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Exploring basal metabolic rate and dietary adequacy in twin pregnancies: the VENERE study

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Abstract

Background Twin pregnancies present unique challenges in maternal healthcare. However, current guidelines primarily address singleton pregnancies, resulting in a knowledge gap regarding their specific metabolic and dietary needs. This study aimed to follow women with twin pregnancies through all three trimesters, assessing basal metabolic rate (BMR), dietary intake, and diet quality.

Methods A two-year prospective observational study was conducted at AOU Careggi Hospital, Florence, Italy, involving 35 twin-pregnant women, with 32 completing the study. Participants underwent calorimetric, anthropometric, and dietary assessments during the first (8–13 weeks), second (14–27 weeks), and third trimesters (28–34 weeks). BMR was measured using indirect calorimetry and compared with predictive equations. Dietary intake was evaluated using 7-day food diaries and the Medi-Lite adherence score.

Results Indirect calorimetry revealed an increase in BMR by 16%, rising from 1479 ± 196 kcal in the first trimester to 1733 ± 224 kcal in the third trimester. Hronek's equation, previously validated for singleton pregnancies, was identified as the most accurate predictive tool for estimating BMR. Dietary analysis revealed that mean daily energy intake increased from 1660 ± 244 kcal in the first trimester to 1889 ± 262 kcal in the third trimester, consistently below recommendations, with insufficient macro- and micronutrient consumption. Poor diet quality was characterized by low intake of fruits, vegetables, legumes, and fresh fish, and high consumption of processed meats, cheese, and sugar-sweetened beverages. Adherence to the Mediterranean diet was moderate across all three trimesters.

Conclusions This study highlights the increased energy demands and nutritional inadequacies in twin pregnancies, underscoring the need for tailored dietary guidelines and interventions.

Keywords Twin pregnancy, Basal metabolic rate, Indirect calorimetry, Mediterranean diet, Dietary intake

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Introduction

In recent decades, the prevalence of twin pregnancies has notably increased, presenting unique challenges to maternal healthcare [1, 2]. Women carrying twins face elevated risks of complications, with significantly higher perinatal morbidity and mortality rates [3–5]. Poor dietary intake or deficiencies in essential micronutrients and macronutrients can strongly impact pregnancy outcomes and neonatal health, heightening the risk of pathologies such as congenital malformations, miscarriage, preeclampsia, gestational diabetes, preterm birth, and low birth weight [6]. Conversely, the benefits of a high-quality diet, such as the Mediterranean diet, for maternal and fetal health are well-documented [7, 8].

Despite extensive research and well-established guidelines for singleton pregnancies, our understanding of twin pregnancies remains limited, creating significant barriers to addressing their specific needs and risks. For example, although it is known that basal metabolic rate (BMR) increases more in twin pregnancies due to the larger placental mass, the exact magnitude of this increase and the disparity between actual and estimated metabolism remain unclear [9–11]. Similarly, while nutritional recommendations for singleton pregnancies are regularly updated, their applicability to twin pregnancies remains uncertain [12]. The literature generally agrees that the energy demand is higher in twin pregnancies, as reported by the Society of Maternal–Fetal Medicine [13], but specific energy intake requirements lack general international endorsement, and due to a scarcity of studies, recommended ranges are primarily theoretical assumptions [9–11]. This knowledge gap extends to vitamins and minerals, which are theoretically depleted faster in twin pregnancies, underscoring the need for careful monitoring of diet quality and potential nutrient deficiencies.

Therefore, additional studies are necessary to establish the energy demands of mothers and investigate their dietary habits in twin pregnancies. This study aimed to assess the BMR in twin-pregnant women throughout the first, second, and third trimesters using both indirect calorimetry and predictive equations. Additionally, we explored their dietary intake to understand diet quality and compliance with current recommendations.

Materials and methods

Study design and setting

A two-year prospective observational study was conducted at the AOU Careggi Multiple Pregnancy Outpatient Service in collaboration with the AOU Careggi Clinical Nutrition Unit, Florence, Italy, from October 2022 to May 2024. Twin-pregnant women enrolled during their initial obstetric visit underwent comprehensive monitoring throughout their pregnancy, with calorimetric, anthropometric, and dietary assessments conducted at three points: first trimester (8–13 weeks), second trimester (14–27 weeks), and third trimester (28–34 weeks). All participants underwent examinations between 7:30 am and 10:30 am following a 12-h fasting period.

The study received ethical approval from the Ethics Committee (CEAVC 21644/OSS, date of approval 13/07/2022) of the Tuscany Region, Careggi University Hospital, Florence. The study adhered to the principles outlined in the Declaration of Helsinki and the Data Protection Act. Informed consent was obtained from all participants.

Participants

Inclusion criteria comprised women aged ≥ 18 years with bichorionic biamniotic or monochorionic biamniotic twin pregnancies, whether spontaneous or obtained through assisted reproductive techniques. Exclusion criteria included age < 18 years, monochorionic monoamniotic or plurigeminal twin pregnancies, fetal genetic syndromes, metabolic conditions (e.g., pre-gestational diabetes mellitus), autoimmune diseases (e.g., dysthyroidism, systemic lupus erythematosus), psychiatric/eating disorders, malabsorption (e.g., chronic inflammatory bowel disease, coeliac disease), inability or unavailability to give informed consent, and/or non-understanding of the Italian language.

Data collection

Assessments and data collection were conducted at the AOU Careggi Multiple Pregnancy Outpatient Service and the Unit of Clinical Nutrition of the Careggi University Hospital by study staff. During the initial obstetric visit, participants were educated about the study's objectives and methods. Following their acceptance and signing of the informed consent, a nutritional visit was scheduled.

The standardized assessment included a questionnaire covering socio-demographic variables, pre-pregnancy weight, body mass index (BMI), previous medical and obstetrical history, pharmacological therapy, family history, and risk factors. Participants were then asked to complete a weighted 7-day dietary record, detailing the type and quantity of food and drinks consumed at each meal. To assess the accuracy of reported intake, we evaluated each participant's reported energy intake (EI) and used Goldberg's EI:BMR cut-off values, as revised by Black [13, 14], to identify potential dietary misreporting. Based on this analysis, 12 women (38%) were classified as potential under-reporters. However, a nutritional consultation indicated that common pregnancy symptoms, such as nausea and gastric fullness, likely contributed to their reduced intake. Given our aim to assess actual intake while accounting for these side effects, we included all participants in the analysis. The Metadieta software (Me.Te.Da., San Benedetto del Tronto, Italy) was used to calculate the mean total daily intake of calories, macronutrients, micronutrients, and energy distribution for meals, and these values were compared to those recommended by the

Society of Maternal–Fetal Medicine, which is generally accepted as a reference in twin pregnancy [15]. Additionally, the daily and weekly consumption of food groups and portion sizes were calculated based on the Italian Recommended Dietary Allowances (LARN) [16] and compared to the Italian Dietary Guidelines (CREA) [17]. Adherence to the Mediterranean diet was assessed using the Medi-Lite questionnaire [18], which assesses the consumption of nine food groups and categorizes consumption in accordance with the Mediterranean diet pattern. The final score ranges from 0 (low adherence) to 18 (high adherence).

Height and weight measurements were taken with a stadiometer and professional weighing scale, respectively, with BMI calculated as weight (kg)/height^2 (m^2). Ponderal status was defined using WHO standards for BMI cut-off points. The gestational weight gain (GWG) was compared to the Institute of Medicine (IOM) recommendations for twin pregnancy: 16.8–24.5 kg (37–54 lb) for women of normal weight, 14.1–22.7 kg (31–50 lb) for overweight women, and 11.3–19.1 kg (25–42 lb) for obese women [19].

Calorimetric assessment was conducted in fasting conditions using the Fitmate GS indirect calorimetry device (COSMED). The Fitmate GS is a portable desktop metabolic monitoring device that calculates resting metabolic rate (RMR), oxygen consumption (VO2), ventilatory power (VP), and expired fraction of oxygen (FEO2). Participants were instructed to fast for 12 h and avoid intense physical activity the day before the test. During the test, participants lay quietly for 30 min in a controlled environment, free from drafts, with a single operator present. After a 5-min calibration, VO2 was continuously measured for the next 25 min while participants remained awake but silent under a transparent hood. VO2 was averaged over this period and RMR was estimated using the abbreviated Weir equation: (3.9 × (VO2) + 1.1 × (RQ × VO2)) × 1.44, with a fixed RQ of 0.85. Additionally, RMR was estimated using the most commonly used predictive equations, as follows:

1. Harris-Benedict Eq. (female): REE (kcal/day) = 655.1 + (9.56 × weight (kg)) + (1.85 × height (cm)) – (4.68 × age (years)) [20]
2. Mifflin-St Jeor Eq. (female): REE (kcal/day) = (10 × weight (kg)) + (6.25 × height (cm))—(5 × age (years)) – 161 [21]
3. Hronek Eq. (pregnancy): REE (kcal/day) = 346.44 + 13.96 × weight (kg) + 2.70 × height (cm)—6.83 × age (years) [22]
4. Owen Eq. (female): REE (kcal/day) = 795 + 7,2 × weight (kg) [23]
5. Schofield Eq. (female) [24]

   age 18–30: REE (kcal/day) = 14.818 × weight (kg) + 486.6

   age > 30: REE (kcal/day) = 8.126 × weight (kg) + 845.6

Hronek equation is the only one that was specifically validated for pregnant women with single foetus, while the others are referred to general female population.

Statistical analysis

Statistical analyses were performed using IBM Statistical Package for Social Science for Macintosh version 27.0 (SPSS 27.0; IBM Corp., Armonk, NY, USA) with a significance level set at $p = 0.05$. Categorical variables were presented as frequencies (percentages), while continuous variables were expressed as mean ± standard deviation (SD). One-way ANOVA models were employed for differences in continuous variables, and Chi-square tests for categorical variables. Pearson correlation coefficients were used for correlation analyses. A linear regression model for repeated measures was used to test changes in BMR across twin pregnancy. For this test, data were first normalized into logs and then, after data analysis, converted back to the original scale (antilog) to facilitate interpretation. Bland–Altman analysis and intraclass correlation coefficient (ICC) were used to assess agreement and reliability of predictive equations compared to indirect calorimetry in estimating BMR.

Results

Characteristics of study participants

Thirty-five women carrying twins were enrolled in the study, of whom 32 completed the follow-up and were included in the analysis. Table 1 summarizes the socio-demographic and clinical characteristics of study participants at baseline. The cohort was predominantly Caucasian (97%), with a mean maternal age of 35.6 ± 4 years. Most women were primiparous (72%) and conceived spontaneously (69%). The mean pre-pregnancy BMI was 24.1 ± 3.9 kg/m^2, with 19 women (59%) exhibiting normal weight. Participants were mainly sedentary (59%) or practiced light physical activity, such as walking (41%).

Anthropometric and calorimetric parameters

Total weight gain at the end of the pregnancy was 12.9 ± 4.9 kg, with 7 women (22%) reaching the IOM recommendations [19]. In most cases (75%), GWG was lower than expected, while 1 woman (3%) exceeded the guidelines range.

In the first trimester, indirect calorimetry showed a mean BMR of 1479 ± 196 kcal, which increased to 1571 ± 187 kcal in the second trimester (+6%) and to 1733 ± 224 kcal in the third trimester (+10%). Linear regression analysis showed that BMR increased gradually

Table 1 Baseline characteristics of the study population

Characteristics	Mean ± SD or n (%)
Maternal age, y	35.6 ± 4.0
Maternal race/ethnicity	31 (96.9)
Caucasian	1 (3.1)
Arab	
Gravidity	19 (59.4)
Primigravida	13 (40.6)
Multigravida	
Parity	23 (71.9)
Nulliparous	9 (28.1)
Multiparous	
Mode of conception	22 (68.8)
Spontaneous	10 (31.2)
IVF	
Type of pregnancy	25 (78.1)
BCBA	7 (21.9)
MCBA	
Smoking habit	12 (37.5)
Ex-smokers	20 (62.5)
Non-smokers	
Type of diet	31 (96.9)
Omnivorous diet	1 (3.1)
Pesco-vegetarian diet	
Light physical activity	13 (40.6)
Supplements	27 (84.4)
Multivitamin	12 (37.5)
Folic acid only	14 (43.8)
Vitamin D only	5 (15.6)
Iron only	
Pre-pregnancy BMI, kg/m^2	24.1 ± 3.9
Underweight	2 (6.2)
Normal weight	19 (59.4)
Overweight	10 (31.3)
Obesity	1 (3.1)

BCBA bichorial biamniotic, *BMI* body mass index, *IVF* in vitro fertilization, *MCBA* monochorial biamniotic

at a mean rate of 15 kcal/gestational week from week 11 to week 34. Results on the agreement between the usual predictive equations and indirect calorimetry in estimating BMR are shown in Table 2. Hronek's equation was the most accurate, with moderate to good reliability in the first (ICC = 0.77; p < 0.001), second (ICC = 0.70; p < 0.001), and third trimester (ICC = 0.79; p < 0.001). All the other equations tended to underestimate maternal BMR.

Eating habits and diet quality

Analysis of weekly food diaries revealed a mean daily energy intake of 1660 ± 244 kcal in the first trimester, which increased by approximately 140 kcal in the second trimester (1801 ± 264 kcal) and by 90 kcal from the second to the third trimester (1889 ± 262 kcal). Baseline analysis showed a daily energy breakdown of 46 ± 7% from carbohydrates, 16 ± 2% from proteins, and 38 ± 56% from fats. The mean energy distribution for meals was 17 ± 4% for breakfast, 6 ± 4% for a mid-morning snack, 33 ± 4% for lunch, 9 ± 3% for a mid-afternoon snack, 33 ± 6% for dinner, and 2 ± 3% for a post-dinner snack. These results did not differ consistently across the trimesters. Regarding diet quality, the Medi-Lite score indicated moderate adherence to the Mediterranean diet in the first (11.1 ± 1.7), second (11.3 ± 1.7), and third trimesters (11.5 ± 1.7), with no significant differences over time.

Table 3 provides detailed information on energy, macro-, and micronutrient intake across each trimester, categorized by pre-pregnancy BMI, and compares these values to the recommendations of the Society of Maternal–Fetal Medicine [15]. None of the participants achieved the recommended levels of energy and macronutrient intake during any trimester. Moreover, all women reported lower micronutrient intake than

Table 2 Reliability of predictive equations in estimating maternal BMR across twin pregnancy

		Indirect calorimetry	Harris-Benedict eq	Mifflin-St. Jeor eq	Hronek eq	Owen eq	Schofield eq
1st trimester	BMR	1479 ± 196.1	1447.6 ± 131.1	1382.6 ± 154.2	1503.5 ± 191.5	1285.2 ± 91.3	1398.8 ± 103
	ICC		0.74	0.75	0.77	0.65	0.68
	95%CI		0.46–0.87	0.48–0.88	0.54–0.89	0.28–0.83	0.35–0.85
	p-value		< 0.001	< 0.001	< 0.001	0.002	0.001
2nd trimester	BMR	1571 ± 186.5	1501.9 ± 138.2	1439.5 ± 161.7	1582.9 ± 201.8	1326.1 ± 96.9	1452.6 ± 126
	ICC		0.68	0.67	0.70	0.61	0.63
	95%CI		0.35–0.84	0.33–0.84	0.38–0.85	0.20–0.81	0.23–0.82
	p-value		0.001	0.001	< 0.001	0.005	0.004
3rd trimester	BMR	1732.8 ± 223.8	1557.8 ± 140.8	1497.9 ± 163.7	1664.5 ± 205.6	1368.2 ± 98.9	1492.5 ± 111.6
	ICC		0.75	0.75	0.79	0.66	0.70
	95%CI		0.48–0.88	0.49–0.88	0.57–0.90	0.31–0.84	0.38–0.85
	p-value		< 0.001	< 0.001	< 0.001	0.002	< 0.001

BMR basal metabolic rate, *CI* confidence interval, *ICC* intraclass correlation coefficient, *SD* standard deviation

Data are reported as mean ± standard deviation

Table 3 Daily intake of calories, macro- and micronutrients, compared to nutritional guidelines across twin pregnancy

	1st trimester	2nd trimester	3rd trimester	RDA*(1st)	RDA* (2nd-3rd)
Total calories (kcal)					
Underweight	1736 ± 29	1919 ± 92	1959 ± 164	4000	4000
Normal weight	1627 ± 240	1799 ± 236	1866 ± 248	3000–3500	3000–3500
Overweight	1767 ± 187	1845 ± 275	1984 ± 224	3250	3250
Obesity	1068	1159	1228	2700–3000	2700–3000
Proteins (g)					
Underweight	76.2 ± 6.6	71.5 ± 6.7	72.5 ± 15.9	200	200
Normal weight	65.2 ± 11.3	73.3 ± 9.4	78.5 ± 17.9	175	175
Overweight	72.4 ± 16.3	76.9 ± 18.2	83.3 ± 15.9	163	163
Obesity	40.3	43.7	46.3	150	150
Carbohydrates (g)					
Underweight	265.3 ± 58.2	260 ± 19.8	256.4 ± 2.3	400	400
Normal weight	206.2 ± 50.2	222 ± 40.1	222 ± 43.6	350	350
Overweight	218 ± 27.4	217.8 ± 45.2	240.3 ± 42.7	325	325
Obesity	95.3	103.4	109.6	300	300
Fats (g)					
Underweight	70 ± 0.3	72.8 ± 4.7	79.2 ± 10.8	178	178
Normal weight	65.8 ± 11.7	74.5 ± 16.5	79.7 ± 16	156	156
Overweight	73.2 ± 16.4	79.7 ± 12.7	83.2 ± 20.7	144	144
Obesity	61	61	70.2	133	133
Total fibre (g)	18.4 ± 5.2	19.7 ± 6.4	20.7 ± 6.9	NA	NA
Iron (mg)	8.7 ± 2.4	9.3 ± 3.1	10 ± 3	30	60
Calcium (mg)	592.5 ± 159.9	629.9 ± 173.8	730 ± 215.9	1500	2500
Vitamin D (mcg)	1.7 ± 1.1	1.7 ± 1.1	1.8 ± 1.4	25	25
Magnesium (mg)	143.9 ± 62.7	146.1 ± 70.5	175.6 ± 71.7	400	800
Zinc (mg)	8.2 ± 1.7	8.9 ± 1.9	9.9 ± 2.5	15	30
DHA + EPA (mg)	209.3 ± 103.5	197.2 ± 112.3	207.5 ± 124.6	300–500	300–500
Folic acid (mg)	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.2	1	1
Vitamin C (mg)	111.4 ± 68.3	114.5 ± 68.8	108.5 ± 76.7	500–1000	500–1000
Vitamin E (mg)	10.5 ± 2.8	11.4 ± 3.3	16.1 ± 24.6	266.8	266.8
Vitamin B12 (mcg)	3.5 ± 2.2	4 ± 3	3.7 ± 1.9	NA	NA

NA not available; *RDA* recommended dietary allowance

* Dietary guidelines for twin pregnancy (*Goodnight* et al. *2009*)

the nutritional recommendations for twin pregnancies, except for DHA/EPA, which was optimally consumed by 7 participants (22%).

Daily/weekly portion intake of food groups in each trimester of twin pregnancy is depicted in Fig. 1. The analysis of portion sizes and consumption frequencies revealed a low average intake of plant-based foods. Specifically, no women in any trimester reached the recommended intake of vegetables, and the consumption of fruit, bread, and cereals was lower than expected. Conversely, cheese and processed meat intake was higher, while intake of fish, eggs, and legumes was lower. More than half of the women also exceeded the intake of sugar-sweetened beverages and sweets.

Discussion

This is the first study to longitudinally assess women with twin pregnancies through all three trimesters, focusing on both BMR and diet quality. Our findings reveal that BMR increased by approximately 6% from the first to the second trimester and by 10% from the second to the third trimester. Additionally, Hronek's equation, previously validated for singleton pregnancies, proved to be the most reliable predictive tool for estimating BMR compared to indirect calorimetry. In each trimester, dietary intakes of energy, macro- and micronutrients were below current recommendations for twin pregnancies, and diet quality was suboptimal when assessed against Italian dietary guidelines [16, 17].

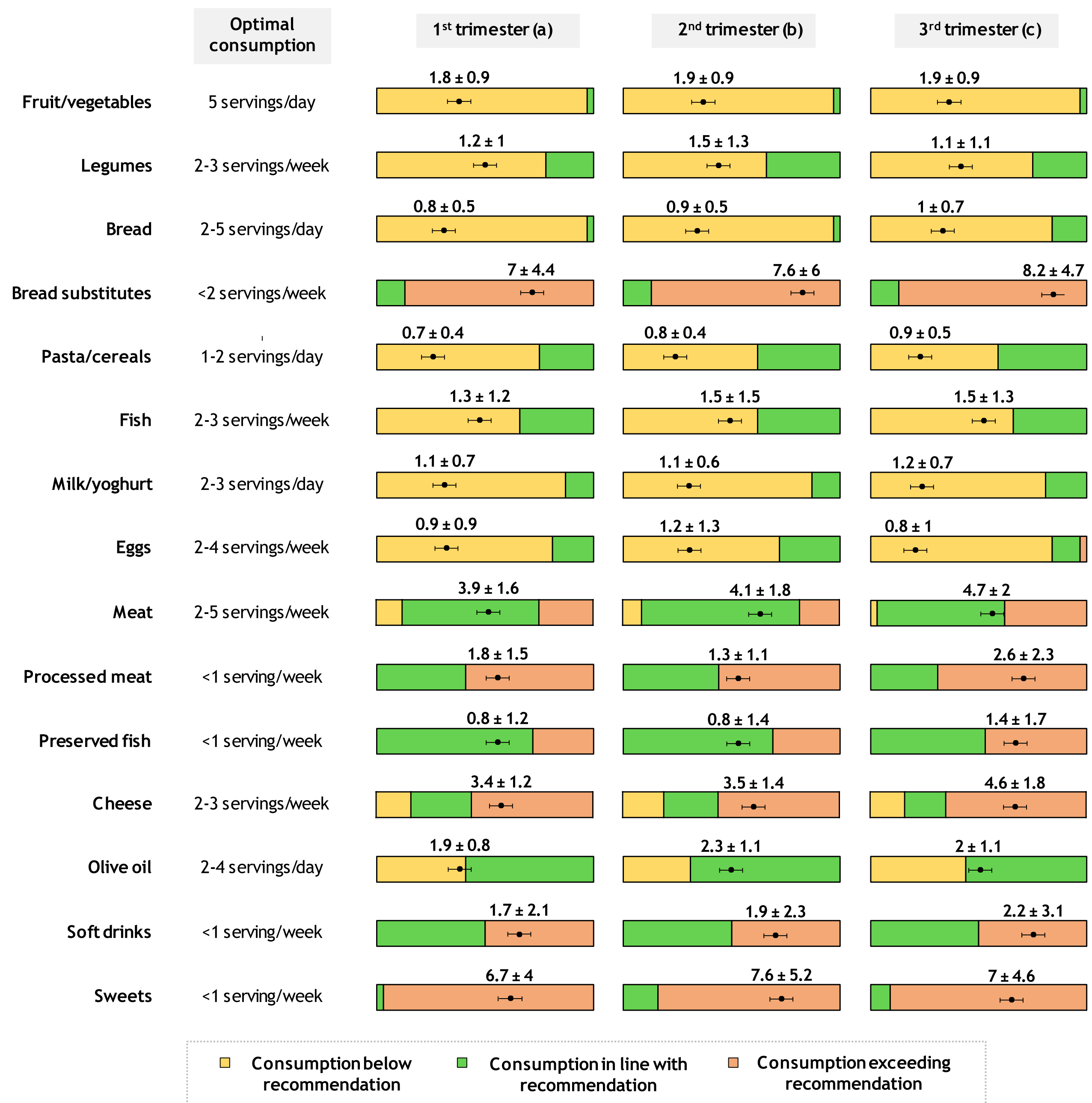

Fig. 1 Daily/weekly portion intake of food groups in each trimester of twin pregnancy Data are reported as mean ± standard deviation servings were calculated according to the portion sizes recommended by the Italian Recommended Dietary Allowances (fruit: 150 g; vegetables: 200 g; legumes: 150 g; bread: 50 g; bread substitutes: 30 g; pasta/cereals: 80 g; fish: 150 g; milk/yoghurt: 125 ml; eggs: 50 g; meat: 100 g; processed meat: 50 g; processed fish: 50 g; cheese: 75 g; olive oil: 10 ml; soft drinks 200 ml: sweets: 20 g

Understanding how energy expenditure and energy requirements vary during the three trimesters of a twin pregnancy is crucial due to the increased risks and challenges associated with multiple gestations. Previous studies indicate higher metabolic demands in twin pregnancies, primarily due to larger placental mass, greater fetal growth, and maternal adaptations, including higher cardiac output and hormonal changes such as increased progesterone, which elevates respiratory rate and oxygen consumption by 20% [25, 26]. Quantifying this increase, however, is challenging due to the limited literature, with only two studies evaluating this aspect [27, 28]. Shinagawa et al. [27] reported a third trimester resting energy expenditure (REE) of 1636 kcal/day, which is slightly lower than our BMR results. Conversely, Gandhi et al. [28] observed an increase in REE from 1392 to 1752 kcal/day across the three trimesters, corresponding to an incremental rise of 21 kcal per gestational week. Our study observed a similar trend, with BMR increasing from 1479 to 1733 kcal/day in the third trimester, reflecting a weekly increase of 15 kcal. The discrepancy in the rate of increase per gestational week may be attributed to the lower baseline BMR observed in Gandhi's cohort.

Regarding the analysis of dietary intake, our study showed a mean daily energy intake reported by the women increasing from about 1700 kcal in the first trimester to about 1900 kcal in the third trimester. These values are consistently below the recommended levels for twin pregnancy, which range from 2700 to 4000 kcal/day, depending on pre-pregnancy BMI [15, 29, 30]. Similar differences were reported by Morley et al., with median daily energy intake ranging from 2363 to 2388 kcal at 29–35 weeks of gestation [31]. These findings, however, are not completely surprising, as the average total energy intake seems to be below the average total energy required during pregnancy in singleton pregnancies as well, as reported by a recent meta-analysis [32]. This may be explained by typical pregnancy symptoms such as nausea, vomiting, and early satiety due to fetal mass pressure on the maternal abdomen [33]. These symptoms are even more pronounced in twin pregnancies, making it challenging to meet the high energy requirements specified in the guidelines.

Participants also reported poor diet quality, characterized by insufficient intake of fruits, vegetables, legumes, cereals, and fresh fish, and excessive consumption of processed meats, preserved fish, cheese, sugar-sweetened beverages, and sweets, relative to Italian dietary guidelines [16, 17]. This aligns with findings from a recent U.S. study on dietary intake in twin pregnancies [34] and a larger cohort study based on 1535 women with single pregnancy, showing a suboptimal intake of vegetables and legumes, and an overconsumption of refined grains [35]. This could lead to micronutrient deficiencies, impacting fetal development and maternal health. In our study, indeed, the intake of essential micronutrients such as iron, calcium, and vitamins D and B12 was found to be insufficient compared with the recommendations. In addition, while 85% of women reported using dietary supplements, the remaining 15% did not take supplements. This is especially concerning given the insufficient intake of nutrients through diet alone. Nutrient deficiencies can have serious implications, including increased risks of preterm birth, low birth weight, and developmental issues [33, 36]. Furthermore, supplement use cannot completely replace a healthy diet. Adherence to the Mediterranean diet, known for its positive impact on pregnancy outcomes, was only moderate among participants, consistent with a similar study on singleton pregnancies that reported a mean Medi-Lite score of 11 [37].

This study has several limitations that should be acknowledged. Firstly, the relatively small sample size may limit the generalizability of the findings, necessitating larger studies to confirm these results and ensure their applicability to a broader population of twin-pregnant women. Secondly, the reliance on self-reported dietary intake data may introduce recall bias and inaccuracies. Although participants received detailed instructions for completing the 7-day food diaries and ongoing telephone support, 38% of the women were still classified as under-reporters based on Goldberg's cut-off values [13]. While this under-reporting may be partly due to pregnancy-related symptoms, such as nausea and gastric fullness, we acknowledge that, unlike biochemical measures that are not subject to self-reporting errors, dietary data remain vulnerable to inaccuracies that cannot be fully ruled out. Nonetheless, this study has several strengths. Longitudinal studies following twin pregnancies are scarce, making our results a significant contribution to the existing literature. Additionally, the use of indirect calorimetry and detailed dietary assessments – considered gold standards for BMR and dietary intake measurement – adds robustness to our findings. The comparison of values obtained with indirect calorimetry to various predictive equations further enhances the study's value, particularly for clinical practice, as there are currently no predictive equations specifically designed for twin pregnancies. Hronek's equation emerged as the most accurate and reliable, demonstrating moderate to good reliability across all trimesters. This finding suggests that Hronek's equation could be a valuable tool for estimating BMR in twin pregnancies in the absence of indirect calorimetry, thereby aiding in the development of more accurate dietary recommendations.

In conclusion, this study examines metabolic and dietary intake patterns in twin pregnancies, a type of gestation often overlooked in obstetric research despite its rising incidence in developed countries. While these findings are based on a small sample size and self-reported dietary data, which may introduce bias, the observed increase in BMR across the three trimesters highlights the heightened energy demands of twin pregnancies. The dietary inadequacies noted also underscore the need for targeted nutritional counseling and intervention. Healthcare providers should focus on helping women carrying twins meet their increased energy and nutrient needs through a balanced diet and appropriate supplementation, providing practical guidance and support throughout pregnancy. Additionally, future research should prioritize longitudinal studies that include pre-pregnancy and postpartum data, which are essential for a more comprehensive understanding of BMR and dietary needs and for developing tailored nutritional guidelines for twin pregnancies.

Author contributions
M.D., B.C., M.D.T and F.S. conceived and designed the study. M.D., A.N. and F.S. analysed and interpreted the data. M.D. and A.N. drafted the article. M.D., A.N., I.G., S.L., A.R., I.R., L.N., I.P., V.S., M.T.A., G.P. and F.S. evaluated the patients. M.D., B.C., M.D.T. and F.S. critically revised the article for important intellectual content. All authors reviewed the manuscript.

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Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study received ethical approval from the Ethics Committee (CEAVC 21644/OSS, date of approval 13/07/2022) of the Tuscany Region, Careggi University Hospital, Florence. The study adhered to the principles outlined in the Declaration of Helsinki and the Data Protection Act. Informed consent was obtained from all participants.

Consent for publication
Patients signed informed consent regarding publishing their data.

Competing interests
The authors declare no competing interests.

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