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Application of Intracavitary Three-Dimensional Ultrasound Volume Contrast Imaging Combined with Free Anatomy Section in the Diagnosis of Intrauterine Adhesions and Classification

Jingping Wang, Jing Song, Hui Zhang, Li Liu, Jun Wang

Department of Ultrasound, Suzhou New District People's Hospital, Suzhou 215129, Jiangsu, China

Abstract: Objective: To study the clinical value of three-dimensional ultrasound volume contrast imaging combined with free anatomy section in the diagnosis of intrauterine adhesions. Methods: 321 patients with suspected intrauterine adhesions admitted to Suzhou High-tech Zone People's Hospital from July 2024 to July 2025 were selected. 94 cases were confirmed by hysteroscopy gold standard. All patients underwent separate examination of three-dimensional ultrasound volume contrast imaging (single examination) and a combined diagnosis scheme with free anatomy section (hereinafter referred to as combined diagnosis). The detection situation was analyzed, the diagnostic efficacy was calculated, and the results were compared with the gold standard to evaluate the advantages of combined diagnosis in disease classification. Results: The sensitivity and accuracy of the combined diagnosis were better than those of the single examination ($P < 0.05$). However, there was no significant difference in the detection rate of disease types between the two schemes ($P > 0.05$). Conclusion: The combination of three-dimensional ultrasound volume contrast imaging and free anatomy section can play a significant role in the diagnosis and classification of intrauterine adhesions, greatly improving the clinical detection rate.

Keywords: Intrauterine adhesion; Three-dimensional ultrasound volume imaging; Free anatomy section

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1. Introduction

Intrauterine adhesion, also known as Asherman's syndrome, refers to the formation of fibrous adhesions in the uterine cavity after damage to the endometrial basal layer, which may lead to partial or complete obstruction of the uterine cavity [1]. The occurrence of this condition can have significant negative impacts on women, such as menstrual abnormalities. Adhesion tissue covers the endometrium, preventing it from proliferating and shedding normally, leading to reduced menstrual flow or amenorrhea. It can even cause infertility, as adhesions reduce the normal endometrial area and affect the implantation of the fertilized egg. Severe adhesions may block the cervical canal or uterine cavity, preventing sperm from entering the fallopian tubes [2]. The main treatment at this stage is hysteroscopic separation, combined with postoperative estrogen therapy or placement of a balloon stent to prevent re-adhesion [3]. However, studies have found that most patients are already in moderate to severe stages when seeking medical attention due to the absence of typical symptoms in the early stages of the disease. Therefore, early diagnosis through ultrasound, hysteroscopy, and intervention can significantly improve prognosis, especially for women with fertility needs [4]. Volume contrast imaging and free anatomical sectioning in three-dimensional ultrasound are two different three-dimensional image processing techniques [5]. Next, this article will explore the combined application value of these two methods in the diagnosis of patients with intrauterine adhesions. The full report is summarized below.

2. Materials and methods

2.1. General information

The hospital examined the study cases from July 2024 to July 2025. A total of 321 suspected intrauterine adhesion patients were admitted to the hospital, with the oldest being 44 years old and the youngest being 21 years old. The average age range was (33.25 ± 3.21) years old. Through hysteroscopic diagnosis, 94 cases were confirmed as intrauterine adhesions, including 26 peripheral type, 32 central type, and 36 mixed type. All patients could provide complete clinical data, voluntarily participated in the study, and signed relevant informed consent documents. Additionally, as the three-dimensional volume probe needs to be placed into the vagina for inspection, it is prohibited for virgins, should be used with caution during menstruation, after abortion surgery, and in cases of acute vaginitis or pelvic inflammatory disease. It is not suitable for patients with vaginal deformities, and pregnant or breastfeeding female patients are not accepted. Since the control method adopted in this study involves the same group of patients undergoing different examination schemes, the above data meet clinical consistency and can be used for data research and analysis.

2.2. Methods

2.2.1. Two-dimensional ultrasonography

The Samsung WS80A color Doppler ultrasound diagnostic instrument was used. The examination was performed during the mid-to-late menstrual cycle when the pre-menstrual endometrium was thicker. For those with amenorrhea, the examination was conducted before hysteroscopy. Patients were examined without the need to hold urine, in a supine lithotomy position. The ultrasound probe frequency was adjusted, disinfected, and coated with a coupling agent. A condom was worn, and the probe was slowly inserted into the patient's vagina (posterior fornix). During the examination, the probe could be rotated to explore the specific state of the pelvic cavity from multiple angles, focusing on observing the position, size, endometrial continuity, and morphology of the uterus. The echo intensity of the endometrium, presence of three-line signs, continuity of uterine cavity echoes, and clarity of the endometrial-myometrial junction were evaluated. Specific parameters of endometrial thickness (ED for short) were also obtained.

2.2.2. Three-dimensional ultrasound volume contrast imaging combined with free anatomic cuts

Based on the premise of the clearest two-dimensional ultrasound endometrial images of the patient, fix the probe, reconstruct the three-dimensional program, sample, acquire data, instruct the patient to hold their breath, collect at least 3 times, and select the best one; distinguish between single and combined inspections from the next processing method. Single inspection obtains planar images of A, B, and C, adjusts the X, Y, and Z axes to obtain the best three-dimensional image, and uses 3D contrast volume imaging to evaluate the specific condition of the endometrium. The combined inspection sets ROI, with plane A as the main reference plane, and sets the

Polyline program in the automatic anatomical section system, so that it can automatically reach the uterine bottom serosa layer from the outer opening of the cervix, and draw a reconstructed line segment along the curvature of the uterine cavity, thereby presenting a coronal image of the uterine cavity. At the same time, 3D volume imaging is used to evaluate parameters such as the coronal plane of the endometrium, endometrium, echo intensity, and defects. Sampling is done on plane A, adjusting the X, Y, and Z axes so that the coronal plane of the uterine cavity and the lesion site can be displayed completely and clearly.

2.3. Criteria for diagnosis

Hysteroscopy is considered the gold standard for diagnosing intrauterine adhesions. Direct observation reveals partial or complete adhesions in the uterine cavity, fibrotic and pale endometrium, and membranous, fibrous cord-like, or muscular adhesions, which are indicative of intrauterine adhesions (positive). Diagnostic efficacy is calculated using the following formulas: Sensitivity = True Positive / (True Positive + False Negative) × 100%, Specificity = True Negative / (True Negative + False Positive) × 100%, and Accuracy = (True Positive + True Negative) / Total Number of Cases × 100%. Additionally, detected intrauterine adhesions are classified into peripheral, central, and mixed types.

2.4. Statistical methods

Data were processed using SPSS 23.0 statistical software. Measurement data were expressed as mean ± standard deviation (SD), and the *t*-value was used for numerical testing. Count indicators (%) were tested using the chi-square value, with $P < 0.05$ considered statistically significant.

3. Results

3.1. Analysis of detection results

As shown in **Table 1**, the combined diagnosis identified 92 positive cases and 224 negative cases. In contrast, 3D ultrasound volume imaging alone detected 85 positive cases and 221 negative cases, indicating that the combined approach provided more accurate detection.

Table 1. Disease detection using different diagnostic methods

Test method		Gold Standard		Total
		Positive	Negative	
Combined diagnosis	Positive	92	3	95
	Negative	2	224	226
Single test	Positive	85	6	91
	Negative	9	221	230
Total	94	227	321	

3.2. Evaluation of diagnostic efficiency

As shown in **Table 2**, the sensitivity and accuracy of the combined diagnosis are relatively high. Compared with the separate application of three-dimensional ultrasound volume imaging, the difference is statistically significant ($P < 0.05$); however, there is no significant difference in specificity ($P > 0.05$).

Table 2. Comparison of diagnostic efficiency of different examination methods [n(%)]

Method	Sensitivity	Specificity	Accuracy
Combined diagnosis	97.87 (92/94)	98.68 (224/227)	98.44 (316/321)
Single test	90.43 (85/94)	97.36 (221/227)	95.33 (306/321)
χ^2	4.7314	1.0202	5.1608
P-value	0.0296	0.3124	0.0231

3.3. Detection and analysis of disease classification

As shown in **Table 3**, the detection rates of the two imaging methods for intrauterine adhesion classification are similar, with no significant difference ($P > 0.05$). Different types of imaging pictures are also provided, as shown in **Figure 1** and **Figure 2** for the central type; **Figure 3** and **Figure 4** for the peripheral type.

Table 3. Comparison of disease classification detection rates between the two examination schemes [n(%)]

Method	Total cases	Peripheral type (n = 26)	Central type (n = 32)	Mixed type (n = 36)
Combined diagnosis	92	26 (100.00%)	31 (96.88%)	35 (97.22%)
Single test	85	24 (92.31%)	28 (87.50%)	33 (91.67%)
χ^2 value	-	2.0800	1.9525	1.0588
P-value	-	0.1492	0.1623	0.3034

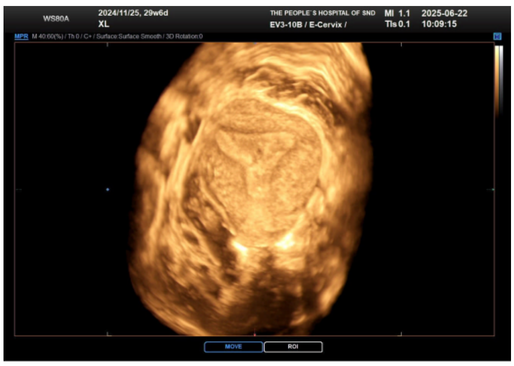

Figure 1. Volume contrast imaging of central intrauterine adhesions (Asherman's syndrome).

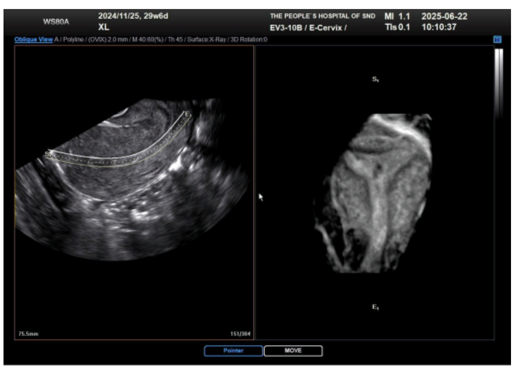

Figure 2. Freehand section of intrauterine adhesions (central type)

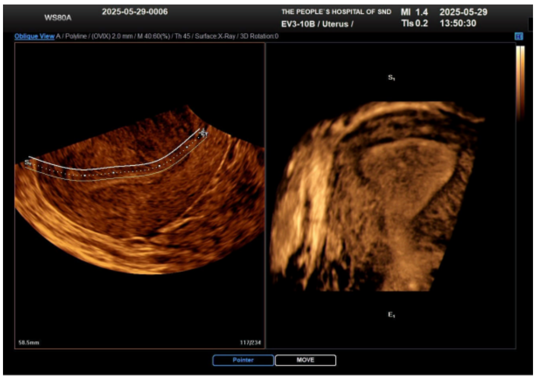

Figure 3. Freehand dissection section showing marginal intrauterine adhesions (IUA).

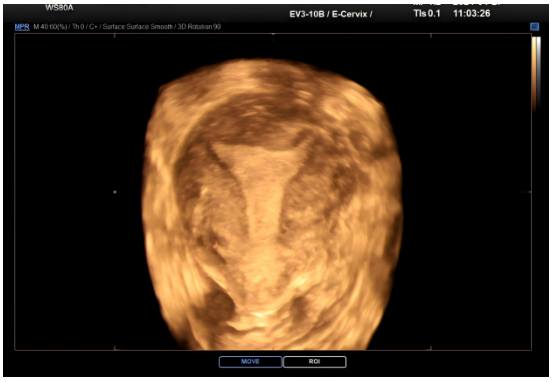

Figure 4. Volume Contrast Imaging (VCI) of Marginal Intrauterine Adhesions (IUA).

4. Discussion

The occurrence of intrauterine adhesions is often associated with damage to the basal layer of the endometrium. The most common causes include uterine cavity surgical procedures, such as induced abortion or uterine curettage. Repeated curettage or improper operation may damage the basal layer of the endometrium. Other causes include improper management of postpartum placental residues [6]. On the other hand, endometritis caused by various pathogens, including tuberculous endometritis, which is a typical infectious factor, and failure to timely administer anti-infective treatment after uterine cavity surgery, can also lead to intrauterine adhesions. Simply put, when the basal layer of the endometrium is damaged, excessive fibrous tissue proliferation occurs during wound healing, forming adhesive bands. In severe cases, it may lead to partial or complete closure of the uterine cavity [7]. In the early stage of intrauterine adhesions, they are mostly composed of loose fibrous tissue, which can be reversed through timely intervention. However, if left untreated, they may develop into dense scar tissue or even completely block the uterine cavity, resulting in permanent infertility or significantly increased treatment difficulty [8]. Therefore, early detection and prompt treatment are crucial to prevent serious consequences. To ensure the effectiveness of patient treatment, accurate diagnostic plans are essential. For those with a history of abortion, curettage, uterine cavity infection, or tuberculosis, immediate investigation should be conducted if menstrual flow decreases or amenorrhea occurs [9]. Currently, hysteroscopy is the gold standard clinical examination method, which can directly evaluate the scope and type of adhesions. However, hysteroscopy is an invasive procedure that requires inserting a scope through the vagina and cervix into the uterine cavity. This process may cause discomfort such as pain and a feeling of heaviness, especially for women with tight cervical openings or high pain sensitivity. Even with preoperative measures such as cervical softening drugs, some women may still experience significant discomfort, and some patients may require anesthesia due to intolerance, which involves additional risk assessment related to anesthesia [10]. Although it is generally a safe examination method, there are still risks such as uterine perforation, bleeding, and infection. Although the incidence is relatively low, these situations can bring unnecessary physical harm and a subsequent treatment burden to patients. Therefore, the clinical field is constantly exploring more effective and relatively “gold standard” examination methods or protocols [11].

3D ultrasound volume contrast imaging is an imaging technique that enhances tissue contrast and resolution through 3D volume data reconstruction [12]. By scanning the same area from multiple angles and stacking data, it reduces noise and highlights the boundaries of structures of interest. It can display tiny structures that are difficult to capture with traditional 2D ultrasound, resulting in clearer images with stronger layering, reduced operator dependence, and more stable imaging [13]. Free anatomical sectioning allows the operator to arbitrarily select the cutting plane in the 3D volume data, generating non-standard sections that cannot be directly obtained by traditional ultrasound. For example, when examining a fetus with an abnormal disease, the coronal or oblique section of the spine can be observed by adjusting the section [14]. Based on 3D data, manual or automatic definition of arbitrary planes for reconstruction breaks through the limitations of traditional ultrasound probe angles, providing multi-perspective analysis and increasing diagnostic flexibility, especially suitable for difficult cases. In recent years, there have been continuous studies combining the two techniques. Firstly, high-contrast data is obtained through 3D ultrasound volume contrast imaging, and then free anatomical sectioning is used to analyze the morphological structure of the uterine cavity from any angle, thereby improving diagnostic efficiency [15].

As seen in the results section of this study, the sensitivity and accuracy of the combined diagnosis were significantly higher than those of the single examination ($P < 0.05$); however, there was no difference in specificity between the two methods ($P > 0.05$). Fundamentally, 3D ultrasound volumetric imaging technology reduces noise and enhances the contrast of tissue boundaries through multi-plane reconstruction and volumetric data stacking, especially when diagnosing low-contrast structures. When combined with free anatomical sections, it allows arbitrary cutting of 3D data to obtain non-standard sections that are difficult to achieve with traditional 2D ultrasound, resulting in clearer and more three-dimensional anatomical details. In terms of specific intrauterine adhesion subtypes, both examination methods demonstrated considerable detection advantages, and there was no significant difference in actual data between the two methods ($P > 0.05$). Upon analysis, 3D reconstruction can present the three-dimensional shape of the uterine cavity, visually displaying the location, scope, and relationship with surrounding structures of adhesions, which is crucial for classification. When the two methods are combined, 3D imaging provides a global view and clarifies the overall classification of adhesions, while free anatomical sections focus on local details to determine specific subtypes.

5. Conclusion

In summary, the combined application of free anatomical sections and 3D ultrasound volumetric contrast imaging achieves a multi-angle, high-resolution three-dimensional representation of intrauterine adhesion structures. This combination not only overcomes the dependence on traditional probe angles but also ensures image clarity under arbitrary sections, providing an ultrasonic basis for accurate identification and detailed classification of intrauterine adhesions. Its high flexibility and diagnostic efficiency make it have prominent application value and promotion prospects in the clinical diagnosis and subtype evaluation of intrauterine adhesions.

Disclosure statement

The authors declare no conflict of interest.

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