The difference in early trimester fetal growth between singletons after frozen embryo transfer and fresh embryo transfer

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BACKGROUND: Frozen embryo transfer resulted in a higher birthweight and an increased risk of macrosomia than fresh embryo transfer. However, the mechanism was still unclear. When the impact of frozen embryo transfer on fetal growth began was unknown. Crown-rump length at 11−13 weeks had been regarded as a good indicator of fetal growth in the first trimester and had been used for gestational age calculation in women with uncertain last menstrual periods.

OBJECTIVE: To evaluate the association between frozen embryo transfer and early fetal growth, particularly the crown-rump length, then fresh embryo transfer. The secondary objective was to investigate the potential correlation between crown-rump length and birthweight.

STUDY DESIGN: This was a retrospective cohort study conducted at the Reproductive Medical Center of Shandong University. A total of 4949 patients who obtained singleton pregnancy after frozen embryo transfer and 1793 patients who got singleton pregnancy after fresh embryo transfer between January 1, 2017 and December 31, 2022 were included. The primary outcome was the crown-rump length measured via ultrasound at 11−13 weeks gestation. The secondary outcomes were perinatal outcomes, including birthweight and the risk of large for gestational age, small for gestational age, macrosomia, low birthweight, and premature delivery. Multivariable linear regression models were used to adjust for potential confounders of crown-rump length.

RESULTS: A total of 6742 live singleton births after frozen embryo transfer or fresh embryo transfer were included in this study. In the univariable analysis, the frozen embryo transfer group had a larger crown-rump length (5.75±0.53 cm vs 5.57±0.48 cm, $P<.001$) and an increased risk of larger-than-expected crown-rump length (13.5% vs11.2%, $P=.013$) than the fresh embryo transfer group. After adjusting for confounders in multivariable linear regression models, frozen embryo transfer was still associated with a larger crown-rump length (regression coefficient, 3.809 [95% confidence intervals, 3.621−3.997], $P<.001$). When subgrouped by fetal gender, the crown-rump length of the frozen embryo transfer group was larger than the fresh embryo transfer group in both male and female fetuses. In addition, the crown-rump length was consistently larger in the frozen embryo transfer group than the fresh embryo transfer group in subgroups of the peak estradiol levels. The comparisons among different crown-rump length groups showed that smaller-than-expected crown-rump length was associated with increased risks of small for gestational age (6.3% vs 3.0%, $P<.001$) and preterm delivery (9.6% vs 6.7%, $P=.004$) than normal crown-rump length.

CONCLUSION: Frozen embryo transfer was associated with a larger crown-rump length than fresh embryo transfer, suggesting that the effect of frozen embryo transfer on fetal growth may begin in the early trimester. Suboptimal fetal growth in the first trimester may be associated with low birthweight and premature delivery.

Key words: crown-rump length, freeze-only strategy, fresh embryo transfer, frozen-thawed embryo transfer, perinatal outcomes

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Why was this study conducted?

Currently, there is confusion over whether frozen embryo transfer (FET) affects early fetal growth as represented by the crown-rump length (CRL) than fresh embryo transfer (Fre-ET).

Key findings

This study showed that singleton pregnancies after FET had a larger CRL, a lower percentage of normal CRL, and a higher percentage of larger-than-expected CRL in the early trimester than those after Fre-ET.

What does this add to what is known?

The effect of FET on fetal growth may begin in the early trimester. The findings of a higher risk of small for gestational age, even in those with normal CRL among pregnancies after Fre-ET than FET, provided clues for further research on late fetal growth.

Introduction

Following the first success of frozen-thawed embryo transfer (FET) in Australia in 1983, FET has gradually become an essential part of assisted reproductive technology.[1] The freeze-all strategies are used to reduce ovarian hyperstimulation syndrome risk and avoid the potential negative effect of ovarian stimulation on endometrial receptivity and implantation.[2,3]

In recent years, concerns have been raised regarding the safety of FET. One of the major concerns was the association between FET and birthweight. Studies have demonstrated that FET resulted in a higher risk of macrosomia and an increased birthweight than in fresh embryo transfer (Fre-ET).[4,5] However, the beginning and mechanism of the impacts of FET on fetal growth remain unclear. A study suggested that FET pregnancies exhibit greater embryo-fetal growth than Fre-ET, as represented by CRL.[6] Nonetheless, other studies reported no significant difference in CRL during the first trimester between Fre-ET and FET.[7]

The first trimester involved the crucial development of fetal organs. Negative fetal exposures during this period may lead to congenital anomalies, later fetal growth retardation, and even impaired long-term health of offspring.[8] Fetal CRL in the early trimester is less impacted by maternal nutrition status than birthweight and is a good indicator of early fetal growth.[9,10] In this study, we analyzed the difference in CRL at 11−13 weeks gestation between the FET and Fre-ET groups and the relationship between CRL and perinatal outcomes.

Materials and Methods

Study population

In this retrospective cohort study, we included patients who underwent in vitro fertilization (IVF) with or without intracytoplasmic sperm injection (ICSI) and had a singleton pregnancy at the Reproductive Medical Center of Shandong University from January 1, 2017 through December 31, 2022. Women who underwent preimplantation genetic testing cycles were excluded. The ultrasound scan was performed at 11−13 weeks to measure fetal CRL (The CRL is a measure of the distance from the highest point of the fetal skull to the lowest point of the fetal buttocks, typically taken in the median sagittal plane when the fetus is in the natural supine position.), nuchal translucency, heartbeats, and amniotic fluid. Patients with polycystic ovary syndrome, uterine malformations, and pregnancies that ended up with late pregnancy loss, uncontrolled hypertension, poorly controlled diabetes, and a history of deep venous thrombosis were excluded.

Study procedures

In the Fre-ET group, cleavage or blastocyst stage embryos was selected and transferred on days 3 or 5 of embryo culture. On day 3 of embryo culture, embryos were graded by morphologic criteria on the basis of the number and size of blastomeres and the percentage of fragmentation.[11] The selection of blastocysts was according to the Gardner scoring criteria,[12] on the basis of the extent of expansion and the development of the inner cell mass and trophectoderm. Luteal phase support was started on the day of oocyte retrieval and was continued till 10−11 weeks gestation.

In the FET group, the regimen for endometrial preparation was determined on the basis of patients' menstrual regularity and also the preferences of patients and physicians. A natural ovulation regimen was the first choice for ovulatory women. For the natural ovulation regimen, transvaginal ultrasound scans were performed to monitor ovulation from days 8−10 of the menstrual cycle and every 2−3 days after that, as previously reported.[13] For the programmed regimen, oral estrogen 4−8 mg daily was administered from day 2−3 of a menstrual cycle for at least 10 days. When endometrial thickness reached ≥7 mm, progesterone was administrated, and oral estrogen was continued. FET was performed on the sixth day after progesterone administration or the sixth day after ovulation. Luteal phase support was continued till 10−11 weeks gestation.

Outcomes

The primary outcome was the first-trimester CRL. The secondary outcomes were perinatal outcomes, including birthweight and the risk of large for gestational age (LGA), small for gestational age (SGA), macrosomia, low birthweight, and premature delivery. Preterm delivery is a delivery that occurs between 28±0 and 36±6 weeks gestation. Low birthweight refers to neonates with a birthweight <2500 g, whereas macrosomia was defined as newborns' birthweight >4000 g. Birthweight was referenced by Chinese birthweight criteria.[14] SGA and LGA were defined as birth weights <10th percentile or above the >90th percentile for the

corresponding gestational week, taking into account infant sex.

The calculated gestational age by the CRL was done following the previously established formula[15]: gestational age in days=8.052√(CRL in millimeters) +23.73. The calculated gestational age was compared with the gestational age calculated on the day of embryo transfer. The discrepancy between the 2 types of gestational age was used to categorize patients into 3 groups: the smaller-than-expected CRL group, the normal CRL group, and the larger-than-expected CRL group. In the smaller-than-expected group, the difference between the calculated gestational age by CRL and gestational age by the day of embryo transfer was −6 to −2 days. In the normal group, the difference was −1 to 1 day. In the larger-than-expected group, the difference was 2−6 days.

Statistical analysis

The normality of the variables was assessed by normality plots and Shapiro-Wilk tests. Continuous variables were presented as mean±standard deviation, and the between-group difference was compared by the Student *t* test or 1-way analysis of variance. Categorical variables were expressed as frequency and percentages n (%). Pearson χ^2 test was used for comparison between groups, and Fisher's exact test was used if the expected frequencies were <5. A multivariable linear regression model was performed to adjust for potential confounders, including maternal age, body mass index (BMI), infertility diagnosis, years of infertility, paternal age, parity, progesterone level on the day of human menopausal gonadotropin (hCG) trigger, estradiol level on the day of hCG trigger, endometrial thickness on the day of hCG trigger, methods of fertilization, and infant gender. Adjusted odds ratio (aOR) and 95% confidence intervals (CI) values were calculated with the multivariable regression models. Multivariable logistic regression was performed to investigate the effect of the groups of CRL on the risks of LGA and SGA, low birthweight, macrosomia, and premature delivery. The interaction between different CRL subgroups and fresh and FET was included in the models. In addition, we performed subgroup analyses on the basis of infant gender, fertilization method, estradiol level on hCG trigger day, and endometrial preparation protocol. A statistical significance was set at $P<.05$. All analyses were run in SPSS (version 25, IBM, Armonk, NY).

Results

Baseline characteristics

A total of 6742 live singleton births after FET or Fre-ET were included in this study. Among them, 1793 women underwent Fre-ET, and 4949 women underwent FET. Table 1 shows the demographic characteristics between the 2 groups. Maternal age, BMI, history of abortion and previous live birth, baseline follicle stimulating hormone (FSH) level, paternal age, and endometrial thickness on the day of hCG trigger were higher in the Fre-ET group than in the FET group. Baseline luteinizing hormone level, baseline testosterone hormone level, estradiol, and progesterone level on the day of hCG trigger, number of antral follicle count, and oocytes retrieved were lower in the Fre-ET group than in the FET group. No significant differences were found between the 2 groups in the duration of infertility and infertility diagnosis.

Clinical outcomes

The ultrasound results in the early trimester between the Fre-ET and FET groups are shown in Table 2. Compared with the Fre-ET, the FET group showed a higher CRL (5.75±0.53 cm vs 5.57±0.48 cm; $P<.001$), a smaller nuchal translucency (0.12±0.04 cm vs 0.13±0.13 cm; $P=.001$), slower heartbeats per minute (150.9±42.87 vs 164.04±7.04; $P<.001$), a deeper amniotic fluid (2.44±4.77cm vs 1.20±3.16 cm; $P<.001$), a higher percentage of the larger-than-expected CRL (13.5% vs 11.2%; $P<.001$). After adjusting for confounding factors using multivariable linear regression analysis, the CRL of FET remained significantly larger than the Fre-ET group ($P<.001$, Supplemental Table 1).

The comparisons of the risk of preterm delivery and birthweight between the Fre-ET and FET groups within different CRL subgroups are shown in Table 3. In the normal CRL subgroup, the risk of SGA in the Fre-ET group was higher than in the FET group (4.3% vs 2.5%, $P=.001$). There was no significant difference in the risk of SGA, LGA, low birthweight, macrosomia, and preterm delivery between the Fre-ET and FET groups within the other 2 subgroups.

The comparisons of the risk of preterm delivery and birthweight of singleton pregnancy among 3 different CRL groups are shown in Table 4. Multivariable logistic regression analyses showed a smaller-than-expected CRL was associated with increased risks of low birthweight (OR, 1.85 [95% CI, 1.29−2.65], $P=.001$), SGA (OR, 1.53 [95% CI,1.07−2.19], $P=.002$), and preterm delivery (OR, 1.50 [95% CI, 1.12−2.00], $P=.007$). A larger-than-expected CRL was associated with increased risks of macrosomia (OR, 1.34 [95% CI, 1.01−1.68]; $P=.012$) and LGA (OR, 1.27 [95% CI, 1.08−1.51], $P=.005$, Supplemental Table 2). In addition, multivariable logistic regression analyses showed no statistically significant interaction between types of embryo transfer and CRL size on the incidences of SGA and LGA, low birthweight, macrosomia, or preterm delivery.

Subgroups analyses

Stratified by infant gender, both male and female infants born after FET showed a higher CRL than those born after Fre-ET (Supplemental Table 3). When stratified by different methods of fertilization, infants born after FET showed a higher CRL than those born after Fre-ET in all subgroups (Supplemental Table 4). When stratified by estradiol level on hCG trigger day, FET infants had a greater CRL than Fre-ET infants across all groups (Supplemental Table 5). When stratified by different regimens for endometrial preparation, infants born after FET showed a higher CRL than those born after Fre-ET in all subgroups (Supplemental Table 6).

TABLE 1
Baseline characteristics in the fresh embryo transfer group and the FET group

Variable	Fre-ET (n=1793)	FET (n=4949)	*P* value
Maternal age (y)	32.11±4.29	30.12±3.97	<.001
Height (cm)	161.14±5.6	161.62±5.58	.002
Weight (kg)	63.74±10.17	61.37±9.73	<.001
BMI (kg/m^2)	24.55±3.73	23.49±3.58	<.001
Years of infertility (y)	3.64±2.68	3.65±2.59	.88
Parity			<.001
≤1	1720 (96)	4864 (98.3)	
≥2	73 (4)	85 (1.7)	
Infertility diagnosis			.01
Male factor	221 (12.3)	840(17)	
Pelvic factors	1173 (65)	3731 (75.4)	
Pelvic and male factor	73 (4.1)	203 (4.1)	
Others	325 (18.1)	175 (3.5)	
History of abortion			<.001
≤1	1392 (77.6)	4378 (88.5)	
≥2	401 (22.4)	571 (11.5)	
History of previous live birth			<.001
≤1	1719 (95.9)	4877(98.5)	
≥2	74 (4.1)	72 (1.5)	
Baseline FSH level (IU/L)	7.29±3.68	6.63±5.43	<.001
Baseline LH level (IU/L)	5.79±14.24	6.97±15.96	.006
Baseline E2 level (pg/mL)	39.6±26.53	38.73±18.78	.206
Baseline Testosterone level (ng/mL)	24.62±13.16	28.75±15.85	<.001
Baseline TSH level (uIU/mL)	2.35±1.23	2.40±1.92	.479
AFC	11.64±8.48	18.93±9.40	<.001
Number of oocytes retrieved	8.26±4.65	16.14±7.26	<.001
paternal age (y)	32.75±4.83	30.91±4.33	<.001
Progesterone level on the day of hCG trigger (ng/mL)	0.62±0.33	0.87±0.92	<.001
Estradiol level on the day of hCG trigger (pg/mL)	2467.89 ± 1355.84	4771.18 ± 2628.89	<.001
Endometrial thickness on the day of hCG trigger (cm)	1.24±0.11	1.20±0.11	<.001
Methods of fertilization			<.001
IVF	1248 (69.6)	3286 (66.4)	
ICSI	457 (25.5)	1338 (27.0)	
Half IVF/half ICSI	88 (4.9)	325 (6.6)	
Stage of embryo transferred			<.001
Cleavage stage	340 (18.9)	548 (11.0)	
Blastocyst stage	1453 (74.1)	4361 (89.0)	

Data are presented as mean±standard deviation and number (percentage).

AFC, antral follicle count; *BMI*, body mass index; *E2*, estradiol; *FET*, frozen embryo transfer; *Fre-ET*, fresh embryo transfer; *FSH*, follicle stimulating hormone; *hCG*, human chorionic gonadotropin; *ICSI*, intracytoplasmic sperm injection; *IVF*, in vitro fertilization; *LH*, luteinizing hormone; *TSH*, thyroid stimulating hormone.

Yang. Larger crown-rump length in frozen embryo transfer group than fresh embryo transfer group. Am J Obstet Gynecol Glob Rep 2024.

TABLE 2
The ultrasound results in the early trimester between the fresh and FET groups

Variable	Fre-ET (n=1793)	FET(n=4949)	*P* value
CRL (cm)	5.57±0.48	5.75±0.53	<.001
NT (cm)	0.13±0.13	0.12±0.04	.001
Heartbeat per minute	164.04±7.04	150.9±42.87	<.001
AF (cm)	1.20±3.16	2.44±4.77	<.001
CRL subgroups			
Smaller-than-expected CRL	172/1793 (9.6)	476/4949 (9.6)	.975
Normal CRL	1401/1793 (78.1)	3695/4949 (74.7)	.003
Larger-than-expected CRL	201/1793 (11.2)	668/4949 (13.5)	.013

Data are presented as mean±standard deviation and n/N (%).

AF, amniotic fluid; *CRL*, crown-rump length; *FET*, frozen embryo transfer; *Fre-ET*, fresh embryo transfer; *NT*, nuchal translucency.

Yang. Larger crown-rump length in frozen embryo transfer group than fresh embryo transfer group. Am J Obstet Gynecol Glob Rep 2024.

Comment

Principal findings

This study showed that singleton pregnancies after FET had a larger CRL, a lower percentage of normal CRL, and a higher percentage of larger-than-expected CRL in the early trimester than those after Fre-ET. Singleton pregnancy, even with a normal CRL in the early trimester, had a lower risk of SGA at birth in those following FET than those following Fre-ET. Pregnancies with a large-than-expected CRL in the early trimester had lower risks of preterm birth, SGA, and birthweight <2500 g, and higher risks of macrosomia and LGA.

Clinical and research implications

These results were consistent with some studies. A study showed that pregnancies after Fre-ET had a smaller CRL than those after FET.[7] A data linkage study involving 161 infants conceived by Fre-ET and 204 infants conceived by FET[6] also found that infants born from Fre-ET showed a smaller CRL than those conceived by FET. However, some studies observed similar CRL between embryos conceived through Fre-ET and FET.[16,17] With a relatively larger sample size, we confirmed FET was associated with a larger CRL during the first trimester than Fre-ET and also demonstrated that the association was consistent among different subgroups.

Some studies have reported the association between embryonic development during early pregnancy and birthweight. A large CRL was associated with an increased birthweight.[18–20] Smith et al[15] and Mook-Kanamori et al[21] identified escalated risks of low birthweight, delivery of an SGA infant, and preterm birth in spontaneous conceptions with a smaller-than-expected infant in the first trimester. A previous study found no association between a small CRL in the first trimester of pregnancy and subsequent adverse birth outcomes such as preterm delivery, SGA, and low birthweight.[22] The potential explanation for these findings was that a smaller CRL than expected may not indicate slow early growth but rather an overestimation of the gestational age at the time of the ultrasound scan. This miscalculation could result from incorrect menstrual dates or delayed ovulation during the conception cycle. Our study showed that a smaller-than-expected CRL was associated with an increased risk of low birthweight, SGA, and preterm delivery. The gestational age was determined by the day of embryo transfer, which may exclude the effect of the above error in gestational age estimation. Evidence suggests that the duration of pregnancy and later complications can be traced to conditions in the earliest stages of pregnancy.[23] These findings support the importance of medical care during the first trimester of pregnancy in the prevention of perinatal complications.

The mechanism underlying the effect of FET on fetal growth was unclear. However, there were studies suggesting that the effect begins in early pregnancy. Shibli Abu Raya et al[24] found that compared with Fre-ET, the initial β-hCG and 2-day β-hCG increments were higher in the FET group. One possible explanation was that embryo cryopreservation improved mitochondrial function and cell viability in embryos with antioxidants in the medium.[25,26] Another possible reason may be the impact of ovarian stimulation on endometrial receptivity and placentation. Frozen embryos were transferred without controlled ovarian hyperstimulation, which may allow for normal placentation. During the fresh embryo transfer cycle, excess estrogen and progesterone produced by ovarian stimulation caused a nonphysiological hormonal environment that comprised the procedure of placentation.[27] One of the primary causes of placental-related fetal growth restriction was a deficiency in the remodeling of uterine spiral arteries supplying the placenta during early pregnancy.[28] Inadequate invasion and remodeling of maternal spiral arteries by the extravillous trophoblast during early pregnancy resulted in malperfusion of the placenta, resulting in hypoxia-reoxygenation stress and leading to selective suppression of protein synthesis and cell proliferation. That led to negative consequences on villous formation.[29] In the early stages of pregnancy, the placental villi had a limited supply of blood vessels and a lack of dense capillaries, which hindered the growth and development of the fetus because of a lack of nutrients.[30] After implantation of the embryo, maternal elevated levels of estrogen may persist for an extended period.[31] High estrogen levels in Fre-ET may affect the embryo's epigenetics, thus affecting fetal development.[32] It was possible that the

TABLE 3
Comparison of preterm delivery and birthweight between the fresh and FET groups in different CRL subgroups

Characteristics	Fre-ET	FET	*P* value
Normal CRL			
Preterm delivery	100/1401 (7.1)	246/3695 (6.7)	.543
Birthweight			
<2500 g	59/1401 (4.2)	121/3695 (3.3)	.106
>4000 g	123/1401 (8.8)	343/3695 (9.3)	.578
SGA	60/1401 (4.3)	92/3695 (2.5)	.001
LGA	288/1401 (20.6)	771/3695 (20.9)	.808
Smaller-than-expected CRL			
Preterm delivery	16/172 (9.3)	46/476 (9.7)	.890
Birthweight			
<2500 g	14/172 (8.1)	30/476 (6.3)	.412
>4000 g	12/172 (7.0)	34/476 (7.1)	.942
SGA	16/172 (9.3)	25/476 (5.3)	.061
LGA	28/172 (16.3)	82/476 (17.2)	.777
Larger-than-expected CRL			
Preterm delivery	10/201 (5.0)	36/668 (5.4)	.818
Birthweight			
<2500 g	2/201 (1.0)	12/668 (1.8)	.429
>4000 g	24/201 (11.9)	84/668 (12.6)	.811
SGA	2/201 (1.0)	8/668(1.2)	.490
LGA	55/201 (27.4)	177/668 (26.5)	.808

Note: Data are presented as n/N (%)

CRL, crown-rump length; *FET*, frozen embryo transfer; *Fre-ET*, fresh embryo transfer; *LGA*, large for gestational age (birthweight >90th percentile); *SGA*, small for gestational age (birthweight <10th percentile).

Yang. Larger crown-rump length in frozen embryo transfer group than fresh embryo transfer group. Am J Obstet Gynecol Glob Rep 2024.

TABLE 4
Comparison of preterm delivery and birthweight of singleton pregnancy between different CRL subgroups

Characteristics	Smaller-than-expected CRL	Normal CRL	Larger-than-expected CRL	*P* value
Preterm delivery	62/648 (9.6)	346/5139 (6.7)	46/869 (5.3)	.004
Birthweight				
<2500 g	44/648 (6.8)	180/5139 (3.5)	14/869 (1.6)	<.001
>4000 g	46/648 (7.1)	466/5139 (9.1)	108/869 (12.4)	.001
SGA	41/648 (6.3)	152/5139 (3.0)	10/869 (1.2)	<.001
LGA	110/648 (17.0)	1059/5139 (20.6)	232/869 (26.7)	<.001

Data are presented as n/N (%).

CRL, crown-rump length; *LGA*, large for gestational age (birthweight >90th percentile); *SGA*, small for gestational age (birthweight <10th percentile).

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unfavorable environment that hinders fetal growth during the fresh embryo transfer cycle may persist throughout the whole pregnancy till delivery. In addition, this mechanism explained that the subgroup with the highest estradiol on hCG trigger day in the Fre-ET group had a smaller CRL. In addition, FET was associated with higher birthweight than natural pregnancy, which means the process of embryo freezing procedure and endometrial preparation may affect CRL. The use of ovulation induction, endometrial preparation, and embryo vitrification may potentially interfere with the maintenance of imprinted genes during preimplantation, thus disrupting genomic imprinting.[33,34] Epigenetic changes may affect embryonic growth and development.

Strengths and limitations

There were strengths in this study. First, the sample size was relatively large, which allowed us to adjust for potential confounding factors and perform several subgroup analyses. These further analyses corroborated previous findings. Second, we have the follow-up data after CRL measurement and assessed the association between CRL in the early trimester and the final pregnancy outcomes. The findings of a higher risk of SGA, even in those with normal CRL among pregnancies after Fre-ET than FET, provided clues for further research on late fetal growth. In addition, this study had limitations. First, as a retrospective cohort study, the potential effect of bias and confounders on the results could not be ruled out. Second, women in the FET group exhibited better ovarian reserve and a higher number of embryos. The FET group may have a better prognosis. Further studies, especially prospective studies are needed to confirm our results.

Conclusion

In summary, FET was associated with a larger CRL than Fre-ET at 11-13 weeks gestation, suggesting that the effect of FET on fetal growth may begin in the early trimester. Suboptimal fetal growth in the first trimester was related to low

birthweight and premature delivery. The underlying mechanisms of FET on fetal growth warrant further investigations. ■

CRediT authorship contribution statement

Huiming Yang: Writing – original draft, Methodology, Investigation, Data curation. **Haozhe Miao:** Writing – original draft, Data curation. **Mengfei Yin:** Writing – original draft, Data curation. **Yixuan Wang:** Writing – original draft, Data curation. **Dingying Zhao:** Supervision. **Min Yang:** Supervision. **Jialin Zou:** Supervision. **Wenwen Zhang:** Formal analysis. **Lingling Zhang:** Formal analysis. **Chendan Liu:** Formal analysis. **Yue Wang:** Formal analysis. **Ze Wang:** Writing – review & editing. **Yunhai Yu:** Writing – review & editing. **Daimin Wei:** Writing – review & editing, Supervision, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.xagr.2024.100334.

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