, reducing the estimation error associated with bladder

shape changes.^[6] Taken together, these studies suggest that while both modalities are clinically acceptable, 3D US offers superior accuracy and reliability, particularly when precise measurement is required for diagnosis or treatment planning (Nagle *et al.*, 2018, Bernardo *et al.*, 2016).^[8,9] Moreover, several studies investigated the difference in accuracy between 2D and 3D US techniques. Underestimation of bladder volume measurement has been observed using both 3D and 2D US modalities as reported by Vinod *et al.* (2019)^[10,11] and Alfuraih *et al.* (2025), while Liang *et al.* (2009) reported volume underestimation by 3D modalities^[12] but volume overestimation using 2D modalities. These studies are summarized in Table 1.

Reproducibility is a key determinant of imaging reliability, particularly in clinical settings where assessments may be performed by multiple operators across different time points. 2D US, while widely accessible, has been shown to be highly operator-dependent, with variations in probe angle, patient positioning, and manual measurement techniques contributing to inter-observer variability. Chowdhury *et al.* (2024) highlighted this challenge in pediatric urology, where consistent positioning and anatomical variability made reproducibility difficult using traditional 2D methods.^[7] In contrast, 3D US reduces dependency on operator skill by capturing volumetric data in a single sweep, minimizing the need for geometric assumptions and manual input. Akkus *et al.* (2020) demonstrated that a fully automated deep learning system applied to 3D US achieved a Dice similarity coefficient of 0.93 in bladder segmentation and wall thickness estimation, indicating a high degree of reproducibility comparable to expert manual tracing.^[4] Moreover, studies utilizing automated or AI-assisted segmentation in 3D imaging have reported significantly improved intra- and inter-rater reliability, particularly in detecting subtle changes in bladder shape and volume. These findings underscore the growing consensus that 3D US, especially when combined

Table 1: Key studies investigating measurements using 2D and 3D ultrasound modalities

| Serial number | Study | Imaging modality | n | Mean value of error | Bladder shape correction | Notes |
|---------------|---------------------------------|--|----|--|--------------------------|--|
| 1 | (Nagle <i>et al.</i> , 2018) | 2D versus 3D US | 12 | 27% (2D US); 15% (3D US) | Yes (2D only) | 3D ultrasound more precise than 2D during overactive bladder testing |
| 2 | (Bernardo <i>et al.</i> , 2016) | 2D versus 3D US | 9 | Not explicitly reported in the study | Yes (2D only) | 3D ultrasound non-significantly more accurate than 2D |
| 3 | (Vinod <i>et al.</i> , 2019) | BladderScan versus 3D US | 16 | 21.8% (BIScan); 20.7% (3D US) | Yes (2D and 3D) | BI and 3D underestimate voided volumes |
| 4 | (Liang <i>et al.</i> , 2009) | Transvaginal 2D versus 3D | 40 | 15.7% (transvaginal 2D); -8.4% (transvaginal 3D) | No | Highlighted underestimation in 3D and overestimation in 2D |
| 5 | (Alfuraih <i>et al.</i> , 2025) | Handheld 3D US versus conventional 2D US | 53 | -11.2--12.0% (handheld 3D US); -27.6--36.7% (conventional 2D US) | No | Both 2D and 3D modalities underestimate bladder volume |

US: Ultrasound, OAB: Overactive bladder

with automation, enhances standardization and reduces variability, making it a more dependable tool for longitudinal bladder volume monitoring.

Beyond accuracy and reproducibility, the clinical utility of US modalities is also shaped by their portability, ease of use, and adaptability to specific patient populations. While 2D US remains the most accessible and cost-effective modality in routine care, its limitations become more apparent in cases requiring high precision or continuous monitoring. In a postpartum setting, Nusee *et al.* (2014) evaluated a portable 3D US scanner and found that its bladder volume measurements correlated strongly with those obtained through catheterization, even when bladder volumes were below 50 mL.^[5] This is particularly relevant in postnatal care, where early detection of urinary retention is essential, and non-invasiveness is a priority. Similarly, Jo *et al.* (2021) introduced a wearable forward-looking 3D US system that enabled real-time, continuous bladder volume measurement during daily activity, which is considered a breakthrough for neurogenic bladder patients or those requiring frequent voiding assessments.^[6] These innovations contrast with conventional 2D US, which typically requires patient repositioning and manual calculation, making it less suitable for dynamic or ambulatory settings. However, 2D US still plays a vital role in primary care and resource-limited environments where advanced imaging tools may not be available. Thus, while 3D US is emerging as the preferred modality in specialized and high-risk scenarios, 2D US retains relevance as a practical, first-line imaging approach.

The evolution of US-based bladder volume assessment has been driven by improved recognition of anatomical variability and rapid technological innovation. Recent advances – such as 3D US and AI-based segmentation – have directly addressed earlier limitations by enabling anatomically accurate, real-time volumetric reconstructions. For instance, Akkus *et al.* (2020) and Chang *et al.* (2021) developed modeling techniques that adapt dynamically to bladder shape variability, eliminating reliance on rigid geometric assumptions.^[3,4] The transition from manual measurements to automated and wearable systems reflects a fundamental shift in bladder imaging – transforming past challenges into opportunities for precision, consistency, and patient-centered care.

ADVANTAGES AND APPLICATIONS OF 3D US TECHNOLOGY

3D US has emerged as a distinctly advanced modality in bladder imaging, not merely due to its volumetric output, but because of its unique compatibility with automation, AI, and wearable technologies. Unlike conventional systems that rely on static, user-dependent measurements, 3D US facilitates real-time anatomical reconstruction, enabling high-resolution imaging that can be processed independently of

operator skill or technique. Akkus *et al.* (2020) demonstrated a fully automated system capable of segmenting the bladder sac and measuring detrusor wall thickness using deep learning, delivering near-instant results with minimal human intervention.^[4] This technological automation positions 3D US as a viable tool for high-efficiency clinical environments, where speed, standardization, and reproducibility are essential.

In addition to automation, 3D US is also highly adaptable to portable and wearable configurations. Jo *et al.* (2021) introduced a forward-looking, wearable bladder scanner that continuously tracked urinary bladder volume through a mobile interface.^[6] This system allowed for dynamic, real-time monitoring throughout daily life, supporting its use in outpatient, home-based, or ambulatory care – settings traditionally beyond the reach of static US technology. For example, in rehabilitation centers or long-term care facilities, such wearable devices may enable patients to be monitored non-invasively, reducing reliance on intermittent catheterization or repeated UD sessions.

Moreover, the integration of AI into 3D imaging workflows has expanded its diagnostic value. Chowdhury *et al.* (2024) reported that machine learning models trained on 3D US data enhanced diagnostic accuracy in pediatric urology, improving detection and classification of bladder dysfunction.^[7] The richer spatial information offered by 3D datasets – such as surface curvature, wall irregularity, and volumetric deformation – enables a level of analysis not possible with 2D inputs. As these systems continue to evolve, 3D US is expected to transition from a diagnostic modality to an intelligent, patient-driven monitoring platform – blurring the line between imaging, intervention, and personalized care. Its compatibility with automation, mobile applications, and AI integration positions it at the forefront of next-generation bladder diagnostics. In addition to the core comparative studies analyzed earlier, several supporting articles offer valuable context on 3D US innovation, shape repeatability, bladder compliance, and AI-driven segmentation.

Several studies reported different applications for US modalities. McCormack *et al.* (2024) provided a comprehensive review of US imaging modalities for efficient diagnosis of bladder functionality.^[2] For comparing 3D versus 2D US modalities, Alfuraih *et al.* (2025) evaluated the accuracy and reproducibility of 3D US device and conventional 2D.^[11,12] While Maddra *et al.* (2022) and Hirahara *et al.* (2006) investigated the use of US modalities for bladder shape analysis.^[13,14] Other bladder properties have been studied using 3D US imaging, such as detrusor compliance^[15] (Nenadic *et al.*, 2016) and bladder weight (Han *et al.*, 2011).^[16] Dietz (2004) used 3D US imaging for investigating the pelvic floor, supporting the use of 3D imaging in urogynecology and pelvic diagnostics.^[17] These studies, while not all providing direct 2D versus 3D comparisons, help frame the broader clinical and technological relevance

Table 2: Supportive literature related to bladder volume estimation and urodynamic imaging

| Serial number | Study | Focus | Population | Main contribution | Comparison | Application to UD | Notes |
|---------------|--------------------------------|------------------------------------|---|---|--|-------------------|---|
| 1 | McCormack <i>et al.</i> (2024) | Ultrasound modalities review | General (clinical and laboratory) | Reviewed real-time 3D US techniques for bladder diagnostics | No head-to-head data | High | Useful for understanding the technological landscape of ultrasound UD |
| 2 | Maddra <i>et al.</i> (2022) | Bladder shape metric repeatability | Healthy volunteers | Studied shape repeatability metrics in 3D bladder ultrasound | No 2D versus 3D accuracy data | Moderate | Shape data supports 3D modeling improvements |
| 3 | Hirahara <i>et al.</i> (2006) | 4D bladder shape analysis | 15 healthy male +5 male patients with urinary disturbance | Evaluated dynamic bladder shape using 4D US | No volume accuracy analysis | Low to Moderate | Useful for future dynamic shape modeling |
| 4 | Alfuraih <i>et al.</i> (2025) | Comparing ultrasound modalities | 53 healthy male volunteers | Evaluated accuracy and reproducibility of handheld 3D US versus Conventional 2D for volume estimation | 3D method demonstrated higher accuracy for volume estimation compared to 2D. | Emerging | The 3D device often faced technical issues in large bladder volumes |
| 5 | Nenadic <i>et al.</i> (2016) | Ultrasound Vibrometry | Porcine bladders+UD patients | Evaluated mechanical properties noninvasively during filling | Focused on wall compliance, not volume | High | Supports dynamic modeling during urodynamic cycles |
| 6 | Dietz (2004) | 3D/4D pelvic floor ultrasound | Female pelvic floor patients | Promoted 3D/4D imaging in urogynecology | Not specific to bladder volume | Supportive | Historical reference for 3D imaging in pelvic diagnostics |
| 7 | Han <i>et al.</i> (2011) | Bladder weight with 3D US | Male LUTS patients | Estimated bladder weight with 3D and correlated with BSA | No volume data | Moderate | Supports the utility of 3D in urological imaging |

AI: Artificial intelligence, DWT: Detrusor wall thickness

of 3D imaging in UDs. A summary of their contributions and applicability is presented in Table 2.

LIMITATION

There are several limitations in this review that should be acknowledged. First, the number of studies directly comparing 2D and 3D US techniques in the context of UD assessments remains limited. Although both modalities have been extensively studied for general bladder volume estimation, few publications have offered direct, head-to-head comparisons within UD testing environments. As a result, this review incorporated a broader scope of studies that used surrogate reference methods such as catheterization

or post-void residual estimation. Second, the inclusion of studies published between 1998 and 2024 introduced a wide temporal range, which may have influenced consistency in technological comparisons. Advancements in transducer technology, segmentation algorithms, and imaging software have progressed significantly during this period. One study from 1998 was included for its early recognition of bladder shape variability, though its methodological limitations were acknowledged and findings interpreted with caution. Third, there was considerable methodological heterogeneity across the included studies. Differences in patient populations, bladder filling protocols, probe types, scanning planes, and volume calculation formulas posed challenges to direct comparison. In some cases, critical parameters such as bladder wall thickness or detrusor compliance were reported inconsistently or not at

all, limiting the ability to draw statistically uniform conclusions. Finally, this review did not include gray literature, unpublished clinical trials, or non-English language studies, which may have excluded additional relevant findings, particularly from emerging clinical centers where portable US applications are rapidly developing. Despite these limitations, this review offers a focused synthesis of the current evidence base and outlines the clinical promise of 3D US in bladder volume assessment.

FUTURE DIRECTIONS

Future directions for 2D and 3D US technologies for bladder volume measurement involve the implementation of AI and machine learning, as well as the development of fully automated and wearable devices. AI and computational technologies are being extensively used in various imaging techniques and across several disciplines, which help operators in decision-making and diagnosis improvement (Sabri *et al.*, 2025). As previously discussed in the advantages of 3D US modalities, Chowdhury *et al.* (2024) demonstrated the efficiency of AI-enhanced bladder imaging and machine learning models trained on 3D US data for the detection and classification of bladder dysfunction. Moreover, developing fully automated and wearable devices will provide a non-invasive alternative to bladder volume measurement that does not rely on the traditional catheter-based approach (Jo *et al.*, 2021).

CONCLUSION

This review highlights the growing clinical and technological significance of US imaging for non-invasive bladder volume assessment, particularly in the context of UD evaluation. While 2D US remains a widely used and accessible modality, its reliance on geometric assumptions and operator technique presents limitations in precision and reproducibility. In contrast, 3D US offers enhanced spatial accuracy, supports automation, and integrates seamlessly with emerging technologies such as wearable devices and AI. These advantages position 3D US as a compelling alternative to traditional catheter-based measurements and static imaging methods. However, the current literature lacks sufficient head-to-head studies comparing 2D and 3D performance within standardized UD protocols, and methodological variability across existing research poses challenges to direct comparison. Future studies should aim to standardize imaging protocols, validate emerging technologies across diverse patient populations, and further explore real-time and ambulatory applications of 3D US. To establish 3D US as a primary diagnostic tool in UDs, future research must validate its performance through large-scale trials and standardized, real-world applications. With continued refinement and clinical integration, 3D US has the potential to reshape bladder monitoring and offer a non-invasive, patient-centered approach to functional urological assessment.

REFERENCES

1. Nenadic I, Mynderse L, Husmann D, Mehrmohammadi M, Bayat M, Singh A, *et al.* Noninvasive evaluation of bladder wall mechanical properties as a function of filling volume: Potential application in bladder compliance assessment. *PLoS One* 2016;11:e0157818.
2. McCormack B, Hampton HL, Speich JE, Radley SC, Burkett LS, Klausner AP. Ultrasound urodynamics: A review of ultrasound imaging techniques for enhanced bladder functional diagnostics. *Curr Bladder Dysfunct Rep* 2024;19:263-71.
3. Chang ML, Li HC, Liu CK, Chiang HS, Hsu CC. Novel three-dimensional bladder reconstruction model from b-mode ultrasound image to improve the accuracy of bladder volume measurement. *Sensors (Basel)* 2021;21:4893.
4. Akkus Z, Kim BH, Nayak R, Gregory A, Alizad A, Fatemi M. Fully automated segmentation of bladder sac and measurement of detrusor wall thickness from transabdominal ultrasound images. *Sensors (Basel)* 2020;20:4175.
5. Nusee Z, Ibrahim N, Rus RM, Ismail H. Is portable three-dimensional ultrasound a valid technique for measurement of postpartum urinary bladder volume? *Taiwan J Obstet Gynecol* 2014;53:12-6.
6. Jo HG, Park BH, Joung DY, Jo JK, Hoh JK, Choi WY, *et al.* Forward-looking ultrasound wearable scanner system for estimation of urinary bladder volume. *Sensors (Basel)* 2021;21:5445.
7. Chowdhury AT, Salam A, Naznine M, Abdalla D, Erdman L, Chowdhury ME, *et al.* Artificial intelligence tools in pediatric urology: A comprehensive review of recent advances. *Diagnostics (Basel)* 2024;14:2059.
8. Nagle AS, Bernardo RJ, Varghese J, Carucci LR, Klausner AP, Speich JE. Comparison of 2D and 3D ultrasound methods to measure serial bladder volumes during filling: Steps toward development of non-invasive ultrasound urodynamics. *Bladder (San Franc)* 2018;5:e32.
9. Bernardo RJ, Nagle AS, Klausner AP, Speich JE. AB316. SPR-43 comparison of bladder volumes between 2D and 3D ultrasound calculations and urodynamic measurements in women with overactive bladder (OAB). *Transl Androl Urol* 2016;5:AB316.
10. Vinod NN, Nagle AS, Naimi HA, Kolli H, Sheen D, Nandan N, *et al.* Bladder volume correction factors measured with 3D ultrasound and BladderScan. *Can J Urol* 2019;26:9829-34.
11. Alfuraih AM, Alkuwileet SK, Alhoysin AK, Alhawwashi AS, Aldakan AI, Alotaibi FK, *et al.* Accuracy and reproducibility of handheld 3D ultrasound versus conventional 2D ultrasound for urinary bladder volume measurement: A prospective comparative study *Diagnostics (Basel)* 2025;15:2229.
12. Liang CC, Wei TY, Chang SD, Hsieh CC. Bladder volume determination: Two-dimensional versus

- three-dimensional transvaginal ultrasound. Taiwan J Obstet Gynecol 2009;48:258-61.
13. Maddra KM, Li R, Nagle AS, Klausner AP, Speich JE. Repeatability of ultrasound-defined bladder shape metrics in healthy volunteers. Res Rep Urol 2022;14:185-92.
 14. Hirahara N, Ukimura O, Ushijima S, Yamada Y, Okihara K, Kawauchi A, *et al.* Four-dimensional ultrasonography for dynamic bladder shape visualization and analysis during voiding. J Ultrasound Med 2006;25:307-13.
 15. Nenadic I, Mynderse L, Husmann D, Mehrmohammadi M, Bayat M, Singh A, *et al.* Noninvasive evaluation of bladder wall mechanical properties as a function of filling volume: Potential application in bladder compliance assessment. PLoS One 2016;11:e0157818.
 16. Han DH, Lee HW, Sung HH, Lee HN, Lee YS, Lee KS. The diagnostic efficacy of 3-dimensional ultrasound estimated bladder weight corrected for body surface area as an alternative nonurodynamic parameter of bladder outlet obstruction. J Urol 2011;185:964-9.
 17. Dietz HP. Ultrasound imaging of the pelvic floor. Part II: Three-dimensional or volume imaging. Ultrasound Obstet Gynecol 2004;23:615-25.

Source of Support: Nil. **Conflicts of Interest:** None declared.