Association of body composition in early pregnancy with gestational diabetes mellitus: A meta-analysis

Fatemeh Alsadat Rahnemaei1*, Fatemeh Abdi2*, Reza Pakzad3*, Seyyedeh Hajar Sharami4*, Fatemeh Mokhtari5*, Elham Kazemian6*

1 Department of Obstetrics & Gynecology, Midwifery, Reproductive Health Research Center, Al-zahra Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran, 2 Non-communicable Diseases Research Center, Alborz University of Medical Sciences, Karaj, Iran, 3 Epidemiology, Faculty of Health, Ilam University of Medical Sciences, Ilam, Iran, 4 Department of Obstetrics & Gynecology, Reproductive Health Research Center, Al-zahra Hospital, School of Medicine, Guilan University of Medical Sciences, Rasht, Iran, 5 Department of Midwifery, Reproductive Health, Faculty of Nursing and Midwifery, Isfahan University of Medical Sciences, Isfahan, Iran, 6 Department of Medicine, Samuel Oschin Comprehensive Cancer Institute, Cedars-Sinai Medical Center, Los Angeles, CA, United States of America

These authors contributed equally to this work.
* abdi@sbmu.ac.ir, fatemeh.abdi87@yahoo.com

Abstract

Introduction

Body composition as dynamic indices constantly changes in pregnancy. The use of body composition indices in the early stages of pregnancy has recently been considered. Therefore, the current meta-analysis study was conducted to investigate the relationship between body composition in the early stages of pregnancy and gestational diabetes.

Method

Valid databases searched for papers published from 2010 to December 2021 were based on PRISMA guideline. Newcastle Ottawa was used to assess the quality of the studies. For all analyses, STATA 14.0 was used. Mean difference (MD) of anthropometric indices was calculated between the GDM and Non-GDM groups. Pooled MD was estimated by “Metan” command, and heterogeneity was defined using Cochran’s Q test of heterogeneity, and $I^2$ index was used to quantify heterogeneity.

Results

Finally, 29 studies with a sample size of 56438 met the criteria for entering the meta-analysis. Pooled MD of neck circumference, hip circumference, waist hip ratio, and visceral adipose tissue depth were, respectively, 1.00 cm (95% CI: 0.79 to 1.20) [N = 5; P$^2$: 0%; p: 0.709], 7.79 cm (95% CI: 2.27 to 13.31) [N = 5; I$^2$: 84.3%; P<0.001], 0.03 (95% CI: 0.02 to 0.04) [N = 9; I$^2$: 89.2%; P<0.001], and 7.74 cm (95% CI: 0.11 to 1.36) [N = 4; I$^2$: 95.8%; P<0.001].
**Conclusion**

Increased neck circumference, waist circumference, hip circumference, arm circumference, waist to hip ratio, visceral fat depth, subcutaneous fat depth, and short stature increased the possibility of developing gestational diabetes. These indices can accurately, cost-effectively, and affordably assess the occurrence of gestational diabetes, thus preventing many consequences with early detection of gestational diabetes.

**Introduction**

Gestational diabetes mellitus (GDM) is defined as carbohydrate intolerance with varying degrees that is first diagnosed in pregnancy [1]. GDM usually begins in the second half of pregnancy when the mother is unable to secrete enough insulin to compensate for the nutritional increase in pregnancy and the possible increase in fat and anti-insulin hormones that occur during pregnancy (such as human placental hormone, cortisol, and prolactin) [2]. GDM has many maternal and fetal consequences that can be both short-term and long-term [3].

Several risk factors increase GDM, including aging, GDM history, body mass index (BMI) greater than 30 kg/m², family history of diabetes, history of a macrosomic infant weighing 4.5 kg, and race [4]. Other maternal complications include shoulder dystocia, preeclampsia, cesarean section, type-2 diabetes, metabolic syndrome, and cardiovascular disease [5–7]. Neonatal complications also include macrosomia, neonatal trauma, hypoglycemia, and other metabolic disorders of the neonatal period [8, 9].

Many maternal and neonatal complications can be improved by careful monitoring of blood glucose during pregnancy, medical treatments (insulin and metformin), diet, physical activity, and lifestyle changes [10, 11].

In 2010, the International Association of Diabetes and Pregnancy Study Groups (IADPSG) developed new diagnostic criteria for GDM, based for the first time on adverse pregnancy outcomes [12]. In 2013, the World Health Organization (WHO) defined the IADPSG criteria adjusted during the 75 g OGTT threshold to 1.75 times the odds ratio for adverse pregnancy outcomes by reducing fasting glucose concentrations by 5.1, 1-h 10, and/or 2-h 8.5 mmol per liter [13].

The global prevalence of gestational diabetes is estimated 1 to 28%; this difference is due to differences in the criteria for measuring GDM, age, race, ethnicity, lifestyle, and history of the populations in which the prevalence was measured [14–16].

Normal pregnancy is characterized by a physiological reduction of 50–60% in insulin sensitivity [17]. Studies have reported that the likelihood of GDM increases with maternal weight gain, especially in early pregnancy. Numerous studies have been conducted worldwide to identify effective risk predictors to support early prevention or treatment [18, 19].

Measurement of body composition seems to be a practical method for potential screening of GDM [20]. Body composition is a risk factor for conditions such as diabetes, preeclampsia, and gestational hypertension [21, 22]. Obesity is a powerful predictor of GDM, and abdominal obesity is a powerful factor in the development of GDM and future diabetes [23, 24]. However, obesity is a complex process in which the distribution of body fat is involved, and body fat leads to adverse metabolic and cardiovascular consequences [25]. Studies show that increasing body composition, especially body fat, is closely related to glucose metabolism in humans [26]. But data on body composition and anthropometric indices are low. Studies show that weight
gain in the first 2–3 months is composed of more fat mass, and patients with higher BMI gain more fat mass [15, 16] which can affect subsequent maternal insulin resistance [27].

However, there are other anthropometric indices that have been considered recently. In addition to showing more accurate information about body composition, they can also predict pregnancy outcomes, including GDM in pregnant women. For example, measurement of visceral abdominal adipose tissue (VAT) [28], neck circumference (NC), hip circumference (HC) and waist circumference (WC) [29], percentage of skeletal muscle mass and percentage of fat mass [30], and central obesity [31] can be used as an approach to predict occurrence GDM. Previous meta-analysis studies have shown a direct relationship with indices of general body obesity including WC, waist to hip ratio (WHR), and VAT with GDM [32].

In this study, according to the time period searched (1985–2020), a small number of studies were analyzed; in addition, a small number of anthropometric indices indicating the body composition were examined. Therefore, the present study was performed by reviewing the updated studies and all anthropometric indices expressed in the studies and using an accurate model in the early stages of pregnancy in a systematic review and meta-analysis to investigate the relationship between anthropometric indices expressing body composition and GDM.

Materials and methods

This study was approved by Alborz University of Medical Sciences (ethical code: IR. ABZUMS.REC.1400.241). Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were observed in the report of the study. PRISMA contains 27 items related to the content of a systematic and meta-analysis, and includes abstracts, methods, results, discussions, and financial resource [33, 34]. Participant consent for this study is not applicable. This study was registered on PROSPERO website by "CRD42022302813" ID.

Search strategy

PubMed, Web of Science, Scopus, Google Scholar, and ProQuest were searched from 2010 to December 2021. MESH keywords and search strategy were as below:

1. ‘Gestational diabetes’ [tiab], OR ‘GD’ [tiab], OR ‘Gestational Diabetes Mellitus’ [tiab], OR ‘GDM’ [tiab], OR ‘pregnancy induced diabetes’[tiab]

2. ‘Anthropometric indicators’ [tiab], ‘Anthropometric indices’ [tiab], OR ‘body size’[tiab], OR ‘body composition’ [tiab] OR, ‘Waist/Hip Ratio’ [tiab], OR ‘WHR’ [tiab], OR ‘visceral fat mass’ [tiab], OR ’VFM’ [tiab], OR ’Neck circumference’ [tiab], OR ‘hip circumference’ [tiab], OR ’waist circumference’ [tiab], OR ’subcutaneous adipose tissue’ [tiab], OR ‘skeletal muscle mass percentage’ [tiab], ‘total adipose tissue thickness’ [tiab], OR ‘subcutaneous adipose tissue’[tiab], OR ’Subcutaneous fat thickness’ [tiab], OR ’visceral adipose tissue depth’ [tiab], OR ’skinfold thickness’ [tiab], OR ’mid upper arm circumference’ [tiab], OR ’subcutaneous fat thickness’ [tiab], OR ’fat mass percentage’ [tiab], OR ’fat mass index’ [tiab], OR ’muscle mass percentage’ [tiab], OR ’Skinfold Thickness’ [tiab]

3. ‘Pregnancy’ [tiab], OR ‘Pregnancies’ [tiab], OR ‘Gestation’[tiab], OR ’early pregnancy’ [tiab]

4. #1 AND #2

5. #1 AND #2 AND #3
Eligibility criteria

Inclusion and exclusion criteria. We set our inclusion and exclusion criteria based on PICO criteria (population, intervention, comparison, outcome, and study design) (Table 1).

Study selection

The initial search yielded 3523 results. The eligibility of these articles was independently evaluated by two authors, and disagreements were resolved by consensus. In the first stage, 2108 irrelevant or duplicate articles were excluded. After reviewing the titles and abstracts of the remaining articles, 918 more papers were excluded. In the evaluation of the full texts, 139 ineligible articles were excluded out of the remaining 180 articles. Finally, a total of 41 eligible articles were reviewed and 29 articles meets criteria to meta-analysis (Fig 1).

Quality assessment

Newcastle Ottawa scale (NOS) was used to measure the quality of studies. This scale is used to measure the quality of cohort and case control studies. The validity and reliability of this tool have been proven in various studies [35, 36].

Data extraction

Two authors independently performed the study selection and validity assessment and resolved any disagreements by consulting a third researcher. Author, year, study design, geographic region, maternal age, diagnostic criteria of GDM, anthropometric indices, accompanying factors, results, and quality assessment scores were extracted from articles.

Statistical analysis

All analyses were conducted with STATA 14.0 (College Station, Texas). For each study, mean value and standard deviation (SD) of anthropometric indices were extracted; if IQR was

| Selection criteria | Inclusion criteria | Exclusion criteria |
|--------------------|--------------------|--------------------|
| Population         | Healthy pregnant women with single fetus and at reproductive age group, GDM based on the diagnostic criteria, Gestational age considered for each study based on ultrasound, Studies were published until December 2021, Full-text available and with no language restrictions | Multiple pregnancies, women taking steroids, pre-pregnancy diabetes, maternal medical disorders such as liver, kidney, thyroid, fetal abnormalities, ovarian cysts, and maternal age less than 18 years |
| Exposure           | Body composition (WHR, visceral adipose mass, NC, HCWC, subcutaneous adipose tissue (SAT), skeletal muscle mass percentage (SMMP), total adipose tissue thickness(TAT), VAT, skinfold thickness, mid upper arm circumference(MUAC), fat mass percentage (FMP), fat mass index(FMI), muscle mass percentage(MMP), skinfold thickness | Other body composition |
| Comparison         | Healthy control group | GDM was combined with other maternal pregnancy complications (HDP, eclampsia, and pre-eclampsia); ethnicity, food habits, and separation were difficult. |
| Outcome            | GDM according to different screening protocols | - |
| Study design       | Cohort, case control, and cross sectional | Case study, case series, case report, lack of access to full text articles, review articles, letter to editor |

https://doi.org/10.1371/journal.pone.0271068.t001
reported, we changed it to SD with IQR/1.35. Then, the mean difference (MD) of anthropometric indices was calculated between GDM and non-GDM group for each study. Then, standard error (SE) of MD was calculated for each study using the following formula:

\[ SE_{MD} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}} \]

Where, \( \sigma_1^2 \), \( n_1 \), \( \sigma_2^2 \), and \( n_2 \) are variance values, and samples size in GDM and control groups, respectively. Then, pooled MD was calculated by “Metan” command [37]. Heterogeneity was determined using Cochran’s Q test of heterogeneity, and the \( I^2 \) index was used to quantify heterogeneity. In accordance with Higgins classification approach, \( I^2 \) values above 0.7 were considered as having high heterogeneity. To estimate the pooled MD for anthropometric indices, the fixed-effect model was used; when heterogeneity was greater than 0.7, the random effects model was used. The meta-regression analysis was used to examine the effect of publication year, age, sample size, and study design as factors affecting heterogeneity among studies. The
"meta bias" command [38] was used to check for publication bias, and if there was any publication bias, the pooled MD was adjusted with the "meta trim" command using the trim-and-fill method [39]. In all analyses, significance level was considered 0.05.

Results

Twenty-nine studies with a sample size of 56,438 met the meta-analysis inclusion criteria (Table 1). Fig 1 shows the flowchart of the study selection process. Anthropometric indices values for the groups with and without GDM of included studies are given in Table 5.

Pooled MD of anthropometric indices

Table 2 shows the pooled MD of all anthropometric indices. As shown in Table 2, twelve studies were carried out for waist circumference, five studies for neck and hip circumference, nine studies for waist hip ratio and height, six studies for subcutaneous adipose tissues, four studies for visceral adipose tissue depth, three studies for mid upper arm circumference, two studies for fat mass index and skeletal muscle mass percentage, and one study for other indices. Fig 2 shows the pooled MD of waist circumference for included studies. The lowest and highest MDs were reported by Kansu-Celik et al. [40] in Turkey (MD: -1.67; 95% CI: -11.30 to 7.96).

Table 2. Pooled MD (95% confidence interval) and heterogeneity of anthropometric indices.

| Outcomes                                | Heterogeneity index | Number of studies | Pooled MD (95% CI)  |
|-----------------------------------------|---------------------|-------------------|---------------------|
| Waist circumference (cm)                | I^2: 78.2%; p<0.001 | 12                | 6.83 (5.37 to 8.30) |
| Neck circumference (cm)                 | I^2: 0%; p: 0.709   | 5                 | 1.00 (0.79 to 1.20) |
| Hip circumference (cm)                  | I^2: 84.3%; p<0.001 | 5                 | 7.79 (2.27 to 13.31)|
| Waist Hip Ratio                         | I^2: 89.2%; p<0.001 | 9                 | 0.03 (0.02 to 0.04) |
| Height (cm)                             | I^2: 0%; p: 0.975   | 9                 | -0.24 (-0.37 to -0.10)|
| Visceral Adipose Tissue Depth (cm)      | I^2: 95.8%; p<0.001 | 4                 | 0.74 (0.11 to 1.36) |
| Fat mass percentage                     | I^2: ---; p: ---    | 1                 | 44.82 (39.92 to 49.72) |
| Subcutaneous adipose tissues (cm)       | I^2: 100%; p<0.001  | 6                 | 2.15 (-1.66 to 5.96) |
| Total adipose tissues thickness (cm)    | I^2: ---; p: ---    | 1                 | 1.23 (0.67 to 1.79) |
| Fat mass Index (kg/m^2)                 | I^2: 85.4%; p: 0.009| 2                 | 0.89 (0.43 to 1.35) |
| Skeletal muscle mass percentage         | I^2: 83.2%; p: 0.015| 2                 | -2.11 (-3.61 to -0.61) |
| Fat free mass (42)                      | I^2: ---; p: ---    | 1                 | 2.14 (2.00 to 2.28) |
| Muscular mass [42]                      | I^2: ---; p: ---    | 1                 | 1.29 (1.21 to 1.37) |
| Skin fold fat thickness (mm)            | I^2: ---; p: ---    | 1                 | 68.40 (36.20 to 100.6) |
| Mid upper arm circumference (mm)        | I^2: 0%; p: 0.655   | 3                 | 0.08 (0.06 to 0.10) |
| Intra peritoneal fat thickness (mm)     | I^2: ---; p: ---    | 1                 | 11.71 (1.31 to 22.11) |
| Perirenal fat thickness (mm)            | I^2: ---; p: ---    | 1                 | 0.57 (-3.66 to 4.80) |
| Fat mass [42]                           | I^2: ---; p: ---    | 1                 | 2.44 (2.28 to 2.60) |
| Visceral fat level                      | I^2: ---; p: ---    | 1                 | 0.27 (0.25 to 0.29) |
| Lean trunk mass [42]                    | I^2: ---; p: ---    | 1                 | 1.04 (0.97 to 1.11) |
| Fat free mass percentage                | I^2: ---; p: ---    | 1                 | -1.71 (-2.20 to -1.22) |
| Fat mass fat free mass ratio            | I^2: ---; p: ---    | 1                 | 0.04 (0.03 to 0.05) |

CI: Confidence Interval
*: significant

# Positive pooled MD means the index was higher in GDM compared to non-GDM, and negative pooled MD means the index was lower in GDM compared to non-GDM.

https://doi.org/10.1371/journal.pone.0271068.t002
and Aydin et al. [41] in Turkey (MD: 13.10; 95% CI: 6.13 to 20.07). Based on random effects model, the pooled MD for waist circumference was 6.83 cm (95% CI: 5.37 to 8.30). In other words, the mean values of waist circumference in people with GDM were higher than that in non-GDM people. Forest plot of other anthropometric indices was provided in supplements 1 to 21, and pooled MD is shown in Table 2 and Fig 3. Pooled MD of neck circumference, hip circumference, waist hip ratio, and visceral adipose tissue depth was 1.00 cm (95% CI: 0.79 to 1.20) [N = 5; I²: 0%; p: 0.709]; 7.79 cm (95% CI: 2.27 to 13.31) [N = 5; I²: 84.3%; P < 0.001]; 0.03 (95% CI: 0.02 to 0.04) [N = 9; I²: 89.2%; p<0.001] and 7.74 cm (95% CI: 0.11 to 1.36) [N = 4; I²: 95.8%; P < 0.001], respectively, which indicates that the average of these indices was higher in the GDM group. An adverse pattern was observed for the height and skeletal muscle mass percentage, which pooled MD for the height, and skeletal muscle mass percentage was -0.24 cm (95% CI: -0.37 to -0.10) [N = 9; I²: 0%; p:0.709]; and -2.11 (95% CI: -3.61 to -0.61) [N = 2; I²: 83.2%; p:0.015], respectively, which indicates that the average of these indices was higher in the non-GDM group. In other words, in general, people with non-GDM had a mean height and skeletal muscle mass percentage higher than GDM people. Although pooled MD was higher for subcutaneous adipose tissues in the GDM group, this difference was not significant (2.15 [95% CI: -1.66 to 5.96]). The pooled MD of other indices are given in Table 2 and Fig 3.
Heterogeneity and meta-regression results

Table 2 shows significant heterogeneity between different studies for waist circumference, hip circumference, waist/hip ratio, visceral adipose tissue depth, subcutaneous adipose tissue (Cochran’s Q test P-value < 0.001 for all lipid profiles) so that the I² index was above 70% for all mentioned indices. Table 3 shows the meta-regression results to investigate the effect of publication year, age, sample size, and study design on heterogeneity between studies. Accordingly, none of the variables had a significant role on heterogeneity between studies (P > 0.05 for all). Fig 4 shows the result of meta-regression for association between pooled MD of waist circumference with age (A) and publication year (B).

Table 4 shows the publication bias results based on the Egger’s test and the fill and trim method. There was a significant publication bias for waist circumference (coefficient: 1.95; P: 0.019) and hip circumference (coefficient: 3.06; P: 0.028). According to the fill and trim method, the value of adjusted pooled MD for waist circumference and hip circumference was

---

**Table 3. Results of the univariate meta-regression analysis on the heterogeneity of the determinant.**

| variables                  | Publication Year (year) | Age               | Sample size | Study Design |
|----------------------------|-------------------------|-------------------|-------------|--------------|
|                            | Coefficient 95% CI      | p-value           | Coefficient 95% CI | P-value       | Coefficient 95% CI | P-value |
| Waist Circumference        | 0.81 (-0.11 to 1.75)    | 0.078             | -0.36 (-1.48 to 0.77) | 0.480         | 0.01 (-0.01 to 0.01) | 0.656   |
| Hip Circumference          | 1.60 (-0.66 to 3.86)    | 0.109             | -0.29 (-3.62 to 3.04) | 0.743         | 0.01 (-0.02 to 0.01) | 0.071   |
| Waist/Hip Ratio            | -0.01 (-0.01 to 0.01)   | 0.979             | -0.01 (-0.01 to 0.01) | 0.067         | 0.01 (-0.01 to 0.01) | 0.705   |
| Visceral Adipose Tissue Depth | 0.22 (-0.43 to 0.88)  | 0.276             | -0.13 (-0.34 to 0.08) | 0.081         | 0.01 (-0.01 to 0.01) | 0.633   |
| Subcutaneous adipose tissue | -1.02 (-3.48 to 1.44)  | 0.313             | 1.59 (-0.89 to 4.08) | 0.134         | -0.01 (-0.07 to 0.06) | 0.846   |

CI: Confidence Interval
*: Significant

Coding for study design: 1 = case control; 2 = cohort; 3 = cross-sectional

https://doi.org/10.1371/journal.pone.0271068.t003
5.35 (95% CI: 3.81–6.88) and 7.80 (95% CI: 2.76–13.31), which was not significantly different from the pooled MD calculated for waist circumference (6.83 [95% CI: 5.37–8.30]) and hip circumference (7.79 [95% CI: 2.27–13.31]). In other words, the publication bias had no considerable effect on the result of meta analysis. No publication bias was observed for other anthropometric indices including neck circumference, waist/hip ratio, height, visceral adipose tissue depth, and subcutaneous adipose tissue. Details of the studies are listed in Table 5.

Discussion

The current study set to investigate the relationship between body composition and GDM as a systematic review and meta-analysis. The results indicate that anthropometric indices such as WC, NC, HC, WHR, VAT, SAT, Height, and MUAC are associated with GDM; an increase in the indices of WC, NC, HC, WHR, VAT, SAT, and MUAC increase developing GDM, also short stature increases the susceptibility to GDM.

We investigated that VAT and SAT are associated with GDM. Alwash et al. (2021) found that all three obesity phenotypes were significantly associated with the risk of developing GDM.

Table 4. Result of publication bias for anthropometric indices and fill and trim method result of adjusting publication bias.

| Variables                  | Publication bias | Trim and fill |
|----------------------------|------------------|---------------|
|                            | Coefficient 95% CI | p-value | Coefficient 95% CI | p-value |
| Waist Circumference        | 1.95 (2.57 to 5.09) | 0.019* | 5.35 (3.81 to 6.88) | <0.001 |
| Neck Circumference         | 0.26 (-2.59 to 3.12) | 0.788 | --- | --- |
| Hip Circumference          | 3.06 (0.64 to 5.49) | 0.028* | 7.80 (2.76 to 13.31) | <0.001 |
| Waist/Hip Ratio            | 2.83 (-0.48 to 6.15) | 0.083 | --- | --- |
| Height                     | 0.11 (-0.39 to 0.62) | 0.608 | --- | --- |
| Visceral Adipose Tissue Depth | 6.75 (-0.41 to 13.91) | 0.056 | --- | --- |
| Subcutaneous adipose tissue | -1.94 (-136.42 to 132.55) | 0.970 | --- | --- |

CI: Confidence Interval

*: Significant

https://doi.org/10.1371/journal.pone.0271068.t004
| ID  | References                  | Study design | Sample size | Geographic region | Age(year) | Diagnostic criteria of GDM | Anthropometric indices | applying Time | Accompanying factors                                                                 | Results                                                                 | QS |
|-----|-----------------------------|--------------|-------------|-------------------|-----------|---------------------------|------------------------|---------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----|
| 1   | Jitngamsajarit et al. (2021) [43] | Cross-sectional | 212         | Thailand          | 27.1 ± 6.7 | WHO                       | WC ≥ 82: (OR 7.85, 95% CI 1.80–34.32) | <18          | • maternal age • history of diabetes in family • history of giving birth to a fetal anomaly • History of giving birth to an infant ≥ 4,000 gm | Significant                   | 8  |
| 2   | Saif Elnasr et al. 2021 [44]  | Cohort       | 83          | Egypt             | 26.8      | ADA                       | VAT: 5.85 ± 0.47 cm SAT:1.80±0.57 cm | 11–14        | BMI                                                                                   | VAT depth ranged from 1.4 to 9.1 cm, with a mean of 3.9 ± 1.6 cm is associated with GDM. | 8  |
| 3   | Cremona et al. 2021 [45]     | Cohort       | 187         | Ireland           | 18–50     | IADPSG                    | • abdominal SAT:1.99 (1.64–2.31) mm • abdominal VAT:1.41 (1.11–1.65) mm • FMP: 45.6 (39.2–49.0) • MUAC:32.9 (30.1–36.4) cm • WC = 90.3 (85.9–96.2) cm • HC: 108.6 (99.9–111.6) cm total SFT:226.4 (184.1–244.7) mm | 10–16      | • BMI • Parity >3 • Family Hx diabetes Age >40 • Smoking • High risk ethnicity • Previous perinatal death • Glucosuria • Previous baby ≥4.0 kg • Previous macrosomia (≥4.5 kg) | Significant for VAT, SAT, WC, HC and total SFT | 7  |
| 4   | Barforoush et al. 2021 [46]  | cohort       | 372         | Iran              | 28.1 ±4.4 | ADA                       | NC: 35.1 ±2.7 cm         | 14–16        | Age Gravidity Family history of type 2 diabetes Pre-pregnancy weight Height | NC ≥ 34.3 cm can be deemed as a predictor of GDM | 8  |
| 5   | Aydin et al. 2021 [41]       | Cohort       | 142         | Turkey            | 31.24±5.11 | IADPSG                    | • Intraperitoneal fat thickness:51.59 ± 22.49 mm • SAT: 19.79 ± 12.52 mm • WC:95.25±15 cm HC:115.38±15.41 cm WHR: 0.82±0.06 cm Perirenal fat thickness: 11.77±8.79 mm, SFTmax: 19.79±12.52 mm | 11–14      | • Pre-pregnancy BMI • BMI • smoking • history of DM in the first degree relatives • GDM during previous pregnancy | Significant for all except Perirenal fat thickness | 7  |

(Continued)
| ID | References | Study design | Sample size | Geographic region | Age(year) | Diagnostic criteria of GDM | Anthropometric indices | applying Time | Accompanying factors | Results | QS |
|----|------------|--------------|-------------|-------------------|-----------|---------------------------|------------------------|----------------|----------------------|----------|----|
| 6  | Zhang et al.2020 [47] | Cohort | 22,223 | China | 28.09 ± 4.48 | IADPSG | FM: 17.95 ± 5.65 kg, 1.085 (1.079–1.091) | <17 | BMI | Significant | 7 |
|    |            |             |            |       |                      | FFM: 40.56 ± 4.92 kg, 1.080 (1.100–1.115) | | | Total body water | |
|    |            |             |            |       |                      | Fat mass percentage: 30.09 ± 5.69%, 1.057 (1.052–1.063) | | | Proteins | |
|    |            |             |            |       |                      | MM21.87 ± 2.96 kg, 1.114 (1.106–1.121) | | | Bone minerals | |
|    |            |             |            |       |                      | VF level: 8.48 ± 0.56, 2.604 (2.459–2.758) | | | Basal metabolic rate | |
|    |            |             |            |       |                      | Lean trunk mass: 18.32 ± 2.47 kg, 1.226 (1.209–1.243) | | | | |
| 7  | Rocha et al.2020 [48] | Cohort | 133 | Brazil | 26±6.2 | IADPSG | VAT: 55.4 ±11.4 mm | ≤20 | BMI | Significant | 9 |
| 8  | Alves et al.2020 [28] | cohort | 518 | Brazil | 26.25±5.8 | IADPSG | VAT: 5.44 ±1.27mm | 14 | age | significant | 8 |
| 9  | Hancerliogullari et al.2020 [29] | cohort | 525 | Turkey | 27 (18–44) | Carpenter and Coustan | NC:37.14 ± 3.34 cm | 11–14 | Age | Significant | 8 |
|    |            |             |            |       |                      | WC: 91.78 ± 11.41 cm | | | Parity | |
| 10 | Liu et al.2020 [30] | cohort | 1318 | China | 32.6±5.1 | IADPSG | FMI: 7.14±2.26 | 13 | Age | Significant | 8 |
|    |            |             |            |       |                      | SMMP: 40.0±8.3 | | | Pre-pregnancy BMI | |
|    |            |             |            |       |                      | FMP: 30.1±5.8 | | | Pre-pregnancy weight | |
| 11 | Thaware et al.2019 [49] | Cohort | 80 | UK | 18–40 | IADPSG/WHO | VAT: 4.36±1.31 cm | 9–18 | Early pregnancy BMI ≥30 kg/m² | Significant for VAT of ≥ 4.27 cm (p = 0.03) | 8 |
|    |            |             |            |       |                      | SAT: 2.24±1.01 cm | | | Family history of diabetes in first-degree relative | |
| 12 | Takmaz et al.2019 [50] | cohort | 261 | Turkey | 30.57±5.78 | IADPSG | WC: 103.91±14.13 cm | 20–24 | Age | Significant | 7 |
|    |            |             |            |       |                      | 8.36(0.74–0.84) | | | Parity | |
|    |            |             |            |       |                      | Weight gain | | | Pre-pregnancy BMI | |
| 13 | Budak et al.2019 [42] | Case control | 100 | Turkey | 33.5 (27–37) | Carpenter and Coustan | SFT: 21.1 (16.6–26.4) mm | 24–28 | Age | Significant | 9 |
|    |            |             |            |       |                      | | | | Parity | |
| 14 | Kawanabe et al.2019 [51] | Cohort | 96 | Japan | 34.4 ± 4.8 | IADPSG | ASM: 17.0 ± 2.1 kg | 16–30 | ISI | Significant | 8 |
|    |            |             |            |       |                      | FM: 18.8 ± 8.2 kg | | | Age | |
|    |            |             |            |       |                      | ASM/FM ratio: 1.02 ± 0.34 | | | HbA1c | |
|    |            |             |            |       |                      | pre-pregnancy BMI | | | Family history of diabetes | |

(Continued)
| ID | References                  | Study design | Sample size | Geographic region | Age(year) | Diagnostic criteria of GDM | Anthropometric indices applying Time | Accompanying factors                                      | Results          | QS |
|----|----------------------------|--------------|-------------|-------------------|-----------|---------------------------|-------------------------------------|-----------------------------------------------------------|-----------------|----|
| 15 | Marshall et al.2019 [52]   | cohort       | 1,775,984   | California        | 18–40     | ICD-9                     | MH: 1.68 (1.58–1.66) m               | nine months prior to birth               | • Age           | 8  |
|    |                            |              |             |                   |           |                           |                                     | • BMI                                      | Taller women were less likely to have GDM 0.81 (0.80, 0.82)^*|                |    |
| 16 | Ulubasoglu et al.2019 [53] | cohort       | 148         | Turkey            | 28.4±3.8  | ADA                       | WC = 87.7 ±13.6 cm                   | 11–14                                      | • Total triglycerides • BMI                      | Significant     | 8  |
| 17 | Wang et al.2019 [54]       | Case-control | 2698        | China             | 30.95± 4.01| IADPSG                    | FFMP: 68.45±4.81                      | 13–20                                      | • Age           | 7  |
|    |                            |              |             |                   |           |                           | FM: 31.55±4.81                       | • PPBMI                                    | Significant      |    |
|    |                            |              |             |                   |           |                           | WHR: 7.00±1.81                       |                                           |                |    |
|    |                            |              |             |                   |           |                           | MUAC: 27.64±2.30 cm                 |                                           |                |    |
|    |                            |              |             |                   |           |                           | FM/FFM ratio: 0.47 ±0.14            |                                           |                |    |
| 18 | Zhu et al.2019 [31]        | Cohort       | 1750        | California        | 18–45     | Carpenter and Coustan    | WHR = 0.91 ±0.06                      | 10–13                                      | • Smoking       | 7  |
|    |                            |              |             |                   |           |                           | WC = 102.4 ±18.5 cm                 | • Family history of diabetes               | Significant      |    |
|    |                            |              |             |                   |           |                           |                                           | • Previous GDM                             |                |    |
|    |                            |              |             |                   |           |                           |                                           | • Preexisting hypertension              |                |    |
|    |                            |              |             |                   |           |                           |                                           | • Physical inactivity in early pregnancy |                |    |
| 19 | Nombo et al.2018 [55]      | Cross sectional | 609         | Tanzania          | 27.5 ± 5.0| WHO                      | MUAC = 27.3± 3.8 cm                  | 20–38                                      | • Previous stillbirth • Family history of type 2 diabetes • Diet habits | Significant     | 9  |
| 20 | Anafcheh et al.2018 [56]   | Case control | 195         | Iran              | 32.35± 0.68| WHO                      | H = 159.72±6.72                      | <24–28                                     | • Blood group • GWG • Age • History of stillbirth • History of GDM • History of type 2 diabetes in first-degree relatives • Birth -History of a baby weighing≥ 4 kg • History of a birth with a congenital anomaly • History of PCO | NS             | 7  |
| 21 | Balani et al.2018 [57]     | cohort       | 302         | UK                | 31        | WHO                       | PBF VFM<210 WHR                      | 15                                         | Age BMI         | Significant | 7  |
|    |                            |              |             |                   |           |                           |                                           | • History of PCOs • Family history of diabetes • History of hypertension and Previous macrosomia |                |    |

(Continued)
| ID  | References                  | Study design | Sample size | Geographic region | Age(year) | Diagnostic criteria of GDM | Anthropometric indices | applying Time | Accompanying factors | Results  | QS |
|-----|-----------------------------|--------------|-------------|-------------------|-----------|---------------------------|------------------------|---------------|----------------------|----------|----|
| 22  | Bourdages et al.2018 [58]   | cohort       | 1048        | Canada            | 28.9 ± 4.1| IADPSG                    | • SAT: 0.66 (0.59–0.73) • TAT: 0.68 (0.61–0.76) • VAT: 0.65 (0.58–0.73)** | 11–14         | • Age≥35              | Significant| 8  |
| 23  | Kansu-Celik et al.2018 [40] | Cross sectional | 223         | Turkey            | 27.46±5.9| Carpenter and Coustan     | • SAT: 19 (11–28) mm • WC: 95 (72–111) cm • WHR: 0.89 ± 0.59 | 24–28        | • BMI                 | Significant| 9  |
| 24  | KhushBakht et al.2018 [59]  | Cross sectional | 90          | Pakistan          | 30.8 ± 3.2| ADA                       | • NC: 36.1 ± 2.8 cm • H: 1.61 ± 0.03 m • WC: 104.2 ± 9.0 cm | 16           |                      |                      |         |
|     |                             |              |             |                   |           |                           |                        |               |                      |          |    |
|     |                             |              |             |                   |           |                           |                        |               |                      |          |    |
| 25  | Nasr et al.2018 [60]        | cohort       | 389         | USA               | 29.7±4.67| ACOG                      | Pre-peritoneal fat: 12 (9–16)** mm SFT: 11 (8–14) mm BFI: 0.78 (0.42 - 1.26) | 18–24        | • Age>30              | Significant| 8  |
| 26  | D’Ambrosi et al.2017 [61]   | Case control | 168         | Italy             | 34.5±5.1 | IADPSG                    | SAT: 107±4.8 mm VAT: 10.1±3.0 mm | 24–28        | • Age                 | Significant| 8  |
| 27  | Han et al.2017 [62]         | Cohort       | 17803       | China             | 28.5±2.8 | IADPSG                    | WC: 82.8±9.7 cm         | 4–12          | • BP                  | Significant| 7  |
| 28  | He et al.2017 [63]          | Case control | 255         | China             | 29.1±3.7 | ADA                       | NC: 35.20±2.56 cm WC: 103.16±8.00 cm | 16           | • Age                 | Significant| 7  |
| 29  | Li et al.2017 [64]          | cohort       | 371         | China             | 31.0±3.0 | IADPSG                    | NC: 34.3±1.5 cm         | 11–13         | • Age                 | Significant| 7  |
| 30  | Yang et al.2017 [65]        | cohort       | 333         | Korea             | 32±3.9   | National Diabetes Data Group | SFT:2.7±0.6 cm | 10–13         | • Age                 | Significant| 7  |
| 31  | Alptekin et al.2016 [66]    | Cohort       | 227         | Turkey            | 28.8 ± 4.8| Carpenter and Coustan     | WC: 89.7 ± 11.9 cm HC: 105.8 ± 14.2 cm WHR: 0.84 ± 0.04 | 7–12         | • HOMA-IR             | Significant| 8  |
| 32  | Basraon et al.2016 [67]     | Cohort       | 2300        | USA               | 23.3±4.9 | Guidelines of each clinical center | WHR: 0.88 ± 0.07 | 9–16         | • IR                  | Significant| 8  |

(Continued)
| ID  | References                         | Study design  | Sample size | Geographic region | Age (year) | Diagnostic criteria of GDM | Anthropometric indices | Time applying | Accompanying factors | Results | QS |
|-----|------------------------------------|---------------|-------------|-------------------|------------|---------------------------|------------------------|---------------|-----------------------|---------|----|
| 33  | White et al. 2016 [68]             | Cohort        | 1303        | UK                | 32.0 ± 4.9 | IADPSG                    | • NC: 37.4 ± 2.5 cm  
  • WC: 110 (103–116) cm  
  • MUAC: 37 (35–40) cm  
  • HC: 123 (116–130) cm  
  • WHR: 0.89 ± 0.07   | 15–18        | • Age  
  • BP  
  • Ethnicity  
  • Parity  
  • IR  
  • Previous GDM  
  • HgbA1C  
  • Adiponectin  
  • Sex hormone binding globulin  
  • Triglycerides  
  • PCOs  
  • Smoking   | Significant   | 8          |
| 34  | De Souza et al. 2015 [69]          | Cohort        | 485         | Canada            | 32.9 ± 4.8 | IADPSG                    | • SAT: 1.9 ± 0.80 cm  
  • VAT: 4.1 ± 1.7 cm  
  • TAT: 5.9 ± 2.1 cm   | 11–14        | • Age,  
  • BMI   | Significant for SAT & VAT         | 7          |
| 35  | Kennedy et al. 2015 [70]           | Cohort        | 1350        | Canada            | 29.3 ± 5.1 | NR                        | • SAT1: 21.2 mm (6.9–73.9)  
  • SAT2: 20.3 mm (7.5–68.0) | 11–14        | • BMI   | Significant               | 7          |
| 36  | Sina et al. 2015 [71]              | Case control  | 131         | Australia         | 23.7 ± 5.5 | ICD-9 and ICD-10          | • WC: 90.3 ± 16.4 cm  
  • HC: 98.3 ± 16.3 cm  
  • WHR: 0.92 ± 0.05   | -            | • BMI   | Significant for WC and HC | 9          |
| 37  | Balani et al. 2014 [72]            | Case control  | 302         | UK                | 32.1 ± 5.5 | WHO                       | • WHR: 1.02 ± 0.07  
  • TPBF: 49.8 ± 3.5  
  • VAT: 199.2 ± 40.5 | 14–17        | • BMI   | Significant for BMI, WHR, VFM | 7          |
| 38  | Bolognani et al. 2014 [73]         | Cross sectional | 240       | Brazil            | 17–40      | WHO                       | WC: 93.548 ± 8.873 cm  | 20–24        | • PPBMI  
  • BMI  
  • GWG   | Significant               | 8          |
| 39  | Gur et al. 2014 [74]               | Cohort        | 94          | Turkey            | 43.4       | WHO                       | WC: 65.3 cm  
  • minimum subcutaneous fat (Smin): 66.7 mm  
  • maximum pre-peritoneal visceral fat (Vmax): 67.2 mm   | 4–14        | • BMI  
  • FBG  
  • Metabolic syndrome  
  • Lipid profile  
  • BP  
  • HOMA-IR  
  • Smoking   | Significant               | 8          |
| 40  | Mameghani et al. 2013 [75]         | Cohort        | 1140        | Iran              | 17–40      | WHO                       | WC: 81.84 ± 0.35 cm   | <12          | • BMI   | Significant               | 8          |
| ID | References | Study design | Sample size | Geographic region | Age (year) | Diagnostic criteria of GDM | Anthropometric indices applying in | Accompanying factors | Results | QS |
|----|------------|--------------|-------------|-------------------|------------|---------------------------|-------------------------------------|----------------------|---------|----|
| 41 | Suresh et al.2012 [76] | Cohort | 1200 | Australia | 17–45 | The Royal Australian and New Zealand College of Obstetricians and Gynaecologists. C-Obs guideline | -SAT: 18.2 mm (range 6.3–50.9 mm) | 18–22 • BMI | Significant | 8 |

ICD9: International Classification of Diseases, 9th Revision-Clinical Modification. H: height, WGDP: weight gained during pregnancy, HOMA-IR: homeostasis model assessment insulin resistance, WHR: Waist/Hip Ratio, QUICKI: quantitative insulin sensitivity check index, VAD: Visceral Adipose Tissue Depth, BMI: Body Mass Index, VFM: visceral fat mass, PBF: percentage body fat, IR: insulin resistance, WC: waist circumference, SAT: subcutaneous tissues thickness, TAT: total adipose tissues thickness, VAT: visceral tissues thickness, ASFT: abdominal subcutaneous fat thickness, FBG: fasting blood glucose, NC: Neck circumference, ISI: insulin sensitivity index, ASM: appendicular skeletal muscle mass, FM: fat mass, HbA1c: glycosylated hemoglobin A1c, SFT: subcutaneous fat thickness, IADPSG: International Association of Diabetes and Pregnancy Study Groups, FMP: fat mass percentage, SMMP: skeletal muscle mass percentage, FMI: Fat mass index, BFI: Body Fat Index = (pre-peritoneal fat x subcutaneous fat/height), FFM: fat free mass, MM: muscular mass, PP: Pre pregnancy, PPBMI: Pre pregnancy BMI, ADA: American Diabetes Association, WHO: World health Organization, ACOG: American College of Obstetricians and Gynecologists, AC: arm circumference, NS: Not Significant

*: OR
**: median (IQR)
***: AUC (CI)
****: median (max-min)

https://doi.org/10.1371/journal.pone.0271068.t005
GDM. In addition, visceral obesity was a stronger risk factor for GDM than other obesity phenotypes [32]. Yao et al. (2020) also stated that the risk of GDM is associated with maternal central obesity in early pregnancy [77]. In the case of central and visceral body fats, Benevides et al. (2020) reported that the cut-off point for subcutaneous, visceral, and total abdominal fat to predict GDM varied between studies in the first and second trimesters of pregnancy. No study confirmed a model for predicting GDM using subcutaneous and visceral fat measurements [78].

De Souza et al. (2015) determined the relationship between SAT depth, TAT depth, and VAT depth in the first trimester of pregnancy and the occurrence of GDM in mid-pregnancy. It was observed that increasing the depth of VAT and TAT independently of BMI could predict the risk of dysglycemia in later stages of pregnancy [69]. Similarly, Balani et al. (2018) showed that visceral adipose mass in obese women can be a predictor of GDM [57]. Increased VAT depth, but not SAT depth, was associated with an increased risk of GDM after adjusting for confounding factors. VAT depth ≥ 4.27 cm is more sensitive compared to the National Institute of Health and Care Excellence criteria and similar feature for the diagnosis of GDM [79]. In addition, Alves et al. (2020) observed an increase in VAT depth in sonographic measurements in early pregnancy; GDM was associated with a higher risk [28]. One of the strengths of the present study is the assessment of most indices of body composition and their relationship with GDM and the large number of up-to-date studies that lead to the investigation of more samples.

The results of the present study also showed WC, HC and WHR are associated with GDM. Various studies have shown an association between WC and WHR-based central obesity around the hip with the occurrence of GDM [31]. However, the data are also contradictory; for example, Basraon et al. (2016) showed that WHR could not replace BMI as a risk factor in pregnancy for GDM [67]. But, Yao et al. (2020) in his subgroup analysis showed that higher levels of central maternal obesity in the first stage have a similar risk of GDM in the first and second trimesters of pregnancy [77]. However, Tornaghi et al. (1994) provided evidence of the superiority of maternal central obesity regarding mid-pregnancy (18–22 weeks) in identifying obesity-related complications in pregnancy. In other words, the factors expressing central obesity in the mother’s body can better predict the risk of GDM than BMI [80]. Central obesity is expressed as a risk factor for insulin resistance associated with deposition and abnormal fat function. WC as one of the indices of central obesity leads to an increased risk of GDM. Multivariate regression analysis with consideration of other risk factors showed that WC ≥ 80 cm could not predict the risk of GDM. However, Ebrahimi-Mameghani et al. (2013) concluded that WC ≥ 88 cm is a significant predictor of GDM (OR: 3.77) [41, 75]. Han et al. (2018) also observed that the risk of GDM increases with WC ≥ 78.5 cm increase [75]. WC at gestation weeks 20–24, pre-pregnancy BMI, and gestational BMI can predict the occurrence of GDM. WC 100 cm with 84% sensitivity and 70% specificity predicts GDM risk [50]. Although other studies have shown that at gestation weeks 20–24, WC: 85.5–88.5 cm was the optimal cut-off point for GDM prediction (Sens/Spec balance between 87.1/41.1% and 77.4/56.9%) [73].

Kansu-Celik et al. (2018) observed a significant relationship between 50g GCT and WC, and SAT thickness. He showed that SAT predicts thickness greater than 16.75 mm GDM with a sensitivity of 71.7% and a specificity of 87.6% [40]. In adults, WHR is independently associated with complications after relative weight adjustment, i.e. the use of relative weight and body shape at the same time provides a better estimate of the risk of disease than either alone [81]. In women with WHR < 0.85, one or more risk factors increased the risk of GDM by 1.99 times, and in women with WHR ≥ 0.85 but without fixed risk factors, the risk of GDM increased by 2.41 times, and in women with fixed risk factors, it increased by 6.22 times. Similar but weak results were observed for WC ≥ 88 cm [31].
We have shown that increased NC also leads to GDM. Hancerliogullari et al. (2020) also stated that NC in women with GDM are significantly higher [29] and NC is assumed to be a better marker than WC for determining metabolic syndrome and its key features. It is also easy to measure and it is replicable [82, 83]. Barforoush et al. (2021) also stated that NC more than 34.3 cm in Iranian women could predict GDM [46].

In this study we reported that short stature increases the susceptibility to GDM. Height in adulthood is an indices of genetic, early and childhood factors and their interactions. Although the biological mechanism associated with adult height and GDM is unknown, several pathways have been suggested. For example, malnutrition of the fetus may lead to low birth weight, which is associated with shorter height in adulthood, and may also be associated with metabolic disorders in adulthood. Height has different variations in different populations [84, 85]. In an analysis of 135861 pregnant women, height was found to be inversely related to the occurrence of GDM. Of course, this relationship can also vary between different races [86].

Body composition in pregnancy has a dynamic process; for example, changes in weight gain and free body adipose mass during pregnancy are clearly observed [87].

Measuring maternal body composition during pregnancy is challenged by existing in-vivo measurement methods that cannot distinguish between maternal and fetal reserves [88] and look at the mother and fetus as a whole. In addition, some pregnancy-induced changes in body composition violate the assumptions that underlie many commonly available measurement methods and require special pregnancy modifications (which often vary at different gestational ages) [89].

The composition of the mother’s body changes during pregnancy to support optimal fetal growth. In the first few months of pregnancy, changes in the composition of the mother’s body indicate the readiness of the female body for fetal growth. Especially, the uterine and breast tissue that makes up the mother unit grows and the blood volume increases. In late pregnancy, more pronounced growth of the embryonic unit (including the fetus, amniotic fluid, and placenta) occurs along with the continued growth of maternal tissue and further increase in blood volume. At the time of delivery, the fetal unit accounts for approximately one-third of the total GWG [90].

Accordingly, central obesity is associated with more obesity-related complications [91]. In contrast, peripheral obesity has been suggested to eliminate or even protect against some of the risks associated with obesity [92]. CT, MRI, body densitometry, or WHR are better indices of central obesity than BMI but are impractical as screening tools in pregnancy. SAT measurement can be used as an alternative measure of central obesity [93] as it is associated with a wide range of cardiovascular and metabolic risk factors. SAT can be easily and accurately measured by ultrasound [94]. BMI can also be potentially useful as a direct and inexpensive method for assessing central fat distribution [95]. In adults, BMI can predict outcomes such as type-2 diabetes and hypertension [81]. Although a sufficient number of studies examining the relationship between BMI and GDM have been performed in the past [96, 97].

Conclusion

Body composition indices such as WC, HC, WHR, AC, VAT, SAT, and height can relate more effectively and accurately to GDM. These available anthropometric indices can be used as a tool to assess the occurrence of GDM in an accessible, cost-effective, and high-precision manner.

Limitation

One of the limitations of the study is the difference in the critical values of the criteria used to diagnose GDM, which may affect the decision on the absence or occurrence of GDM based on
different indices. In addition, studies conducted in different populations and races, which is a determining factor in body composition and can affect both body composition and the occurrence of GDM, have not been considered in the present study. Also, the small number of studies performed on some anthropometric indices is another limitation of the study, which makes it difficult to draw conclusions about such indices.

Supporting information

S1 File. Forest plot of different anthropometric indices between GMD and non-GDM group.

S1 Checklist. PRISMA-2009-checklist.

Author Contributions

Conceptualization: Fatemeh Alsadat Rahnemaei, Fatemeh Abdi.

Data curation: Fatemeh Alsadat Rahnemaei, Seyedeh Hajar Sharami, Fatemeh Mokhtari.

Formal analysis: Reza Pakzad.

Methodology: Reza Pakzad.

Visualization: Fatemeh Abdi.

Writing – original draft: Fatemeh Abdi.

Writing – review & editing: Fatemeh Abdi, Elham Kazemian.

References

1. McIntyre HD, Catalano P, Zhang C, Desoye G, Mathiesen ER, Damm P. Gestational diabetes mellitus. Nature reviews Disease primers. 2019; 5(1):1–19.

2. Afkhami M, Rashidi M. Gestational diabetes mellitus. Hormozgan Medical Journal. 2007; 11(1):1–12.

3. Wang H, Li N, Chivese T, Werfalli M, Sun H, Yuen L, et al. IDF diabetes atlas: estimation of global and regional gestational diabetes mellitus prevalence for 2021 by International Association of Diabetes in Pregnancy Study Group’s Criteria. Diabetes research and clinical practice. 2022; 183:109050. https://doi.org/10.1016/j.diabres.2021.109050 PMID: 34883186

4. Ali AD, Mehrass AA-KO, Al-Adhroey AH, Al-Shammakh AA, Amran AA. Prevalence and risk factors of gestational diabetes mellitus in Yemen. International journal of women’s health. 2016; 8:35. https://doi.org/10.2147/IJWH.S97502 PMID: 26869814

5. Bellamy L, Casas J-P, Hingorani AD, Williams D. Type 2 diabetes mellitus after gestational diabetes: a systematic review and meta-analysis. The Lancet. 2009; 373(9677):1773–9. https://doi.org/10.1016/S0140-6736(09)60731-5 PMID: 19465232

6. Fadi H, Magnuson A, Östlund I, Montgomery S, Hanson U, Schwarcz E. Gestational diabetes mellitus and later cardiovascular disease: a Swedish population based case–control study. BJOG: An International Journal of Obstetrics & Gynaecology. 2014; 121(12):1530–6.

7. Bener A, Saleh NM, Al-Hamaq A. Prevalence of gestational diabetes and associated maternal and neonatal complications in a fast-developing community: global comparisons. International journal of women’s health. 2011; 3:367. https://doi.org/10.2147/IJWH.S26994 PMID: 22140323

8. Domanski G, Lange AE, Ittermann T, Allenberg H, Spoo RA, Zygmunt M, et al. Evaluation of neonatal and maternal morbidity in mothers with gestational diabetes: a population-based study. BMC pregnancy and childbirth. 2018; 18(1):1–11.

9. Prakash GT, Das AK, Habeebullah S, Bhat V, Shamanna SB. Maternal and neonatal outcome in mothers with gestational diabetes mellitus. Indian journal of endocrinology and metabolism. 2017; 21(6):854. https://doi.org/10.4103/ijem.IJEM_66_17 PMID: 29285448
Crowther CA, Hiller JE, Moss JR, McPhee AJ, Jeffries WS, Robinson JS. Effect of treatment of gestational diabetes mellitus on pregnancy outcomes. New England journal of medicine. 2005; 352 (24):2477–86. https://doi.org/10.1056/NEJMoa042973 PMID: 15951574

11. Au CP, Raynes-Greenow CH, Turner RM, Carberry AE, Jeffery HE. Body composition is normal in term infants born to mothers with well-controlled gestational diabetes mellitus. Diabetes care. 2013; 36 (3):562–4. https://doi.org/10.2373/dc12-1557 PMID: 23223404

12. Diabetes IAo Panel PSGC. International association of diabetes and pregnancy study groups recommendations on the diagnosis and classification of hyperglycemia in pregnancy. Diabetes care. 2010; 33 (3):676–82. https://doi.org/10.2373/dc09-1848 PMID: 20190296

13. Nallaperumal S, Bhadvanirini B, Mahalakshmi MM, Maheswari K, Jalaja R, Moses A, et al. Comparison of the world health organization and the International association of diabetes and pregnancy study groups criteria in diagnosing gestational diabetes mellitus in South Indians. Indian Journal of Endocrinology and Metabolism. 2013; 17(5):906. https://doi.org/10.4103/2230-8210.117241 PMID: 24083175

14. Behboudi-Gandevani S, Amir M, Bidhendi Yarandi R, Ramezani Tehrani F. The impact of diagnostic criteria for gestational diabetes on its prevalence: a systematic review and meta-analysis. Diabetology & metabolic syndrome. 2019; 11(1):1–18. https://doi.org/10.1186/s13098-019-0406-1 PMID: 30733833

15. Hunt KJ, Schuller KL. The increasing prevalence of diabetes in pregnancy. Obstetrics and gynecology clinics of North America. 2007; 34(2):173–99. https://doi.org/10.1016/j.ogc.2007.03.002 PMID: 17572266

16. Zhang C, Ning Y. Effect of dietary and lifestyle factors on the risk of gestational diabetes: review of epidemiologic evidence. The American journal of clinical nutrition. 2011;94(suppl_6):197S-9S. https://doi.org/10.3945/ajcn.110.001032 PMID: 21613663

17. Hao M, Lin L. Fasting plasma glucose and body mass index during the first trimester of pregnancy as predictors of gestational diabetes mellitus in a Chinese population. Endocrine journal. 2017:EJ16-0359. https://doi.org/10.1507/endocrj.EJ16-0359 PMID: 28420856

18. Farina A, Eklund E, Bernabini D, Paladino M, Righetti F, Monti G, et al. A first-trimester biomarker panel for predicting the development of gestational diabetes. Reproductive sciences. 2017; 24(6):954–9. https://doi.org/10.1177/1933719116675057 PMID: 27837083

19. Tatsukawa Y, Misumi M, Kim YM, Yamada M, Ohishi W, Fujiwara S, et al. Body composition and development of diabetes: a 15-year follow-up study in a Japanese population. European journal of clinical nutrition. 2018; 72(3):374–80. https://doi.org/10.1038/s41430-017-0077-7 PMID: 29362458

20. Shao J-T Qi J-q. The relationship between body adiposity index and pregnancy-induced hypertension in third-trimester pregnant women. Blood pressure monitoring. 2017; 22(5):279–81. https://doi.org/10.10.1075/MBP.00000000000000273 PMID: 28591007

21. Sjöqvist F, Uddman M, Gärling M, Skoghammar A, Fratiglioni L, Kullman P. The increasing prevalence of diabetes in pregnancy. Obstetrics & Gynecology and Reproductive Biology. 2016; 204:69–73. https://doi.org/10.1016/j.ejogrb.2016.07.502 PMID: 27525683

22. Neeland IJ, Turer AT, Ayers CR, Powell-Wiley TM, Vega GL, Farzaneh-Far R, et al. Dysfunctional adiposity and the risk of prediabetes and type 2 diabetes in obese adults. Jama. 2012; 308(11):1150–9. https://doi.org/10.1001/2012.jama.113132 PMID: 22990274

23. Staelens AS, Vonck S, Molenberghs G, Malbrain ML, Gysemans W. Maternal body fluid composition in uncomplicated pregnancies and preeclampsia: a bioelectrical impedance analysis. European Journal of Obstetrics & Gynecology and Reproductive Biology. 2016; 204:69–73. https://doi.org/10.1016/j.ejogrb.2016.07.502 PMID: 27525683

24. Després JP. Body fat distribution and risk of cardiovascular disease: an update. Circulation. 2012; 126 (10):1301–13. https://doi.org/10.1161/CIRCULATIONAHA.111.067264 PMID: 22949540

25. PEIRIS AN, STRUVE MF, MUELLER RA, LEE MB, KISSEBAH AH. Glucose metabolism in obesity: influence of body fat distribution. The Journal of Clinical Endocrinology & Metabolism. 1988; 67(4):760–7. https://doi.org/10.1210/jcem-67-4-760 PMID: 3047162

26. Vidanalage CK, Seneath U, Silva K, Lekamge U, Liyanage I. Effects of initial body mass index on development of gestational diabetes in a rural Sri Lankan population: A case-control study. Diabetes & Metabolic Syndrome: Clinical Research & Reviews. 2016; 10(2):S10–S3.

27. Alves JG, Souza ASR, Figueirnca JN, de Araújo CAL, Guimarães A, Ray JG. Visceral adipose tissue depth in early pregnancy and gestational diabetes mellitus-a cohort study. Scientific reports. 2020; 10 (1):1–4.
29. Hancerliogullari N, Kansu-Celik H, Asli Oskovi-Kaplan Z, Kisa B, Engin-Ustun Y, Ozgu-Erdinc AS. Optimal maternal neck and waist circumference cutoff values for prediction of gestational diabetes mellitus at the first trimester in Turkish population; a prospective cohort study. Gynecological Endocrinology. 2020;1–4. https://doi.org/10.1080/09513590.2020.1750003 PMID: 32274939

30. Liu Y, Liu J, Gao Y, Zheng D, Pan W, Nie M, et al. The body composition in early pregnancy is associated with the risk of development of gestational diabetes mellitus late during the second trimester. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy. 2020; 13:2367. https://doi.org/10.2147/DSMO.S245155 PMID: 32753921

31. Zhu Y, Hedderson MM, Quesenberry CP, Feng J, Ferrara A. Central Obesity Increases the Risk of Gestational Diabetes Partially Through Increasing Insulin Resistance. Obesity (Silver Spring, Md). 2019; 27 (1):152–60. https://doi.org/10.1002/oby.22339 PMID: 30461219

32. Alwash SM, McIntyre HD, Mamun A. The association of general obesity, central obesity and visceral body fat with the risk of gestational diabetes mellitus: Evidence from a systematic review and meta-analysis. Obesity Research & Clinical Practice. 2021; 15(5):425–30.

33. Page MJ, McKenzie JE, Bossuyt PM, Bountrók I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International Journal of Surgery. 2021; 88:105906. https://doi.org/10.1016/j.ijsu.2021.105906 PMID: 33789826

34. Abdi F, Roozbakh N. The effects of Humulus lupulus L.) hops) on menopausal vasomotor symptoms: a systematic review and meta-analysis. The Iranian Journal of Obstetrics, Gynecology and Infertility. 2016; 19(26):9–17.

35. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. European journal of epidemiology. 2010; 25(9):603–5. https://doi.org/10.1007/s10654-010-9491-z PMID: 20652370

36. Sedgh G, Bearak J, Singh S, Bankole A, Popinckla T, Ganatra B, et al. Abortion incidence between 1990 and 2014: global, regional, and subregional levels and trends. The Lancet. 2016; 388 (10041):258–67.

37. Rahenemaei FA, Pakzad R, Amirian A, Pakzad I, Abdi F. Effect of gestational diabetes mellitus on lipid profile: A systematic review and meta-analysis. Open Medicine. 2022; 17(1):70–86. https://doi.org/10.1015/revneuro-2020-0108 PMID: 33618441

38. Soltani S, Tabibzadeh A, Zakeri A, Zakeri AM, Latifi T, Shabani M, et al. COVID-19 associated central nervous system manifestations, mental and neurological symptoms: a systematic review and meta-analysis. Reviews in the Neurosciences. 2021. https://doi.org/10.1515/revneuro-2020-0108 PMID: 34993347

39. Hallajzadeh J, Khoramdad M, Izadi N, Karamzad N, Almasi-Hashemi A, Ayubi E, et al. The association between metabolic syndrome and its components with systemic lupus erythematosus: a comprehensive systematic review and meta-analysis of observational studies. Lupus. 2018; 27(6):899–912. https://doi.org/10.1177/0961203317751047 PMID: 29301471

40. Kansu-Celik H, Karakaya BK, Tasci Y, Hancerliogullari N, Yaman S, Ozgu-Erdinc AS. Relationship maternal subcutaneous adipose tissue thickness and development of gestational diabetes mellitus. Interventional medicine & applied science. 2018; 10(1):13–8. https://doi.org/10.1556/1646.10.2018.01 PMID: 30363336

41. Aydin GA, Ozsoy HG, Akdur PO, Ozgen G. The predictive value of first-trimester anthropometric and ultrasonographic adipose tissue measurements in gestational diabetes mellitus. Journal of Obstetrics and Gynaecology Research. 2021. https://doi.org/10.1111/jog.14887 PMID: 34137118

42. Budak MS, Kahramanoglu I, Vitale SG, Akgol S, Dilek ME, Kartal S, et al. Maternal abdominal subcutaneous fat thickness as a simple predictor for gestational diabetes mellitus. Journal of perinatal medicine. 2019; 47(6):605–10. https://doi.org/10.1515/jpm-2018-0431 PMID: 3114488

43. Jitngamsujarit S, Pittyanont S, Thamarngwuttikul C. Waist Circumference at 18 weeks of gestation as a Predictor for Gestational Diabetes Mellitus in Women with Normal Pre-pregnancy Body Mass Index. Thai Journal of Obstetrics and Gynaecology. 2021:177–87.

44. Saif Elnasr I, Ammar H. Ultrasound markers for prediction of gestational diabetes mellitus in early pregnancy in Egyptian women: observational study. The Journal of Maternal-Fetal & Neonatal Medicine. 2021; 34(19):3120–6. https://doi.org/10.1080/14767058.2019.1678132 PMID: 32138572

45. Cremona A, O’Gorman CS, Ismail KI, Hayes K, Donnelly JE, Hamilton J, et al. A risk-prediction model using parameters of maternal body composition to identify gestational diabetes mellitus in early pregnancy. Clinical Nutrition ESPEN. 2021; 45:312–21. https://doi.org/10.1016/j.clnesp.2021.08.002 PMID: 34620334

46. Barforoush TS, Ghadimi R, Pahlevan Z, Ahmadi N, Delavar MA. The relationship between neck circumference and gestational diabetes mellitus in Iranian women. Clinical Diabetes and Endocrinology. 2021; 7(1):1–7.
Association of body composition in early pregnancy with gestational diabetes mellitus

47. Zhang R-Y, Wang L, Zhou W, Zhong Q-M, Tong C, Zhang T, et al. Measuring maternal body composition by biomedical impedance can predict risk for gestational diabetes mellitus: a retrospective study among 22,223 women. The Journal of Maternal-Fetal & Neonatal Medicine. 2020;1–8. https://doi.org/10.1080/14767058.2020.1797666 PMID: 32722949

48. Rocha AdS Bernardi JR, Matos S, Kretzer DC, Schöffel AC, Goldani MZ, et al. Maternal visceral adipose tissue during the first half of pregnancy predicts gestational diabetes at the time of delivery—a cohort study. PLoS One. 2020; 15(4):e0232155. https://doi.org/10.1371/journal.pone.0232155 PMID: 32353068

49. Thaware PK, Patterson CC, Young IS, Casey C, McCance DR. Clinical utility of ultrasonography-measured visceral adipose tissue depth as a tool in early pregnancy screening for gestational diabetes: a proof-of-concept study. Diabetic medicine: a journal of the British Diabetic Association. 2019; 36 (7):896–901. https://doi.org/10.1111/dme.13906 PMID: 30672019

50. Taktmaz T, Yalvac ES, Ozcan P, Coban U, Karasu AFG, Unsal M. The predictive value of weight gain and waist circumference for gestational diabetes mellitus. Turkish journal of obstetrics and gynecology. 2019; 16(3):199. https://doi.org/10.4274/tjogal.2019.03266 PMID: 31673474

51. Kawanabe S, Naga Y, Nakamura Y, Nishine A, Nakagawa T, Tanaka Y. Association of the muscle/fat tissue during the first half of pregnancy predicts gestational diabetes at the time of delivery—a cohort study. Diabetes research and clinical practice. 2018; 145:130–7. https://doi.org/10.1016/j.diabres.2018.05.001 PMID: 29852237

52. Marshall NE, Biel FM, Boone-Heinonen J, Dukhovny D, Caughey AB, Snowden JM. The Association between Maternal Height, Body Mass Index, and Perinatal Outcomes. American journal of perinatology. 2019; 36(6):632–40. https://doi.org/10.1055/s-0038-1673395 PMID: 30292175

53. Ulubağoğlu H, Bakay K, Özdemir AZ, Güven D, Batioglu S. Can we use waist circumference in the first trimester to screen for gestational diabetes? Journal of Experimental and Clinical Medicine. 2019; 36 (1):9–12. https://doi.org/10.1507/endocrj.EJ18-0252 PMID: 30393250

54. Wang Y, Luo BR. The association of body composition with the risk of gestational diabetes mellitus in Chinese pregnant women: A case-control study. Medicine. 2019; 98(42):e17576. https://doi.org/10.1097/MD.0000000000017736 PMID: 31626126

55. Nombo AP, Mwanri AW, Brouwer-Brolsma EM, Ramaiya KL, Feskens EJ. Gestational diabetes mellitus risk score: a practical tool to predict gestational diabetes mellitus risk in Tanzania. Diabetes research and clinical practice. 2018; 145:130–7. https://doi.org/10.1016/j.diabres.2018.05.001 PMID: 29852237

56. Anafchesti M, Ahmadzadeh B, Albookordi M, Najafian M. Effect of blood group, height, and weight gain during pregnancy on gestational diabetes mellitus. The Iranian Journal of Obstetrics, Gynecology and Infertility. 2018; 21(4):34–42. https://doi.org/10.17534/1753495X17754149 PMID: 30214477

57. Balani J, Hyer SL, Shehata H, Mohareb F. Visceral fat mass as a novel risk factor for predicting gestational diabetes in obese pregnant women. Obstetric medicine. 2018; 11(3):121–5. https://doi.org/10.1177/1753495X17754149 PMID: 30214477

58. Bourdages M, Demers M-E, Dubé S, Gasse C, Girard M, Boutin A, et al. First-Trimester Abdominal Adipose Tissue Thickness to Predict Gestational Diabetes. Journal of Obstetrics and Gynaecology Canada. 2018; 40(7):883–7. https://doi.org/10.1016/j.jogcc.2017.09.026 PMID: 29724492

59. KhushBakht D, Mazhar S, Bhalia A, Rashid A, Khan K, Jahanzaib U. Correlation Between Neck Circumference and Gestational Diabetes Mellitus and Associated Risk Factors During Pregnancy. Cureus. 2018; 10(5):e2699. https://doi.org/10.7759/cureus.2699 PMID: 30620703

60. Nassr AA, Shazty SA, Trinidad MC, El-Nashar SA, Marroquin AM, Brost BC. Body fat index: A novel alternative to body mass index for prediction of gestational diabetes and hypertensive disorders in pregnancy. European Journal of Obstetrics & Gynecology and Reproductive Biology. 2018; 228:243–8. https://doi.org/10.1016/j.ejogrb.2018.07.001 PMID: 30014931

61. D'Ambrosi F, Crovetto F, Colosi E, Fabbietti I, Carbone F, Tassisi B, et al. Maternal subcutaneous and visceral adipose ultrasound thickness in women with gestational diabetes mellitus at 24–28 weeks’ gestation. Fetal diagnosis and therapy. 2018; 43(2):143–7. https://doi.org/10.1159/000475988 PMID: 28624818

62. Han Q, Shao P, Leng J, Zhang C, Li W, Liu G, et al. Interactions between general and central obesity in predicting gestational diabetes mellitus in Chinese pregnant women: A prospective population-based study in Tianjin, China:单纯性肥胖和中心性肥胖在预测中国孕妇妊娠糖尿病中的交互作用: 一个中国天津前瞻性人群队列研究. Journal of diabetes. 2018; 10(2):168–73. https://doi.org/10.1111/1753-0407.12558 PMID: 28383185

63. He F, He H, Liu WQ, Lin JY, Chen BJ, Lin YC, et al. Neck circumference might predict gestational diabetes mellitus in Han Chinese women: A nested case-control study. Journal of Diabetes Investigation. 2017; 8(2):168–73. https://doi.org/10.1111/jdi.12574 PMID: 27589681
Association of body composition in early pregnancy with gestational diabetes mellitus

64. Li P, Lin S, Cui JH, Li L, Zhou SS, Fan JH. First-trimester neck circumference as a predictor of the development of gestational diabetes mellitus. Diabetes-Metabolism Research and Reviews. 2017; 33. https://doi.org/10.1007/s13291-017-1004-8 PMID: 29406042

65. Yang SH, Kim C, An HS, An H, Lee JS. Prediction of Gestational Diabetes Mellitus in Pregnant Korean Women Based on Abdominal Subcutaneous Fat Thickness as Measured by Ultrasonography. Diabetes & metabolism journal. 2017; 41(6):486–91. https://doi.org/10.4093/dmj.2017.41.6.486 PMID: 29199403

66. Alptekin H, Cizmecioglu A, Isik H, Cengiz T, Yildiz M, Iyisoy MS. Predicting gestational diabetes mellitus during the first trimester using anthropometric measurements and HOMA-IR. Journal of endocrinological investigation. 2016; 39(5):577–83. https://doi.org/10.1007/s40618-015-0427-z PMID: 26754418

67. Basraon SK, Mele L, Myatt L, Roberts JM, Hauth JC, Leveno KJ, et al. Relationship of early pregnancy waist-to-hip ratio versus body mass index with gestational diabetes mellitus and insulin resistance. American journal of perinatology. 2016; 2(01):114–22. https://doi.org/10.1055/s-0035-1562928 PMID: 26352680

68. White SL, Lawlor DA, Briley AL, Godfrey KM, Nelson SM, Oteng-Ntim E, et al. Early antenatal prediction of gestational diabetes in obese women: Development of prediction tools for targeted intervention. PLoS ONE. 2016; 11(12). https://doi.org/10.1371/journal.pone.0167846 PMID: 27930967

69. De Souza LR, Berger H, Retnakaran R, Maguire JL, Mathers AB, Connolly PW, et al. First-trimester maternal abdominal adiposity predicts dysglycemia and gestational diabetes mellitus in midpregnancy. Diabetes Care. 2016; 39(1):61–4. https://doi.org/10.2337/dc15-2027 PMID: 26525976

70. Kennedy NJ, Peek MJ, Quinton AE, Lanzarone V, Martin A, Benzie R, et al. Maternal abdominal subcutaneous fat thickness as a predictor for adverse pregnancy outcome: A longitudinal cohort study. BJOG: An International Journal of Obstetrics and Gynaecology. 2016; 123(2):225–32. https://doi.org/10.1111/1471-0528.13758 PMID: 26840907

71. Sina M, Hoy WE, Callaway L, Wang Z. The associations of anthropometric measurements with subsequent gestational diabetes in Aboriginal women. Obesity research & clinical practice. 2015; 9(5):499–506. https://doi.org/10.1016/j.obr.2015.02.005 PMID: 25797102

72. Baihani J, Hyer S, Johnson A, Shehata H. The importance of visceral fat mass in obese pregnant women and relation with pregnancy outcomes. Obstetric medicine. 2014; 7(1):22–5. https://doi.org/10.1177/1753495X13495192 PMID: 27512414

73. Bolognani CV, Reis L, de Souza SS, Dias A, Rudge MVC, Calderon IDP. Waist circumference in predicting gestational diabetes mellitus. Journal of Maternal-Fetal Neonatal Medicine. 2014; 27(9):943–8.

74. Gur EB, Ince O, Turan GA, Karadeniz M, Tatar S, Celik E, et al. Ultrasonographic visceral fat thickness in the first trimester can predict metabolic syndrome and gestational diabetes mellitus. Endocrine. 2014; 47(2):475–84. https://doi.org/10.1007/s12020-013-0154-1 PMID: 24462873

75. Ebrahimi-Mameghani M, Mehrabi E, Kamaliifard M, Yavariikia P. Correlation between body mass index and central adiposity with pregnancy complications in pregnant women. Health Promotion Perspectives. 2013; 3(1):73. https://doi.org/10.5681/hpp.2013.009 PMID: 24688955

76. Suresh A, Liu A, Poullon A, Quinton A, Amer Z, Mongelli M, et al. Comparison of maternal abdominal subcutaneous fat thickness and body mass index as markers for pregnancy outcomes: A stratified cohort study. Australian and New Zealand Journal of Obstetrics and Gynaecology. 2012; 52(5):420–6. https://doi.org/10.1111/j.1475-937X.2012.01471.x PMID: 23045985

77. Yao D, Chang Q, Wu Q-Y, Gao S-Y, Zhao H, Liu Y-S, et al. Relationship between maternal central obesity and the risk of gestational diabetes mellitus: a systematic review and meta-analysis of cohort studies. Diabetes-Metabolism Research and Reviews. 2017; 33. https://doi.org/10.1007/s40618-016-0526-1 PMID: 28471491

78. Basraon SK, Mele L, Myatt L, Roberts JM, Hauth JC, Leveno KJ, et al. Relationship of early pregnancy waist-to-hip ratio versus body mass index with gestational diabetes mellitus and insulin resistance. American journal of perinatology. 2016; 2(01):114–22. https://doi.org/10.1055/s-0035-1562928 PMID: 26352680

79. Wells JCK, Fewtrell MS. Measuring body composition. Arch Dis Child. 2006; 91(7):612–7. https://doi.org/10.1136/adc.2005.085522 PMID: 16790722
82. Ben-Noun LL, Laor A. Relationship between changes in neck circumference and cardiovascular risk factors. Experimental & Clinical Cardiology. 2006; 11(1):14. PMID: 18651013

83. Zhou J-y, Ge H, Zhu M-f, Wang L-j, Chen L, Tan Y-z, et al. Neck circumference as an independent predictive contributor to cardio-metabolic syndrome. Cardiovascular-diabetology. 2013; 12(1):1–7. https://doi.org/10.1186/1475-2840-12-76 PMID: 23680280

84. Yeung EH, Hu FB, Solomon C, Chen L, Louis G, Schisterman E, et al. Life-course weight characteristics and the risk of gestational diabetes. Diabetologia. 2010; 53(4):668–78. https://doi.org/10.1007/s00125-009-1634-y PMID: 20043144

85. Rudra CB, Sorensen TK, Leisenring WM, Dashow E, Williams MA. Weight characteristics and height in relation to risk of gestational diabetes mellitus. American journal of epidemiology. 2007; 165(3):302–8. https://doi.org/10.1093/aje/kwk007 PMID: 17074967

86. Brite J, Shiroma E, Bowers K, Yeung E, Laughon S, Grewal J, et al. Height and the risk of gestational diabetes: variations by race/ethnicity. Diabetic medicine. 2014; 31(3):332–40. https://doi.org/10.1111/dme.12355 PMID: 24308574

87. Hutchison JA, Piatt RW, Abrams B, Himes KP, Simhan HN, Bodnar LM. A weight-gain-for-gestational-age z score chart for the assessment of maternal weight gain in pregnancy. The American of Clinical Nutrition. 2013; 97(5):1062–7. https://doi.org/10.1093/ajcn.112.051706 PMID: 23466397

88. Forbes GB. Human body composition: growth, aging, nutrition, and activity: Springer Science & Business Media; 2012.

89. Widen E, Gallagher D. Body composition changes in pregnancy: measurement, predictors and outcomes. European journal of clinical nutrition. 2014; 68(6):643–52. https://doi.org/10.1038/ejcn.2014.40 PMID: 24667754

90. Most J, Marliatt KL, Altazan AD, Redman LM. Advances in assessing body composition during pregnancy. European journal of clinical nutrition. 2018; 72(5):645–56. https://doi.org/10.1038/s41430-018-0152-8 PMID: 29748651

91. Björntorp P. "Portal" adipose tissue as a generator of risk factors for cardiovascular disease and diabetes. Arteriosclerosis: An Official Journal of the American Heart Association, Inc. 1990; 10(4):493–6. PMID: 2196039

92. Hamdy O, Porramatikul S, Al-Ozairi E. Metabolic obesity: the paradox between visceral and subcutaneous fat. Current diabetes reviews. 2006; 2(4):367–73. https://doi.org/10.2174/1573399810602040367 PMID: 18220642

93. Fox CS, Massaro JM, Hoffmann U, Pou KM, Maurovich-Horvat P, Liu C-Y, et al. Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. Circulation. 2007; 116(1):39–48. https://doi.org/10.1161/CIRCULATIONAHA.106.675355 PMID: 17576866

94. Ruhl CE, Everhart JE, Ding J, Goodpaster BH, Kanaya AM, Simonsick EM, et al. Serum leptin concentrations and body adipose measures in older black and white adults. The American journal of clinical nutrition. 2004; 80(3):576–83. https://doi.org/10.1093/ajcn/80.3.576 PMID: 15321795

95. Cole TJ, Freeman JV, Preece MA. Body mass index reference curves for the UK, 1990. Arch Dis Child. 1995; 73(1):25–9. https://doi.org/10.1136/adc.73.1.25 PMID: 7639544

96. Najafi F, Hasani J, Izadi N, Hashemi-Nazari SS, Namvar Z, Mohammadi S, et al. The effect of prepregnancy body mass index on the risk of gestational diabetes mellitus: A systematic review and dose-response meta-analysis. Obesity Reviews. 2019; 20(3):472–86. https://doi.org/10.1111/obr.12803 PMID: 30536891

97. D’Souza R, Horyn I, Pavalagantarajah S, Zaffar N, Jacob C-E. Maternal body mass index and pregnancy outcomes: a systematic review and metaanalysis. American Journal of Obstetrics & Gynecology MFM. 2019; 1(4):100041. https://doi.org/10.1016/j.ajogmf.2019.100041 PMID: 33345836