DOI: https://doi.org/10.17816/DD629721

Ultrasound in *in vitro* fertilization programs

Evgeniya V. Kirakosyan

City Clinical Hospital № 31, Moscow, Russia

ABSTRACT

Currently, increasing attention is being paid to the value of ultrasound as an integral part of *in vitro* fertilization programs, which determines the relevance of the topic of this review. This review analyzes the main studies published in recent years and attempts to identify the leading method for assessing ovarian reserve and predicting in vitro fertilization outcome, which remains controversial. The paper evaluates advantages and limitations of two-dimensional and three-dimensional transvaginal ultrasound methods for counting ovarian follicles. Ultrasound characteristics of the endometrium and blood flow parameters in the uterine arteries are presented as possible predictors of the outcome of in vitro fertilization programs. The current options for transabdominal oocyte aspiration for in vitro fertilization programs are presented. The analysis of literature data concluded the high informational value of ultrasound for in vitro fertilization programs.

Keywords: ovarian reserve; number of ovarian follicles; transvaginal ultrasound; in vitro fertilization; assisted reproductive technologies.

To cite this article:
Kirakosyan EV. Ultrasound in *in vitro* fertilization programs. *Digital Diagnostics.* 2024;5(4):870–881. DOI: https://doi.org/10.17816/DD629721

Received: 31.03.2024 **Accepted:** 04.07.2024 **Published online:** 05.11.2024

DOI: https://doi.org/10.17816/DD629721

Ультразвуковое исследование в программах экстракорпорального оплодотворения

Е.В. Киракосян

Городская клиническая больница № 31 имени академика Г.М. Савельевой, Москва, Россия

АННОТАЦИЯ

В настоящее время всё больше внимания уделяют ценности ультразвукового исследования как неотъемлемой части программ экстракорпорального оплодотворения, чем обусловлена актуальность темы данного обзора. В представленном обзоре научной литературы, основанном на самых значимых исследованиях последних лет, сделана попытка ответить на дискуссионный вопрос о выборе ведущего метода оценки овариального резерва и прогнозирования результатов программ экстракорпорального оплодотворения. В работе проведён анализ преимуществ и недостатков методов двухмерного и трёхмерного трансвагинального ультразвукового исследования при подсчёте количества фолликулов яичников. Приведены ультразвуковые характеристики эндометрия и показатели кровотока в маточных артериях, являющиеся возможными предикторами результатов программ экстракорпорального оплодотворения. Представлены современные возможности трансабдоминальной аспирации ооцитов в программах экстракорпорального оплодотворения. В результате анализа данных литературы сделан вывод о высокой информативности ультразвукового исследования в программах экстракорпорального оплодотворения.

Ключевые слова: овариальный резерв; количество фолликулов яичников; трансвагинальное ультразвуковое исследование; экстракорпоральное оплодотворение; вспомогательные репродуктивные технологии.

Как цитировать:
Киракосян Е.В. Ультразвуковое исследование в программах экстракорпорального оплодотворения // Digital Diagnostics. 2024. Т. 5, № 4. С. 870–881. DOI: https://doi.org/10.17816/DD629721

Рукопись получена: 31.03.2024 **Рукопись одобрена:** 04.07.2024 **Опубликована online:** 05.11.2024

DOI: https://doi.org/10.17816/DD629721

体外受精项目中的超声检查

Evgeniya V. Kirakosyan

City Clinical Hospital № 31, Moscow, Russia

摘要

目前，超声检查作为体外受精项目不可分割的部分，其价值越来越受到人们的关注，这正是本综述主题的现实意义。在这篇科学文献综述中，以近年来最重要的研究为基础，试图回答一个有争议的问题，那就是如何选择主要的方法来评估卵巢储备和预测体外受精计划的结果。本文对二维和三维经阴道超声检查在计算卵泡数量时的优缺点进行了分析。列出了子宫内膜的超声特征和子宫动脉血流指标，它们是体外受精计划结果的可能预测因素。介绍了在体外受精项目中经腹卵母细胞抽吸的现代可能性。通过对文献数据的分析，可以做出如下结论，超声在体外受精项目中可提供的信息量巨大。

关键词：卵巢储备；卵泡数量；经阴道超声波检查；体外受精；辅助生殖技术。

引用本文:
Kirakosyan EV. 体外受精项目中的超声检查. *Digital Diagnostics.* 2024;5(4):870–881. DOI: https://doi.org/10.17816/DD629721

收到: 31.03.2024 **接受:** 04.07.2024 **发布日期:** 05.11.2024

OVARIAN RESERVE MARKER: ANTRAL FOLLICLE COUNT OR ANTI-MÜLLERIAN HORMONE LEVEL?

In vitro fertilization (IVF) programs rely on assessing ovarian reserve, tailoring ovarian stimulation protocols, and predicting the ovarian response. These steps are crucial for obtaining mature oocytes, ensuring effective aspiration, generating high-quality embryos, and ultimately improving clinical pregnancy rates [1]. The follicular apparatus—comprising follicles at various stages of development within the ovarian cortex—serves as an ultrasound (US)-based indicator of ovarian reserve [2]. In 2018, an international consensus endorsed the use of the antral follicle count (AFC) via transvaginal US for this purpose [3]. The examination is conducted with the patient in the lithotomy position and the bladder emptied. The ovaries are evaluated using the following protocol:

- Each ovary is scanned in both longitudinal and coronal views to identify the best imaging plane.
- The ovary is positioned to fill at least 50% of the US screen along its longest axis.
- US settings are adjusted to maximize contrast between the follicular fluid and ovarian stroma.
- Measurements are taken along the inner diameter of all non-echogenic follicular areas, spanning from the upper to the lower pole of the ovary. For round follicles, the diameter is measured directly; for oval follicles, both the long and short axes are measured, and the mean is calculated.
- Only follicles measuring 2–10 mm in diameter are counted; those smaller than 2 mm or larger than 10 mm are excluded.
- The presence or absence of a dominant follicle, ovarian cysts, or tumors is noted.
- If uncertainty arises, the scan is repeated from an alternative imaging plane.
- The total follicle count from both ovaries is recorded [3].

Discrepancies between AFC and blood anti-Müllerian hormone (AMH) levels are frequently encountered in clinical settings. In 2019, the Peking University Clinic conducted a study involving 1,121 women with infertility who underwent IVF. AFC and AMH levels were assessed on Days 2–3 of the menstrual cycle. Transvaginal US was performed using the Aloka™ SSD-1000 scanner (Hitachi Aloka Medical, Japan) equipped with a 5 MHz vaginal probe. Based on the results, patients were categorized into four groups: group A (n = 611) included those with both normal AFC (⩾7) and AMH (⩾1.1 ng/mL); group B (n = 85) had normal AFC (⩾7) but low AMH (<1.1 ng/mL); group C (n = 118) had low AFC (<7) with normal AMH (⩾1.1 ng/mL); and group D (n = 307) had both low AFC (<7) and low AMH (<1.1 ng/mL). A total of 203 patients (18.11%, Groups B and C) exhibited discordance between AFC and AMH values. Among these, patients in group B had significantly higher numbers of aspirated oocytes and high-grade embryos, along with a higher clinical pregnancy rate, and a lower incidence of poor ovarian response compared to group C [4]. The study revealed that approximately one in five patients undergoing IVF showed discrepancies between AFC and AMH levels in routine clinical practice. AFC was identified as the more reliable marker for assessing ovarian reserve and predicting ovarian response and IVF outcomes.

A multicenter retrospective study was conducted using data from 5 reproductive medicine centers in China, comprising 89,002 patients and 327,059 IVF cycles, to compare the diagnostic value of various ovarian reserve markers. The markers assessed included AFC, AMH level, follicle-stimulating hormone (FSH) level, and patient age. Both AMH and AFC individually demonstrated high diagnostic performance, with AUC[1] values of 0.862 and 0.842, respectively. However, the highest diagnostic accuracy was achieved when combining AMH level, AFC, FSH level, and age (AUC 0.873). The authors noted that AMH levels can be reliably evaluated using an automated electrochemiluminescence assay. They also recommended assessing AFC in conjunction with patient age (AUC 0.846) [5].

Another study analyzed data from 15,283 patients and 25,854 ovarian stimulation cycles conducted across 12 assisted reproductive technology (ART) centers in France. Among 25-year-old patients, the mean AFC was 16.3 (95% CI[2], 14.5–18.4), showing a linear decline of 3.9% per year ($p < 0.001$). The mean AMH level was 3.9 ng/mL (95% CI, 3.6–4.2 ng/mL), decreasing by 5% annually. The study found only a weak correlation between AMH levels and AFC, with half of the patients who had low AMH levels still exhibiting normal AFC values. According to the authors, two main factors limit the reliability of AMH level assessment: the absence of international standardization in automated laboratory methods—which tend to report AMH values 16%–20% lower than manual methods—and the high cost of testing. In France, AMH is typically measured once per year, whereas transvaginal US with AFC evaluation is routinely included in all ART protocols [6].

A 2023 systematic review and meta-analysis of 42 studies involving 7,190 patients demonstrated that both AFC and AMH levels are strong predictors of ovarian response, whether favorable or poor. The review concluded that AFC is slightly more accurate than AMH in identifying poor ovarian response [7].

Currently, there is no consensus on whether AFC or AMH should be the primary marker for guiding ovarian

[1] AUC ROC, area under the ROC curve (the sensitivity and specificity parameter characterizing the validity of diagnostic tests).

[2] Confidence interval.

DOI: https://doi.org/10.17816/DD629721

stimulation. However, most researchers agree that AFC is at least as diagnostically valuable as AMH, and in some cases preferable due to its greater technical accessibility and lower cost.

DOES THE NUMBER OF FOLLICLES VARY BY MENSTRUAL CYCLE DAY?

Ovarian reserve depends on the number of primordial follicles present in the ovaries. As there are currently no methods to directly measure the number of primordial follicles, ovarian reserve is assessed indirectly using patient age, AFC, and serum AMH levels. AMH levels can be measured on any day of the menstrual cycle [8]. Over the past decade, it has been recommended to perform AFC assessment during the early follicular phase of the cycle, likely to standardize evaluation. However, this timing for transvaginal US is often inconvenient for both patients and clinicians [9].

A study published in 2022 included 410 patients aged 20–42 years with regular menstrual cycles who underwent a single IVF cycle. AFC was measured twice using transvaginal US with the Voluson™ S8, E8, or E10 systems (GE Healthcare, USA), equipped with a high-frequency 3D vaginal probe (>7 MHz). Follicles measuring 2–10 mm in diameter were counted in each ovary, and the total AFC was calculated as the sum. The first AFC measurement was taken during the initial consultation on a random day of the menstrual cycle: 150 patients (36.8%) in the early follicular phase (Days 1–6), 177 patients (43.2%) in the midfollicular phase (Days 7–12), and 83 patients (20%) in the luteal phase (Day 13 or later). The second AFC was measured on the day ovarian stimulation began. AMH levels were measured during the early follicular phase. A positive correlation was found between the random-day AFC and AMH levels ($r = 0.69$, $p < 0.001$), the AFC on the day of stimulation ($r = 0.75$, $p < 0.001$), and the number of aspirated oocytes ($r = 0.49$, $p < 0.001$) [9]. These findings indicate AFC has strong diagnostic value for assessing ovarian reserve and is a reliable predictor of ovarian response, regardless of the menstrual cycle day.

A retrospective study involving 3,117 women with infertility demonstrated that AFC is a reliable predictor of poor ovarian response (defined as fewer than four aspirated oocytes), regardless of the menstrual cycle day [10]. In a separate analysis of 72 women with malignant neoplasms who underwent IVF for fertility preservation, AFC measured on any day of the cycle was found to be a strong predictor of the number of mature oocytes retrieved [11]. Importantly, the ability to assess AFC on any day of the menstrual cycle avoids scheduling difficulties during menstruation for both patients and physicians and reduces the need for repeat examinations, thereby lowering the logistical burden. Performing transvaginal US with AFC assessment during the midfollicular or late follicular phase also offers reliable information on ovarian reserve and allows simultaneous assessment of ovarian and uterine anatomy [9].

COUNTING OVARIAN FOLLICLES AND PREDICTING THE NUMBER OF MATURE OOCYTES: 2D OR 3D TRANSVAGINAL ULTRASOUND EXAMINATION?

Recent improvements in US technology have significantly enhanced image resolution and quality. In ART programs, high-frequency vaginal probes have replaced abdominal transducers, leading to better visualization of the uterus and ovaries. 2D transvaginal US is a well-established diagnostic method in reproductive medicine. 3D transvaginal US is a newer technique, and ongoing research is evaluating its potential benefits and limitations. The quality of ovarian imaging by transvaginal US largely depends on the US system used. In 2D US, the accuracy of follicle identification and measurement depends heavily on the operator's experience. In contrast, 3D US requires only one high-quality image per ovary to automatically calculate ovarian volume, follicle diameter, and AFC [12, 13]. The oblique coronal plane view available in 3D US allows for more precise volume measurement, improving the consistency and reliability of the results—particularly important when evaluating irregularly shaped structures like follicles during ovarian stimulation [14]. The ability to store and later review data, including images in any plane, helps reduce diagnostic uncertainty during treatment planning. A prospective study involving 89 women undergoing IVF found no significant differences in the number or size of follicles when comparing manual assessment to 3D transvaginal US. However, 3D transvaginal US significantly reduced total examination time compared to 2D US (1 min vs. 2 min, $p < 0.01$), even though it required additional time for operator setup. Additionally, 3D US demonstrated significantly better data reproducibility than 2D, indicating lower interoperator variability [15].

Another study assessed 50 women aged 18–37 years undergoing IVF. Both 2D and 3D transvaginal US were performed using the Voluson™ S8 system with a 5–10 MHz RIC5-9-RS vaginal probe (GE Healthcare, USA). To evaluate interoperator variability, two operators performed scans 1 h apart. 2D US followed standard procedures. Subsequently, each patient underwent 3D US with the following steps:

- Identification of the maximum ovarian diameter
- Image stabilization
- Full ovary 3D scanning
- Ovary volume measurement using Virtual Organ Computer-Aided Analysis (VOCAL™, GE Healthcare), with 30° rotational steps in the coronal and longitudinal planes, and reconstruction of transverse and coronal images

- Definition of the region of interest through computerized mechanical slow scanning, followed by saving of the 3D dataset

The SonoAVC™ automated volume count software (GE Medical Systems, Austria) was used to identify and measure the number and diameter of fluid-filled areas (follicles). The time for each 2D and 3D transvaginal US procedure was recorded with a precision of 1 s. The mean time for automated AFC and ovary volume assessment using 3D transvaginal US was significantly shorter than with 2D US, although the diagnostic value of both methods was similar [16].

Assessing follicle maturation and determining the appropriate timing for oocyte aspiration are critical for obtaining mature oocytes without complications [17]. Previous studies have suggested that final follicular maturation should be triggered when the dominant follicle reaches a diameter of 16–22 mm according to 2D transvaginal US [18]. A recent study found that aspirating follicles with diameter of 19–24.5 mm result in high-quality embryos [19]. Manually counting follicles with an average diameter of ⩾10 mm using 2D transvaginal US remains a reliable predictor of mature oocyte numbers, although some studies indicate this parameter does not always correlate with mature oocyte counts [20]. In a study involving 515 women undergoing IVF, 3D transvaginal US was used on the day of final follicular maturation trigger to assess the dominant follicle volume as a predictor of mature oocyte count, using artificial intelligence. The threshold dominant follicle volume was found to be 0.5 см3, and this new marker significantly outperformed the conventional marker ($p < 0.001$) [21].

Both 2D and 3D transvaginal US offer comparable diagnostic value for assessing the AFC and determining ovarian reserve. 3D transvaginal US allows for automated AFC and ovary volume measurement with high accuracy and efficacy, and its ability to measure follicle volume helps predict the number of mature oocytes. Additionally, 3D transvaginal US has the advantage of a shorter examination time compared to 2D US. In high-volume ART clinics, using 3D transvaginal US can reduce exam time and increase the number of IVF procedures. Conversely, 2D transvaginal US can still be effectively used in clinics with lower patient volumes or in resource-limited settings with fewer healthcare resources [16].

ULTRASOUND EXAMINATION OF THE ENDOMETRIUM FOR PREDICTING CLINICAL PREGNANCY RATES

Transvaginal US is a noninvasive, reproducible, and accessible method commonly used in IVF programs to assess the endometrium [22]. A 2014 systematic review and meta-analysis of 22 studies involving 10,724 patients found that endometrial thickness measured by transvaginal US does not significantly predict IVF outcomes. The analysis showed that an endometrial thickness of <7 mm was associated with a decreased likelihood of pregnancy; however, such thin endometrium are rare. Notably, none of the studies included in the review examined the endometrial histology in patients with thin endometrium to explore the potential underlying pathophysiological mechanisms [23].

In 2016, a study conducted in China evaluated 3D transvaginal US parameters as potential predictors of implantation and pregnancy rates in IVF programs. The study included 435 first-time IVF patients who underwent a long ovarian stimulation protocol. On the day of human chorionic gonadotropin injection, 3D transvaginal US was used to assess endometrial thickness, structure, volume, and hemodynamic parameters, including peak systolic velocity, end-diastolic velocity, pulsatility index (PI), resistance index (RI), systolic/diastolic ratio (S/D), vascularization index (VI), flow index (FI), and endometrial and subendometrial vascularization flow index (VFI). Two or more high-grade embryos were obtained in all cases, and they were transferred on Day 3. The procedure led to clinical pregnancy in 253 patients (58.2%) and miscarriage in 49 patients (11.3%), while 133 patients (30.5%) did not conceive. No significant differences were found in endometrial thickness, volume, and structure, or in the hemodynamic parameters (PI, RI, S/D, VI, FI, and VFI) among the three groups. Patients with relatively low endometrial thickness (⩽8.5 mm; 10%) experienced both successful and unsuccessful pregnancies, and these patients had similar endometrial volume and structure and hemodynamic parameters (PI, RI, S/D, VI, FI, and VFI) [24].

A recent meta-analysis that included 14 studies involving 4,842 women of similar age who underwent IVF found that women who became pregnant had significantly higher endometrial thickness and volume, as well as higher uterine artery vascularization indices (VI, FI, and VFI), compared to those who did not become pregnant. In contrast, the S/D was lower in women who achieved pregnancy. There were no significant differences in the RI and PI. The authors concluded that endometrial receptivity plays a significant role in implantation rates and that endometrial thickness and volume, in combination with uterine artery S/D, VI, FI, and VFI assessed via transvaginal US, can serve as predictors of IVF outcomes [25].

Thus, the role of US evaluation of the endometrium and uterine blood flow in predicting clinical pregnancy rates in IVF remains a subject of debate.

TRANSABDOMINAL OOCYTE ASPIRATION IN THE IN VITRO FERTILIZATION PROGRAM

Transvaginal oocyte aspiration is preferred over the transabdominal approach due to its quicker and less invasive nature [26]. In a 2015 comparative study conducted

DOI: https://doi.org/10.17816/DD629721

in the USA, 278 patients underwent transvaginal oocyte aspiration, while 95 patients underwent transabdominal oocyte aspiration (15 had only transabdominal oocyte aspiration, and 80 had both transabdominal and transvaginal approaches). The average age of the patients was 37.60 ± 5.15 years. The average procedure time was 20.2 min for transvaginal oocyte aspiration and 28.2 min for transabdominal oocyte aspiration, with the latter usually performed after an attempted transvaginal oocyte aspiration. Hemostatic suturing was required in two patients in the transvaginal group and one in the transabdominal group. No hospitalizations or infections requiring antibiotics were reported in either group. After transabdominal oocyte aspiration, 39.4% of patients experienced mild pain, and 51.1% experienced moderate to severe pain. In the transvaginal oocyte aspiration group, 20.4% of patients reported mild pain, while 42.5% reported moderate to severe pain. There were no significant differences in the incidence of complications or pregnancy rates between the study. The authors created a scoring system to determine the need for transabdominal oocyte aspiration based on the following factors: low-quality ovarian imaging with transvaginal US (4 points), a history of pelvic surgery (3 points), and a body mass index ⩾30 kg/m^2 (2 points). For a total score of ⩾4 points, the system showed a sensitivity of 75%, specificity of 80%, positive predictive value of 57%, and negative predictive value of 90%. In this study, only 57% of patients with a score of ⩾4 points required transabdominal oocyte aspiration after transvaginal oocyte aspiration. Therefore, a positive score indicates a higher risk of needing transabdominal oocyte aspiration but is not an absolute indication for it. The authors concluded that transabdominal oocyte aspiration is a useful supplementary approach to transvaginal oocyte aspiration, yielding more oocytes in certain cases when the scoring system is applied [27].

A 2020 study involved 64 women who underwent transabdominal oocyte aspiration for various reasons, including fertility preservation in virgins with diminished ovarian reserve, malignant and benign neoplasms, ovarian transposition due to intestinal surgery, and Mayer–Rokitansky–Küster–Hauser syndrome. The procedure was performed using a 17G double-lumen aspiration needle (Cook Medical, USA) and a 150–180 mm Hg aspiration pump (Labotec, Germany), under US guidance with the Logiq™ P5 scanner and a 4–8 MHz vaginal US sensor (Shimadzu, Japan). The vaginal US sensor was chosen for its pointed tip and smaller surface area, which allowed for precise pressure application in the target area during oocyte aspiration. The sensor was positioned to view the ovary, and all patients emptied their bladder before the procedure to ensure the ovaries were close to the sensor. The average AFC was 6.14 ± 1.30, with a total of 315 aspirated oocytes and an average of 4.92 ± 1.70 per patient. The mean procedure time was 12.4 ± 1.2 min, similar to the transvaginal approach. The number and percentage of mature oocytes were 272 and 86.3%, respectively, which was a favorable outcome. A total of 14 frozen embryos were obtained for 4 patients, and transferring one embryo resulted in a live birth [28].

In 2023, the same authors conducted a study on transabdominal oocyte aspiration using a vaginal US sensor for fertility preservation in 116 virgins with diminished ovarian reserve (80.1%) and malignant or benign neoplasms (19.9%). The control group consisted of 33 women of similar age, clinical characteristics, hormone levels, and ovarian reserve who underwent transvaginal oocyte aspiration for the same indications (84.8% and 15.2%, respectively). No significant differences were observed between the groups in terms of the mean duration of ovarian stimulation (8.05 ± 1.91 days vs. 8.35 ± 1.72 days), mean total gonadotropin dose per stimulation cycle (1,507.9 ± 475.3 IU vs. 1,571.74 ± 404.60 IU), average procedure time (12.4 ± 1.2 min vs. 13.4 ± 1.6 min), mean AFC (4.62 ± 4.54 vs. 5.44 ± 4.52), mean number of aspirated oocytes (4.44 ± 4.14 vs. 5.33 ± 4.52), mean number of frozen mature oocytes (4.01 ± 3.67 vs. 4.53 ± 4.13), percentage of mature oocytes (78 ± 24% vs. 82 ± 26%), and percentage of follicles (86 ± 63% vs. 84 ± 19%). Two patients in the treatment group experienced a superficial epigastric artery injury, which resolved on its own[29].

In 2006, a clinical case of transabdominal oocyte aspiration was reported in Israel involving a 29-year-old patient with Mayer–Rokitansky–Küster–Hauser syndrome and an unusually high ovarian position in the hypochondrium. A 3–5 MHz abdominal US sensor (Philips Medical Systems, USA) was used. A single puncture was made on each side with a 17-G double-lumen aspiration needle. All accessible follicles were aspirated along the shortest path from the anterior abdominal wall to the ovaries, with simultaneous imaging of the right kidney, gallbladder, intestine, liver, and spleen. A total of 4 IVF cycles were performed, resulting in the aspiration of 19 oocytes, retrieval of 13 zygotes, and transfer of 11 embryos to a surrogate mother; however, pregnancy did not occur [30].

In 2011, a comparative retrospective study was conducted in the USA with 69 patients who underwent transvaginal oocyte aspiration and 69 patients who underwent transabdominal oocyte aspiration (of which 57 patients had transabdominal oocyte aspiration alone, and 12 patients had both transabdominal and transvaginal oocyte aspiration). Transabdominal oocyte aspiration was performed when one or both ovaries were inaccessible for transvaginal aspiration due to conditions such as adenomyosis, uterine fibroids, obesity, congenital reproductive tract disorders, surgical ovarian transposition, or pelvic adhesions. A 17G double-lumen aspiration needle (Cook Medical, USA) and a 1–4 MHz abdominal US sensor (Acuson Sequoia™, Siemens Healthineers AG, Germany) were used, positioned in the ovary view. The number of retrieved oocytes in the transabdominal oocyte aspiration group (including both transabdominal and transvaginal) was significantly lower than in the transvaginal oocyte aspiration group (11.9 ± 0.8 vs. 14.1 ± 1.0, respectively; $p = 0.008$). However, there were no significant differences between the groups in the number of mature oocytes (9.2 ± 0.9 vs. 7.3 ± 0.9, respectively; $p = 0.14$), damaged oocytes (0.09 ± 0.05 vs. 0.07 ± 0.04, respectively; $p = 0.94$), fertilization rate (63.4 ± 3.1% vs. 67.1 ± 2.7%, respectively; p = 0.35), high-grade embryos (6.4 ± 0.6 vs. 7.7 ± 0.7, respectively; $p = 0.08$), or pregnancy rates (27.5% and 36.2%, respectively; $p = 0.36$). The authors concluded that US-guided transabdominal oocyte aspiration is a safe and effective method that can be used when ovaries are inaccessible for transvaginal aspiration [31].

Available studies suggest that US-guided transabdominal oocyte aspiration is a feasible, effective, and safe option for oocyte retrieval in IVF programs, particularly for fertility preservation and in cases where ovaries are inaccessible for transvaginal oocyte aspiration.

CONCLUSION

US examinations play a crucial role in IVF programs, providing diagnostic value comparable to other diagnostic methods. Assessing ovarian reserve and predicting ovarian response and IVF outcomes requires determining the number of ovarian follicles. Some studies suggest that the AFC can be measured at any point during the menstrual cycle without compromising diagnostic accuracy, offering convenience for both patients and clinicians. 3D transvaginal US enables automated, highly accurate, and efficient AFC assessment, and it is quicker than 2D transvaginal US. The use of 3D transvaginal US with artificial intelligence-based data processing has been employed to establish the threshold dominant follicle volume (0.5 cm3) as a predictor of mature oocyte count in IVF programs. While the role of US in evaluating the endometrium and uterine blood flow for predicting clinical pregnancy rates in IVF is still debated, available research indicates that factors such as endometrial thickness and volume, along with VI, FI, VFI, and S/D ratio in the uterine artery, measured via transvaginal US, may help predict IVF outcomes. Transabdominal oocyte aspiration, using different US sensors, is a feasible, effective, and safe method for oocyte retrieval in IVF programs, particularly for patients with ovaries inaccessible for transvaginal aspiration.

ADDITIONAL INFORMATION

Funding source. This article was not supported by any external sources of funding.

Competing interests. The author declares that she has no competing interests.

Author's contribution. The author made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

REFERENCES

1. Li YW, Liang XW, Fang JH, Chen ZY. Application of ultrasound markers measured at different time points of COH cycle in the prediction of ovarian response for individualised ovulation induction. *J Obstet Gynaecol.* 2022;42(5):1467–1473. doi: 10.1080/01443615.2021.2004101

2. Ozerskaya IA. *Manual on ultrasound diagnostics in obstetrics and gynecology: textbook.* Moscow: MEDpress-Inform; 2021. (In Russ.). EDN: RNUAOE doi: 10.24421/978-5-00030-860-8

3. Coelho Neto MA, Ludwin A, Borrell A, et al. Counting ovarian antral follicles by ultrasound: a practical guide. *Ultrasound Obstet Gynecol.* 2018;51(1):10–20. doi: 10.1002/uog.18945

4. Zhang Y, Xu Y, Xue Q, et al. Discordance between antral follicle counts and anti-Müllerian hormone levels in women undergoing in vitro fertilization. *Reprod Biol Endocrinol.* 2019;17(1):51. doi: 10.1186/s12958-019-0497-4

5. Wang X, Jin L, Mao YD, et al. Evaluation of Ovarian Reserve Tests and Age in the Prediction of Poor Ovarian Response to Controlled Ovarian Stimulation-A Real-World Data Analysis of 89,002 Patients. *Front Endocrinol (Lausanne).* 2021;12:702061. doi: 10.3389/fendo.2021.702061

6. Arvis P, Rongières C, Pirrello O, Lehert P. Reliability of AMH and AFC measurements and their correlation: a large multicenter study. *J Assist Reprod Genet.* 2022;39(5):1045–1053. doi: 10.1007/s10815-022-02449-5

7. Liu Y, Pan Z, Wu Y, et al. Comparison of anti-Müllerian hormone and antral follicle count in the prediction of ovarian response: a systematic review and meta-analysis. *J Ovarian Res.* 2023;16(1):117. doi: 10.1186/s13048-023-01202-5

8. Jacobs MH, Reuter LM, Baker VL, et al. A multicentre evaluation of the Elecsys anti-Müllerian hormone immunoassay for prediction of antral follicle count. *Reprod Biomed Online.* 2019;38(5):845–852. doi: 10.1016/j.rbmo.2018.12.041

9. Razafintsalama-Bourdet M, Bah M, Amand G, et al. Random antral follicle count performed on any day of the menstrual cycle has the same predictive value as AMH for good ovarian response in IVF cycles. *J Gynecol Obstet Hum Reprod.* 2022;51(1):102233. doi: 10.1016/j.jogoh.2021.102233

10. Rombauts L, Onwude JL, Chew HW, Vollenhoven BJ. The predictive value of antral follicle count remains unchanged across the menstrual cycle. *Fertil Steril.* 2011;96(6):1514–1518. doi: 10.1016/j.fertnstert.2011.09.005

11. Filippi F, Martinelli F, Paffoni A, et al. Fertility preservation in women with malignancies: the accuracy of antral follicle count collected randomly during the menstrual cycle in predicting the number of oocytes retrieved. *J Assist Reprod Genet.* 2019;36(3):569–578. doi: 10.1007/s10815-018-1377-0

12. Chen Q, Sun L, Huang J, et al. Three-dimensional transvaginal ultrasonography in the evaluation of diminished ovarian reserve and premature ovarian failure. *Pak J Med Sci.* 2023;39(3):747–751. doi: 10.12669/pjms.39.3.7372

13. Mathur P, Kakwani K, Diplav, et al. Deep Learning based Quantification of Ovary and Follicles using 3D Transvaginal Ultrasound in Assisted Reproduction. *Annu Int Conf IEEE Eng Med Biol Soc.* 2020;2020:2109–2112. doi: 10.1109/EMBC44109.2020.9176703

14. Srivastava D, Gupta S, Kudavelly S, et al. Unsupervised Deep Learning based Longitudinal Follicular Growth Tracking during IVF Cycle using 3D Transvaginal Ultrasound in Assisted Reproduction. *Annu Int Conf IEEE Eng Med Biol Soc.* 2021;2021:3209–3212. doi: 10.1109/EMBC46164.2021.9630495

15. Raine-Fenning N, Jayaprakasan K, Deb S, et al. Automated follicle tracking improves measurement reliability in patients undergoing ovarian stimulation. *Reprod Biomed Online.* 2009;18(5):658–663. doi: 10.1016/s1472-6483(10)60010-7

16. Re C, Mignini Renzini M, Rodriguez A, et al. From a circle to a sphere: the ultrasound imaging of ovarian follicle with 2D and 3D technology. *Gynecol Endocrinol.* 2019;35(3):184–189. doi: 10.1080/09513590.2018.1522297

17. Yang J, Gao J, Wang Y, et al. Impact of follicular size categories on oocyte quality at trigger day in young and advanced-age patients undergoing GnRH-ant therapy. *Front Endocrinol (Lausanne).* 2023;14:1167395. doi: 10.3389/fendo.2023.1167395

18. Abbara A, Patel A, Hunjan T, et al. FSH Requirements for Follicle Growth During Controlled Ovarian Stimulation. *Front Endocrinol (Lausanne).* 2019;10:579. doi: 10.3389/fendo.2019.00579

19. Shapiro BS, Rasouli MA, Verma K, et al. The effect of ovarian follicle size on oocyte and embryology outcomes. *Fertil Steril.* 2022;117(6):1170–1176. doi: 10.1016/j.fertnstert.2022.02.017

20. Liang X, Zeng F, Li H, et al. Deep Learning Based Two-Dimensional Ultrasound for Follicle Monitoring in Infertility Patients. *BIOI.* 2023;4(3):125–131. doi: 10.15212/bioi-2022-0024

21. Liang X, Liang J, Zeng F, et al. Evaluation of oocyte maturity using artificial intelligence quantification of follicle volume biomarker by three-dimensional ultrasound. *Reprod Biomed Online.* 2022;45(6):1197–1206. doi: 10.1016/j.rbmo.2022.07.012

22. Devine K, Dolitsky S, Ludwin I, Ludwin A. Modern assessment of the uterine cavity and fallopian tubes in the era of high-efficacy assisted reproductive technology. *Fertil Steril.* 2022;118(1):19–28. doi: 10.1016/j.fertnstert.2022.05.020

23. Kasius A, Smit JG, Torrance HL, et al. Endometrial thickness and pregnancy rates after IVF: a systematic review and meta-analysis. *Hum Reprod Update.* 2014;20(4):530–541. doi: 10.1093/humupd/dmu011

24. Zhang T, He Y, Wang Y, et al. The role of three-dimensional power Doppler ultrasound parameters measured on hCG day in the prediction of pregnancy during in vitro fertilization treatment. *Eur J Obstet Gynecol Reprod Biol.* 2016;203:66–71. doi: 10.1016/j.ejogrb.2016.05.016

25. Wu J, Sheng J, Wu X, Wu Q. Ultrasound-assessed endometrial receptivity measures for the prediction of in vitro fertilization-embryo transfer clinical pregnancy outcomes: A meta-analysis and systematic review. *Exp Ther Med.* 2023;26(3):453. doi: 10.3892/etm.2023.12152

26. ESHRE Working Group on Ultrasound in ART; D'Angelo A, Panayotidis C, Amso N, et al. Recommendations for good practice in ultrasound: oocyte pick up. *Hum Reprod Open.* 2019;2019(4):hoz025. doi: 10.1093/hropen/hoz025

27. Roman-Rodriguez CF, Weissbrot E, Hsu CD, et al. Comparing transabdominal and transvaginal ultrasound-guided follicular aspiration: A risk assessment formula. *Taiwan J Obstet Gynecol.* 2015;54(6):693–699. doi: 10.1016/j.tjog.2015.02.004

28. Sönmezer M, Gülümser Ç, Sönmezer M, et al. Transabdominal ultrasound guided oocyte retrieval using vaginal ultrasound probe: Definition of the technique. *J Obstet Gynaecol Res.* 2021;47(2):800–806. doi: 10.1111/jog.14618

29. Sönmezer M, Saçıntı KG, Gülümser Ç, et al. Transabdominal ultrasound-guided oocyte retrieval for oocyte cryopreservation using a vaginal probe: a comparison of applicability, effectiveness, and safety with conventional transvaginal approach. *J Assist Reprod Genet.* 2023;40(2):399–405. doi: 10.1007/s10815-022-02705-8

30. Raziel A, Vaknin Z, Schachter M, et al. Ultrasonographic-guided percutaneous transabdominal puncture for oocyte retrieval in a rare patient with Rokitansky syndrome in an in vitro fertilization surrogacy program. *Fertil Steril.* 2006;86(6):1760–1763. doi: 10.1016/j.fertnstert.2006.05.039

31. Barton SE, Politch JA, Benson CB, et al. Transabdominal follicular aspiration for oocyte retrieval in patients with ovaries inaccessible by transvaginal ultrasound. *Fertil Steril.* 2011;95(5):1773–1776. doi: 10.1016/j.fertnstert.2011.01.006

СПИСОК ЛИТЕРАТУРЫ

1. Li Y.W., Liang X.W., Fang J.H., Chen Z.Y. Application of ultrasound markers measured at different time points of COH cycle in the prediction of ovarian response for individualised ovulation induction // J Obstet Gynaecol. 2022. Vol. 42, N 5. P. 1467–1473. doi: 10.1080/01443615.2021.2004101

2. Озерская И.А. Руководство по ультразвуковой диагностике в акушерстве и гинекологии: учебно-методическое пособие. Москва: МЕДпресс-информ, 2021. EDN: RNUAOE doi: 10.24421/978-5-00030-860-8

3. Coelho Neto M.A., Ludwin A., Borrell A., et al. Counting ovarian antral follicles by ultrasound: a practical guide // Ultrasound Obstet Gynecol. 2018. Vol. 51, N 1. P. 10–20. doi: 10.1002/uog.18945

4. Zhang Y., Xu Y., Xue Q., et al. Discordance between antral follicle counts and anti-Müllerian hormone levels in women undergoing in vitro fertilization // Reprod Biol Endocrinol. 2019. Vol. 17, N 1. ID 51. doi: 10.1186/s12958-019-0497-4

5. Wang X., Jin L., Mao Y.D., et al. Evaluation of Ovarian Reserve Tests and Age in the Prediction of Poor Ovarian Response to Controlled Ovarian Stimulation-A Real-World Data Analysis of 89,002 Patients // Front Endocrinol (Lausanne). 2021. Vol. 12. ID 702061. doi: 10.3389/fendo.2021.702061

6. Arvis P., Rongières C., Pirrello O., Lehert P. Reliability of AMH and AFC measurements and their correlation: a large multicenter study // J Assist Reprod Genet. 2022. Vol. 39, N 5. P. 1045–1053. doi: 10.1007/s10815-022-02449-5

7. Liu Y., Pan Z., Wu Y., et al. Comparison of anti-Müllerian hormone and antral follicle count in the prediction of ovarian response: a systematic review and meta-analysis // J Ovarian Res. 2023. Vol. 16, N 1. ID 117. doi: 10.1186/s13048-023-01202-5

8. Jacobs M.H., Reuter L.M., Baker V.L., et al. A multicentre evaluation of the Elecsys anti-Müllerian hormone immunoassay for prediction of antral follicle count // Reprod Biomed Online. 2019. Vol. 38, N 5. P. 845–852. doi: 10.1016/j.rbmo.2018.12.041

9. Razafintsalama-Bourdet M., Bah M., Amand G., et al. Random antral follicle count performed on any day of the menstrual cycle has the same predictive value as AMH for good ovarian response in IVF cycles // J Gynecol Obstet Hum Reprod. 2022. Vol. 51, N 1. ID 102233. doi: 10.1016/j.jogoh.2021.102233

10. Rombauts L., Onwude J.L., Chew H.W., Vollenhoven B.J. The predictive value of antral follicle count remains unchanged across the menstrual cycle // Fertil Steril. 2011. Vol. 96, N 6. P. 1514–1518. doi: 10.1016/j.fertnstert.2011.09.005

11. Filippi F., Martinelli F., Paffoni A., et al. Fertility preservation in women with malignancies: the accuracy of antral follicle count collected randomly during the menstrual cycle in predicting the number of oocytes retrieved // J Assist Reprod Genet. 2019. Vol. 36, N 3. P. 569–578. doi: 10.1007/s10815-018-1377-0

12. Chen Q., Sun L., Huang J., et al. Three-dimensional transvaginal ultrasonography in the evaluation of diminished ovarian reserve and premature ovarian failure // Pak J Med Sci. 2023. Vol. 39, N 3. P. 747–751. doi: 10.12669/pjms.39.3.7372

13. Mathur P., Kakwani K., Diplav, et al. Deep Learning based Quantification of Ovary and Follicles using 3D Transvaginal Ultrasound in Assisted Reproduction // Annu Int Conf IEEE Eng Med Biol Soc. 2020. Vol. 2020. P. 2109–2112. doi: 10.1109/EMBC44109.2020.9176703

14. Srivastava D., Gupta S., Kudavelly S., et al. Unsupervised Deep Learning based Longitudinal Follicular Growth Tracking during IVF Cycle using 3D Transvaginal Ultrasound in Assisted Reproduction // Annu Int Conf IEEE Eng Med Biol Soc. 2021. Vol. 2021. P. 3209–3212. doi: 10.1109/EMBC46164.2021.9630495

15. Raine-Fenning N., Jayaprakasan K., Deb S., et al. Automated follicle tracking improves measurement reliability in patients undergoing ovarian stimulation // Reprod Biomed Online. 2009. Vol. 18, N 5. P. 658–663. doi: 10.1016/s1472-6483(10)60010-7

16. Re C., Mignini Renzini M., Rodriguez A., et al. From a circle to a sphere: the ultrasound imaging of ovarian follicle with 2D and 3D technology // Gynecol Endocrinol. 2019. Vol. 35, N 3. P. 184–189. doi: 10.1080/09513590.2018.1522297

17. Yang J., Gao J., Wang Y., et al. Impact of follicular size categories on oocyte quality at trigger day in young and advanced-age patients undergoing GnRH-ant therapy // Front Endocrinol (Lausanne). 2023. Vol. 14. ID 1167395. doi: 10.3389/fendo.2023.1167395

18. Abbara A., Patel A., Hunjan T., et al. FSH Requirements for Follicle Growth During Controlled Ovarian Stimulation // Front Endocrinol (Lausanne). 2019. Vol. 10. ID 579. doi: 10.3389/fendo.2019.00579

19. Shapiro B.S., Rasouli M.A., Verma K., et al. The effect of ovarian follicle size on oocyte and embryology outcomes // Fertil Steril. 2022. Vol. 117, N 6. P. 1170–1176. doi: 10.1016/j.fertnstert.2022.02.017

20. Liang X., Zeng F., Li H., et al. Deep Learning Based Two-Dimensional Ultrasound for Follicle Monitoring in Infertility Patients // BIOI. 2023. Vol. 4, N 3. P. 125–131. doi: 10.15212/bioi-2022-0024

21. Liang X., Liang J., Zeng F., et al. Evaluation of oocyte maturity using artificial intelligence quantification of follicle volume biomarker by three-dimensional ultrasound // Reprod Biomed Online. 2022. Vol. 45, N 6. P. 1197–1206. doi: 10.1016/j.rbmo.2022.07.012

22. Devine K., Dolitsky S., Ludwin I., Ludwin A. Modern assessment of the uterine cavity and fallopian tubes in the era of high-efficacy assisted reproductive technology // Fertil Steril. 2022. Vol. 118, N 1. P. 19–28. doi: 10.1016/j.fertnstert.2022.05.020

23. Kasius A., Smit J.G., Torrance H.L., et al. Endometrial thickness and pregnancy rates after IVF: a systematic review and meta-analysis // Hum Reprod Update. 2014. Vol. 20, N 4. P. 530–541. doi: 10.1093/humupd/dmu011

24. Zhang T., He Y., Wang Y., et al. The role of three-dimensional power Doppler ultrasound parameters measured on hCG day in the prediction of pregnancy during in vitro fertilization treatment // Eur J Obstet Gynecol Reprod Biol. 2016. Vol. 203. P. 66–71. doi: 10.1016/j.ejogrb.2016.05.016

25. Wu J., Sheng J., Wu X., Wu Q. Ultrasound-assessed endometrial receptivity measures for the prediction of in vitro fertilization-embryo transfer clinical pregnancy outcomes: A meta-analysis and systematic review // Exp Ther Med. 2023. Vol. 26, N 3. ID 453. doi: 10.3892/etm.2023.12152

26. ESHRE Working Group on Ultrasound in ART; D'Angelo A., Panayotidis C., Amso N., et al. Recommendations for good practice in ultrasound: oocyte pick up // Hum Reprod Open. 2019. Vol. 2019, N 4. ID hoz025. doi: 10.1093/hropen/hoz025

27. Roman-Rodriguez C.F., Weissbrot E., Hsu C.D., et al. Comparing transabdominal and transvaginal ultrasound-guided follicular aspiration: A risk assessment formula // Taiwan J Obstet Gynecol. 2015. Vol. 54, N 6. P. 693–699. doi: 10.1016/j.tjog.2015.02.004

28. Sönmezer M., Gülümser Ç., Sönmezer M., et al. Transabdominal ultrasound guided oocyte retrieval using vaginal ultrasound probe: Definition of the technique // J Obstet Gynaecol Res. 2021. Vol. 47, N 2. P. 800–806. doi: 10.1111/jog.14618

29. Sönmezer M., Saçıntı K.G., Gülümser Ç., et al. Transabdominal ultrasound-guided oocyte retrieval for oocyte cryopreservation using a vaginal probe: a comparison of applicability, effectiveness, and safety with conventional transvaginal approach // J Assist Reprod Genet. 2023. Vol. 40, N 2. P. 399–405. doi: 10.1007/s10815-022-02705-8

30. Raziel A., Vaknin Z., Schachter M., et al. Ultrasonographic-guided percutaneous transabdominal puncture for oocyte retrieval in a rare patient with Rokitansky syndrome in an in vitro fertilization surrogacy program // Fertil Steril. 2006. Vol. 86, N 6. P. 1760–1763. doi: 10.1016/j.fertnstert.2006.05.039

31. Barton S.E., Politch J.A., Benson C.B., et al. Transabdominal follicular aspiration for oocyte retrieval in patients with ovaries inaccessible by transvaginal ultrasound // Fertil Steril. 2011. Vol. 95, N 5. P. 1773–1776. doi: 10.1016/j.fertnstert.2011.01.006

AUTHOR'S INFO

*** Evgeniya V. Kirakosyan,** MD, Cand. Sci. (Medicine);
address: 42 Lobachevsky str., 119415, Moscow, Russia;
ORCID: 0000-0002-6021-2449;
eLibrary SPIN: 4813-5625;
e-mail: evgeniya.kirakosyan@gmail.com

ОБ АВТОРЕ

*** Киракосян Евгения Валериковна,** канд. мед. наук;
адрес: Россия, 119415, Москва, ул. Лобачевского, д. 42;
ORCID: 0000-0002-6021-2449;
eLibrary SPIN: 4813-5625;
e-mail: evgeniya.kirakosyan@gmail.com