






## SYSTEMATIC REVIEW

# Lifestyle-based and psychological interventions during pregnancy and risk of obesity and obesity-associated metabolic complications in the offspring: A scoping review

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## Abstract

**Introduction:** Obesity is a major global health challenge. Maternal health issues may increase the risk for obesity and associated conditions in the offspring, emphasizing the importance of successful interventions during pregnancy. However, systematic data are lacking.

**Material and Methods:** A systematic literature review of the effectiveness of maternal interventions in preventing childhood obesity and associated metabolic comorbidities was conducted. The search was conducted by two independent reviewers using PubMed, Scopus, ScienceDirect, and reference screening for relevant studies published between 1990 and 2023. Interventions were included that were lifestyle-based, but those with psychological components were also eligible for inclusion. Only studies with data on offspring anthropometrics and/or metabolic comorbidities after age  $\geq 2$  years were included.

**Abbreviations:** BMI, body mass index; GDM, gestational diabetes mellitus; GWG, gestational weight gain; RCT, randomized controlled trial.

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**Results:** Altogether 22 studies met the inclusion criteria, 14 with physical activity and dietary components, six with one or the other of these, and two with other interventions. Of the studies combining diet and physical activity, eight reported reductions in gestational weight gain and two less gestational diabetes. One study reported lower offspring body mass index in compliant participants and another lower resting pulse rate. Of the studies with only a dietary or physical activity component or other interventions, four reported lower gestational weight gain. One of these reported lower weight and skinfold thickness in the offspring and another lower fasting glucose.

**Conclusions:** A limited number of studies have evaluated offspring outcomes beyond the neonatal period. Lifestyle-based interventions including psychological components are particularly scarce. The research conducted demonstrated only a minor impact on childhood anthropometric and metabolic outcomes; however, the interpretation of these findings is hampered by a considerable risk of bias, largely due to missing offspring data.

#### KEYWORDS

children, gestational, intervention, lifestyle, maternal, obesity

## 1 | INTRODUCTION

The global prevalence of obesity is increasing rapidly.<sup>1,2</sup> This has marked individual and public health consequences, as excess body adiposity predisposes individuals to various metabolic and cardiovascular complications. Many of these conditions, such as metabolic-associated steatotic liver disease and type 2 diabetes, are increasingly observed in childhood.<sup>3-5</sup> Besides individual lifestyle-related issues, certain maternal factors, such as gestational weight gain (GWG),<sup>6-8</sup> gestational diabetes (GDM),<sup>6,7,9</sup> gestational hypertension, and preeclampsia,<sup>10,11</sup> may also be associated with an increased risk of obesity and associated complications in offspring. Potential mechanisms include direct metabolic effects on the fetus and placenta, as well as epigenetic modifications – a concept encapsulated in the Developmental Origins of Health and Disease (DOHaD) hypothesis.<sup>6,10</sup>

According to the Developmental Origins of Health and Disease framework, effective interventions during pregnancy could benefit the long-term metabolic health of the offspring.<sup>12</sup> This period of life also involves regular visits to healthcare facilities and renders the mother generally more receptive to advice on health and lifestyle changes.<sup>13,14</sup> For optimal results, we need to identify which interventions are likely to be most effective. Some evidence suggests that focusing on lifestyle could improve maternal outcomes, such as limiting weight gain.<sup>15-18</sup> However, systematic data evaluating the implications for the offspring, especially after the neonatal period or infancy, are lacking. It is important to evaluate the effects of interventions with longer follow-up periods as it has been suggested that noticeable overweight starts to develop relatively early in childhood, with differences becoming observable from the age of two

#### Key message

A limited number of studies have evaluated the effects of maternal lifestyle-based interventions on offspring obesity and its related complications in children aged  $\geq 2$  years. The research conducted has demonstrated only a minor impact on offspring health; however, the limited data availability hinders robust interpretation.

onwards.<sup>19,20</sup> Another aspect that remains poorly defined is the role of psychological and behavioral factors in the success of interventions, as well as the potential offered by modern virtual platforms.

In this scoping review, we scrutinized the literature on interventions during pregnancy to prevent obesity and associated complications in the offspring. We studied whether lifestyle-related elements were utilized alone, or if psychological and behavioral aspects were also considered. The findings were summarized to identify possible gaps in the literature and suggest potential areas for future research.

## 2 | MATERIAL AND METHODS

The study was conducted at the Tampere Center for Child, Adolescent, and Maternal Health Research, Tampere University. The aims and prespecified protocol of the review were registered in the Open Science Framework (OSF) before the creation of the data (<https://doi.org/10.17605/OSF.IO/TFC6Q>). Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) were

moreover followed<sup>21</sup> and the results are reported according to the PRISMA Extension for Scoping Reviews.<sup>22</sup>

## 2.1 | Eligibility criteria

Eligibility criteria were determined by defining population, intervention, control, outcome, and study design, as in the PICOS framework. The studies included were peer-reviewed original research articles describing randomized (RCT) or non-randomized controlled trials (non-RCT). The interventions were required to have been conducted during the gestational period, but studies starting when planning pregnancy and those continuing after delivery were also included if part of the intervention was implemented during pregnancy.

Interventions were required to aim to prevent excess adiposity in the offspring and/or obesity-associated metabolic disturbances. Additional goals might include reductions in maternal GWG and/or metabolic dysfunction such as gestational diabetes, and/or improvement of maternal mental health and resilience to stressful circumstances. Geographical location or type of intervention (e.g., digital, home visiting program or visits to primary or secondary/tertiary healthcare facilities) was not limited if the study included a lifestyle component. Mothers undergoing standard prenatal care were included as controls. Maternal interventions lacking a lifestyle component, such as studies with only nutritional supplement or medication, and those aiming to prevent malnutrition or nutritional deficiencies, were excluded.

Offspring data were required to include at least one anthropometric outcome reflecting relative body weight and/or adiposity, such as body mass index (BMI), age- and sex-adjusted ISO-BMI or BMI Z-score, weight-to-height ratio, waist circumference, or skinfold thickness, dual energy X-ray absorptiometry (DEXA) or electrical bioimpedance analysis for body composition. Other information collected included blood pressure, measures of lipid (blood triglycerides and cholesterol) and glucose metabolism (fasting glucose, glycated hemoglobin [HbA1C], 2h-oral glucose tolerance test [OGTT], insulin or homeostatic model assessment for insulin resistance [HOMA-IR]), and hepatic transaminase levels, as well as the possible presence of hypertension, dyslipidemia, pre-diabetes, type 2 diabetes, and metabolic-associated steatotic liver disease as defined in the study in question. Only offspring outcomes recorded at the age of two or thereafter were considered. Comparisons of offspring data between the maternal intervention group and controls were also required.

## 2.2 | Data sources and search strategy

Human studies published in English between January 1990 and October 2023 from all geographical locations were included in the analyses. First, two of the authors (T.P. and L.A.) conducted a pilot search. Screening in PubMed and search terms were modified

based on the results obtained. Next, the actual literature search was carried out in PubMed, Scopus, and Science Direct using improved search terms (Table S1). Additional restrictions on study type, year of publication, and language were applied as predefined in the search plan (Table S1). Possibly relevant references in the studies included were moreover screened, as well as relevant meta-analyses and reviews.

## 2.3 | Study selection, data extraction, and study assessment

A list of potential publications was generated by two of the authors (T.P. and L.A.) first screening the titles and abstracts independently. Full texts of the potentially relevant articles were read before making decisions on their final inclusion and differences were resolved, when necessary, by discussion with the corresponding author (K.K). In the case of articles undergoing screening of the full text the reasons for eventual exclusion were reported (Figure 1). T.P. and L.A. performed the data extraction from the selected articles, and the data were organized into a table, with the column titles guiding the extraction process. To assess the quality and risk of bias in each of the studies included, the "Risk of Bias 2" (RoB 2.0) tool was used for RCTs, and "Risk of Bias in Non-randomized Studies—of Interventions (ROBIN-I)" for non-randomized trials (Table S2).

## 3 | RESULTS

The search identified 1334 studies, of which 308 were removed as duplicates and 10 due to being published in languages other than English (Figure 1). Of the remaining studies, 961 were excluded based on title and abstract assessment and a further 33 after reading the full text. Two studies were added after screening the reference lists. The final dataset comprised 22 studies (Figure 1). Nineteen of these included diet and/or exercise components and two other types of interventions. No studies focused primarily on digital or psychological interventions, although a few studies included psychosocial and/or behavioral components.

### 3.1 | Combined diet and exercise interventions

Altogether, 14 studies included both physical activity and dietary components. Twelve of these were conducted in Europe, one in Australia, and one in the USA (Table 1). Eleven studies were RCTs, three were non-RCTs, and 12 were follow-up studies/secondary analyses of original research. The size of the intervention cohorts ranged from 109 to 2212 individuals, and of offspring cohorts from 72 to 1418 individuals. Duration of offspring follow-up was from 2 to 7 years. Eleven studies focused on at-risk mothers (e.g., overweight or at increased risk for GDM)<sup>24,26,30,32–34,36,39,41,43,47</sup> and three involved population samples.<sup>28,37,45</sup>

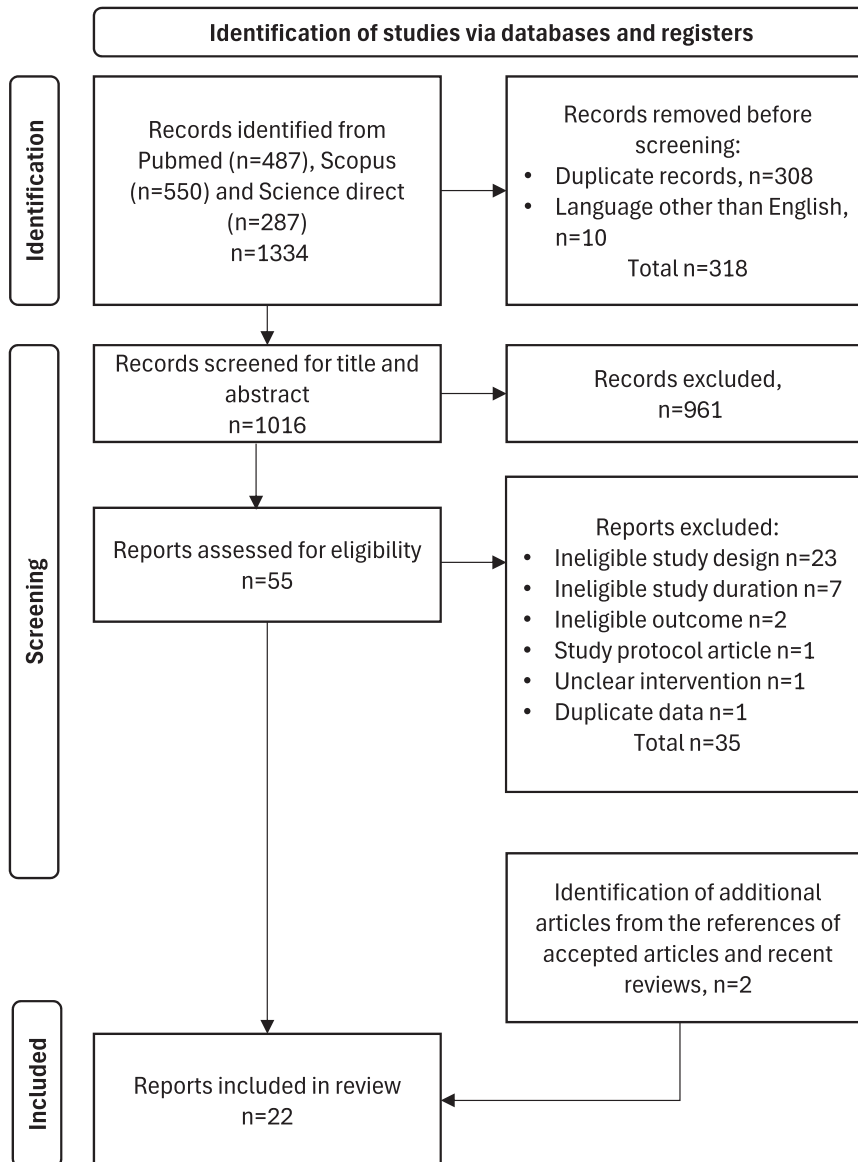


FIGURE 1 Flowchart of literature screening and study selection.

In 13 studies, the intervention began during the first or second trimester of pregnancy, and in one study in prepregnancy in a subgroup (Figure 2). In 11 studies, the intervention lasted until delivery or the postpartum period,<sup>24,26,28,30,32,33,36,37,41,45,47</sup> while one maternal intervention ended when the offspring were 1 year old,<sup>39</sup> another when the offspring were 2 years old,<sup>43</sup> and one when the offspring were 5 years old.<sup>34</sup>

The interventions were delivered through counseling on diet and physical activity, either integrated into routine healthcare visits or provided as separate sessions (Table 1). In addition to the counseling sessions, three studies included optional exercise sessions.<sup>24,28,32</sup> In all 14 studies, controls received at least some dietary and exercise advice. Three studies used additional motivational talks or interviews<sup>24,34,43</sup> and two behavioral techniques.<sup>36,40</sup> One study included psychosocial components,<sup>33</sup> but none mentioned psychological elements. Data were partly incomplete, but the number of contacts involved in the intervention was estimated to range from four to ~30.

Eight studies reported significant reductions in GWG,<sup>24,32,36,39,41,43,45,47</sup> and two studies observed a lower incidence of GDM in the intervention group than among the controls.<sup>34,39</sup> No studies reported significant changes in offspring's anthropometric measures in the intervention group as a whole. However, one study reported lower BMI in participants who adhered to the intervention.<sup>26</sup> In addition, one study reported a lower resting pulse rate in 3-year-old children whose mothers had received the combined diet and exercise interventions.<sup>36</sup>

### 3.2 | Diet only, exercise only, and other interventions

Six studies from Europe, Oceania, and the USA included solely exercise or dietary interventions, while two studies involved other interventions (Table 2). Five manuscripts reported follow-up studies on original research. The sizes of the maternal intervention cohorts

TABLE 1 Combined diet and exercise interventions.

Study	Intervention			Maternal and offspring outcomes				
	Design	Intervention and control cohorts	Strategy	Duration	Intensity	Maternal outcomes <sup>b,c</sup>	Offspring cohorts	Offspring outcomes
Haby 2018, <sup>23</sup> Haby 2022 <sup>24</sup> Sweden	Non-RCT + follow-up study	Women with obesity <i>n</i> = 438, standard care <i>n</i> = 100	Individualized support and motivational talks for a healthier lifestyle and diet and physical activity, optional dietitian visit, specific exercises	From first antenatal visit to postpartum visit	Two extra appointments, 5 min extra follow-ups at antenatal visits (nine visits) + optional activities	Lower GWG in the intervention group, no significant difference in GDM	Intervention group <i>n</i> = 284, controls <i>n</i> = 77	After 2.5 years no significant differences in overweight or obesity (questionnaires and registry data)
Luoto 2010, <sup>25</sup> Kolu 2016 <sup>26</sup> Finland	Cluster RCT + follow-up study	Women at-risk for GDM <i>n</i> = 219, standard care <i>n</i> = 180	Dietary and physical activity counseling with individual goals, targets to restrain GWG	From 8–12th to 37th week of pregnancy	Five separate visits	No significant differences in BMI, WC, HbA1c or fasting glucose	Intervention group <i>n</i> = 85, controls <i>n</i> = 88	After 7 years no significant differences in BMI, fasting blood glucose and HbA1c. Children's BMI significantly lower in adherent intervention group ( <i>n</i> = 24)
Kinnunen 2007, <sup>27</sup> Mustila 2012 <sup>28</sup> Finland	Non-RCT + follow-up study	Nulliparous women <i>n</i> = 53, standard care, <i>n</i> = 56	Individual counseling on physical activity and healthy diet, an option for supervised weekly exercise sessions	From 8–9th to 37th week of pregnancy	Five separate visits + optional exercise sessions weekly	No significant difference in the fraction of women exceeding normal GWG	Intervention group <i>n</i> = 34, controls <i>n</i> = 38	After 4 years no significant differences in BMI Z-scores or weight-for-length (questionnaires)
Dodd 2014, <sup>29</sup> Dodd 2020 <sup>30</sup> Australia	RCT + follow-up study	Women with overweight or obesity <i>n</i> = 1108, standard care <i>n</i> = 1104	Individualized support, counseling and goals on healthy diet and physical activity	From 10–20th to 36th week of pregnancy	Two dietitian visits, three calls and one visit to research assistant	No significant difference in GWG	Intervention group <i>n</i> = 727, controls <i>n</i> = 691	After 3–5 years no significant differences in BMI Z-scores, weight Z-scores or height Z-scores
Vinter 2011, <sup>31</sup> Tanvig 2015 <sup>32</sup> Denmark	RCT + follow-up study	Women with obesity <i>n</i> = 180, standard care <i>n</i> = 180	Individual counseling on physical activity and healthy diet, free membership to a fitness centre and aerobics classes	From 10–14th to 35th week of pregnancy	Four dietary counseling sessions + 20 optional exercise sessions	Lower GWG in the intervention group	Intervention group <i>n</i> = 82, controls <i>n</i> = 75	After 2.5–3 years no significant differences in BMI Z-scores or metabolic risk factors <sup>b,c</sup>

(Continues)

TABLE 1 (Continued)

Study	Intervention		Maternal and offspring outcomes				
	Intervention and control cohorts	Strategy	Duration	Intensity	Maternal outcomes <sup>b,c</sup>	Offspring cohorts	Offspring outcomes
<b>Parat 2019</b> <sup>33</sup> France	Women with overweight or obesity $n=132$ , standard care <sup>c</sup> $n=136$	Individual counseling and goals on healthy diet and physical activity, psychosocial elements included	From $\leq 21$ st week of pregnancy to 2 months postpartum	Two individual visits and four group sessions	No significant difference in excessive postnatal weight gain	Intervention group $n=102$ , controls $n=104$	After 2 years No significant differences in the rate of excessive weight gain
<b>Mustila 2018</b> <sup>34</sup> Finland	Women at risk for GDM $n=127$ , standard care $n=89$	Individual counseling on diet and physical activity counseling using motivating interview method	From 8 to 9th week of pregnancy to 5 years postpartum	Two group counseling sessions, counseling at every routine visit (13 visits)+ 2 group counseling sessions (1–2 years)+ counseling during yearly controls (1–5 years)	Less GDM in the intervention group, no significant difference in GWG	Intervention group $n=71$ , controls $n=76$	After 6 years no significant differences in weight gain or overweight/obesity (questionnaires and registry data)
<b>Poston 2015, Dalrymple 2021</b> <sup>35,36</sup> UK	Women with obesity $n=629$ , standard care $n=651$	Individual counseling on healthy diet and physical activity, behavioral techniques and voluntary extra activities	From 15 to 19th to ~37th week of pregnancy	Eight individual sessions, if needed replaced by phone call or email	Lower GWG and skinfold thicknesses in the intervention group, no significant difference in GDM	Intervention group $n=241$ , controls $n=254$	After 3 years lower resting pulse rate in the intervention group, no significant differences in BMI Z-score, WC or skinfold thicknesses
<b>Spies 2022</b> <sup>37</sup> Germany	Population sample $n=1139$ , standard care $n=1122$	Individual counseling on optimal GWG, healthy diet and exercise, educational brochures	From 12th week of pregnancy to ~6–8th weeks postpartum	Three visits antenatally and one postpartum	No significant differences in GWG or GDM	Intervention group $n=828$ , controls $n=797$	After 3 years no significant difference in BMI/BMI Z-scores or anthropometric measurements (questionnaires and registry data)
<b>Koivusalo 2016, Grotenfelt 2020</b> <sup>38,39</sup> Finland	Women with obesity and high risk for GDM $n=304$ , standard care $n=303$	Individualized counseling on diet, physical activity and weight, meetings with a dietitian, option for guided exercises	From prepregnancy/ <20th week of pregnancy to 1 yr postpartum	One prepregnancy visit, three visits and four group sessions antenatally, three visits postpartum	Less GDM and lower GWG in the intervention group	Intervention group $n=126$ , controls $n=137$	After 5 years no significant difference in BMI Z-score, WC or body composition by electrical bioimpedance, intervention group less optimal total metabolic parameters <sup>d</sup>

TABLE 1 (Continued)

Study	Intervention		Maternal and offspring outcomes				
	Intervention and control cohorts	Strategy	Duration	Intensity	Maternal outcomes <sup>b,c</sup>	Offspring cohorts	Offspring outcomes
Phelan 2018 <sup>40</sup> and 2021 <sup>41</sup> USA	RCT + follow-up study Women with overweight or obesity n = 132, standard care n = 132	Behavioral intervention with partial meal replacement <sup>e,f</sup> , individual counseling on physical activity, healthy diet and optimal GWG.	From 9 to 16th weeks of pregnancy to birth	Bimonthly <20 weeks, monthly until delivery, additional bimonthly visits if goals not met	Lower GWG/fraction of women exceeding normal GWG in the intervention group, no significant difference in GDM	Intervention group n = 77, controls n = 80	After 3 years no significant differences in BMI Z-scores, skinfold thicknesses or obesity
Claesson 2008, <sup>42</sup> Claesson 2016 <sup>43</sup> Sweden	Non- RCT + follow-up study Women with obesity n = 160, standard care, n = 208	Motivational talks and individual counseling and support on healthy diet and physical activity, option to join aqua aerobic classes	From <15th week of pregnancy to 2 years postpartum	Weekly visits antenatally, biannual visits postpartum (~30 visits)	Lower GWG in the intervention group	Intervention group n = 137, controls n = 165	After 5 years no significant difference in BMI (registry data)
Ronberg 2015, <sup>44</sup> Ronberg 2017 <sup>45</sup> Sweden	RCT (secondary analysis) Healthy women n = 221, standard care n = 224	Individual counseling on GWG, exercise prescriptions	From 16th week of pregnancy to birth	7-8 separate visits	Lower GWG in the intervention group	Intervention group n = 156, controls n = 144	After 5 years no significant difference in BMI or BMI Z-scores (registry data)
Renault 2014, <sup>46</sup> Jönsson 2021 <sup>47</sup> Denmark	RCT + follow-up study Two groups of women with obesity n = 130 and n = 125, standard care n = 134	Group 1: individual counseling on healthy diet, counseling on physical activity Group 2: counseling on physical activity	From 16th week of pregnancy to birth	Both groups: step counts registered for 1 week every 4 weeks Group 1: contact or visit with a dietician every 2 weeks (11-13 contacts)	Lower GWG in the intervention groups	Intervention group n = 51, controls n = 28	After 3 years no significant difference in BMI Z-scores (registry data)

Abbreviations: BMI, body mass index; GDM, gestational diabetes; GWG, gestational weight gain; Non-RCT, non-randomized controlled trial; RCT, randomized controlled trial; WC, waist circumference.

<sup>a</sup>References in bold face indicate studies identified in the literature search; references not in bold face refer to separate publications on the same cohort.

<sup>b</sup>Cohort size in final analyses may be smaller than in the original cohort.

<sup>c</sup>Metabolic risk factors including: abdominal circumference, blood pressure, and fasting levels of plasma glucose, insulin, triglycerides, and HDL.

<sup>d</sup>Including one dietician visit.

<sup>e</sup>Total metabolic parameters including: WC, mean arterial pressure, fasting insulin/glucose ratio, inverted high-density lipoprotein, cholesterol, and triglyceride concentrations.

<sup>f</sup>Free of charge replacement shakes and/or bars to replace two meals per day.

ranged from 40 to 1000 and of offspring cohorts from 40 to 285. Offspring follow-up time ranged from 2 to 9 years. Two studies included mothers with metabolic risk factors,<sup>51,61</sup> one included mothers with low income<sup>59</sup> and one physically active mothers.<sup>54</sup> The other studies involved population samples.<sup>49,53,56,58</sup>

In five studies, the intervention began in the first or second trimester, in two others, later in pregnancy, and one in prepregnancy (Figure 2). In six studies, the intervention ended at delivery or in the postpartum period, and in two studies it lasted  $\geq 1$  year (Figure 2).

One intervention focused on the glycemic indices of foods,<sup>49</sup> one combined dietary counseling with probiotics,<sup>53</sup> and one involved self-monitoring of glucose metabolism and potential insulin use.<sup>51</sup> One intervention included exercise three times a week,<sup>54</sup> one a 12-week training program,<sup>56</sup> and one cycling five times a week.<sup>58</sup> One study utilized a family-centered program,<sup>59</sup> and one lifestyle advice with or without counseling.<sup>61</sup>

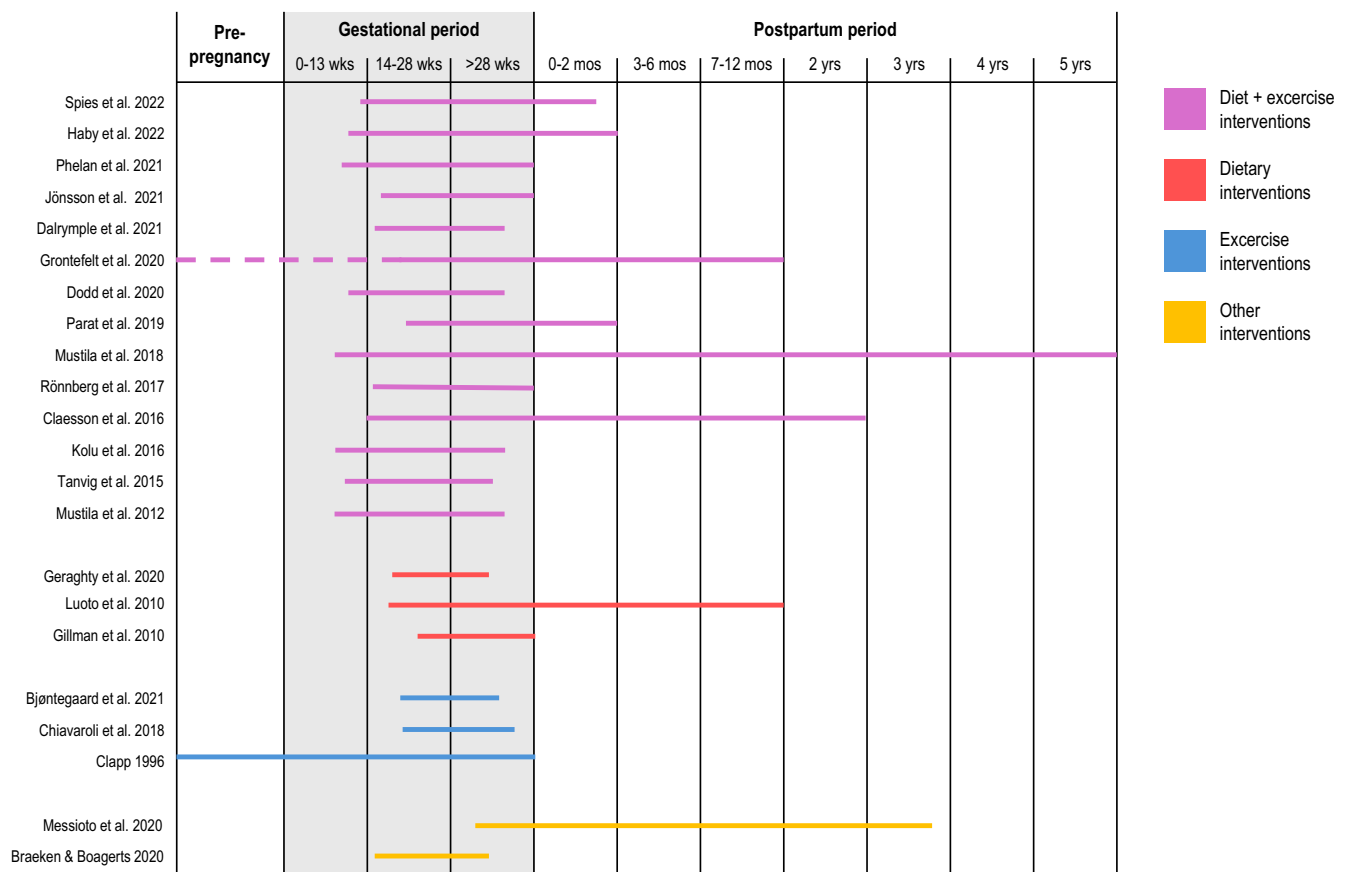
Two dietary interventions,<sup>49,51</sup> one exercise intervention,<sup>54</sup> and one other intervention<sup>61</sup> led to a reduction in GWG, while one dietary intervention also improved glucose metabolism.<sup>49</sup> One maternal exercise study reported reduced weight and skinfold thickness in offspring,<sup>54</sup> whereas another study found lower fasting glucose levels but a higher body fat percentage in the offspring.<sup>58</sup>

### 3.3 | Study quality

The overall quality of the studies included varied significantly (Table S2). Eleven studies were classified as having a high or serious risk of bias,<sup>24,26,28,32,34,39,41,49,56,59,61</sup> nine as having a moderate risk of bias or some concerns<sup>30,33,36,37,43,47,51,54,58</sup> and two as having a low risk of bias.<sup>45,53</sup> The main source of bias across all studies was missing follow-up outcome data on children and lack of appropriate methods to address this issue.

## 4 | DISCUSSION

Despite the marked increase in obesity and the growing interest in the association between the fetal period and childhood health outcomes, trials reporting the effect of maternal interventions on subsequent offspring obesity and associated metabolic comorbidities were rare. Moreover, none of the studies utilized modern digital technologies, and only a few involved psychosocial components. Our findings also highlight the heterogeneity of current research in terms of the populations studied, the frequency, intensity, and duration of the interventions, and the outcome measures used. Furthermore,



**FIGURE 2** Intervention types and durations. Purple lines denote combined dietary and physical activity intervention, red lines dietary interventions only, blue line physical activity interventions only and yellow line other interventions. Broken line indicates that the intervention was only offered to a subgroup of participants. Gray area denotes gestational period.

TABLE 2 Diet only, exercise only and other interventions.

Study	Intervention			Maternal and offspring outcomes					
	Authors and country <sup>a</sup>	Design	Intervention and control cohorts	Strategy	Duration	Intensity	Maternal outcomes <sup>b</sup>	Offspring cohorts	Offspring outcomes
<i>Diet only interventions</i>									
Walsh 2012, <sup>48</sup> Geraghty 2020 <sup>49</sup> Australia	RCT + follow-up study	Women with second pregnancy n = 383, standard care n = 393	Dietary counseling on replacing high glycemic index foods with low glycemic index foods as	From <18 to 34 weeks of pregnancy	One group session Two individual sessions	Lower GWG and less dysglycemia in the intervention group	Intervention group n = 31, controls n = 32	After 5 years no significant differences in measured weight, height or body composition	
Crowther 2005, <sup>50</sup> Gillman 2010 <sup>51</sup> Australia	RCT	Women with mild GDM n = 490, standard care n = 510	Individualized dietary counseling, glucose self-monitoring, insulin if needed	From 24 to 34 weeks of pregnancy to birth	During regular antenatal visits	Lower GWG in the intervention group	Intervention group n = 94, controls n = 105	After 4–5 years no significant difference in registry-based BMI-Z or obesity	
Laitinen 2008, <sup>52</sup> Luoto 2010 <sup>53</sup> Finland	RCT + follow-up study	Healthy women and intervention with probiotics n = 85 or placebo n = 86, standard care n = 85	Dietary counseling by a nutritionist and either probiotics or placebo	From <17 weeks of pregnancy to 1 year postpartum	3 × during pregnancy 3 × postpartum	-	Intervention with probiotics n = 67 or placebo n = 63, controls n = 61	After 2 years no significant differences in measured weight gain or growth (registry data)	
<i>Exercise only interventions</i>									
Clapp 1996 <sup>54</sup> US	Matched case-control study	Physically active women n = 20, controls discontinuing exercise n = 20	Vigorous exercise at intensity greater than 55% of maximal capacity	From preconception to birth	3 × 30 min/week before and during pregnancy	Lower GWG in the intervention group	Intervention group n = 20, controls n = 20	After 5 years lower weight and skinfolds measurements in the intervention group	
Stafne 2012, <sup>55</sup> Bjøntegaard 2021 <sup>56</sup> Norway	RCT + follow-up study	Pregnant women n = 429, standard care n = 426	30 min moderate intensity aerobic activity and 15 min strength and balance training + group training sessions	From 18–22 weeks to 32–36 weeks of pregnancy	12 weeks program: training ≥2x/weeks. + group sessions 1 h/wk.	No significant differences in GWG, GDM or HOMA-IR	Intervention group n = 164, controls n = 117	After 7 years no significant differences in ISO-BMI or prevalence of overweight (parental questionnaire)	
Hopkins 2010, <sup>57</sup> Chiavaroli 2018 <sup>58</sup> New Zealand	RCT + follow-up study	Pregnant women n = 47, standard care n = 37	Exercise intervention, home-based stationary cycling	From 20 to 36 weeks of pregnancy	15 weeks program: 5 × 40 min/week	No significant differences in body weight, BMI or insulin sensitivity	Intervention group n = 33, controls n = 24	After 6–9 years intervention group had increased total body and abdominal fat percentage but lower fasting glucose (parental questionnaire)	

(Continues)

TABLE 2 (Continued)

Study	Intervention		Maternal and offspring outcomes				
	Intervention and control cohorts	Strategy	Duration	Intensity	Maternal outcomes <sup>b</sup>	Offspring cohorts	Offspring outcomes
<i>Other interventions</i>							
Messio 2020 <sup>59</sup> USA	Low-income pregnant women n = 266, standard care n = 267	Family-centered program, motivational interview, social support, prenatal nutrition counseling and parenting support groups	From 32 weeks of pregnancy to 33 months postpartum	About 15 visits, including two individual sessions	-	Intervention group n = 132, controls n = 153	After 3 years no significant differences in registry-based or measured weight Z-scores or obesity
Bogaerts 2013, <sup>60</sup> Braeken and Boagerts 2020 <sup>61</sup> Belgium	Pregnant women with obesity: brochure group n = 64, prenatal session group n = 78, standard care n = 63	Group 1: received written lifestyle advice material Group 2: in addition to written material prenatal lifestyle group counseling	From <15 to 30–34 weeks of pregnancy	Group 1: no visits Group 2: 4 group sessions	Lower GWG in the intervention groups	Brochure n = 27 and prenatal session groups n = 39, controls n = 30	After 3–7 years no significant differences in measured anthropometric or cardiovascular outcomes

Abbreviations: BMI, body mass index; GDM, gestational diabetes; GWG, gestational weight gain; OMA-IR, Homeostatic Model Assessment for Insulin Resistance; RCT, randomized controlled trial.

<sup>a</sup>References in bold face indicate studies identified in the literature search; references not in bold face refer to separate publications on the same cohort.

<sup>b</sup>Cohort size in final analyses may be smaller than original cohort.

given that most studies demonstrated some or a high risk of bias, and only two met the criteria for low overall risk, the interpretation of the findings should be approached with caution.

Overall, while most interventions appeared to improve maternal health, particularly reducing the risk of GWG and some also of GDM, the effects on offspring outcomes were limited. Only two studies reported significant reductions in obesity or in metabolic dysfunction in the intervention groups as a whole and one study found lower BMI in the compliant group. In addition, one study reported a lower resting pulse rate among children whose mothers were in the intervention group. As such, the minor benefits observed are consistent with those reported in earlier reviews focusing primarily on the neonatal period.<sup>62–65</sup> However, we aimed to assess whether follow-up beyond infancy might reveal the potential impact of gestational interventions on offspring's metabolic health, an area where systematic literature analyses have so far been lacking. The absence of major benefits was somewhat surprising, given that maternal GWG and GDM have been risk factors for childhood obesity and metabolic syndrome.<sup>7,8</sup> It is possible that lifestyle aspects, such as diet and physical activity, play a more significant role and override the effects of prenatal factors, if any. In this respect, interventions continuing in childhood may yield better results.<sup>66</sup> Furthermore, recent studies emphasize the importance of the preconception period, although evidence on the benefits of preconception lifestyle interventions for the long-term health of offspring remains limited, and the few studies presented have mostly included severely obese infertile mothers.<sup>67</sup> Overall, however, it is challenging to distinguish between the effects of gestational and childhood factors, and also of those of shared genetics.

On the other hand, we should be cautious not to overinterpret the mostly negative results of the gestational intervention studies. Besides their limited number, a significant challenge lies in the variability and inconsistent reporting of health outcomes. For example, measurements of offspring's metabolism were often lacking, and various methods were used to report anthropometric data, thus hampering comparison between studies. In addition, the considerable risk of bias in most of the studies poses a challenge for interpretation and may have contributed to the absence of more definitive results. A major source of bias identified in the quality assessment was the considerable proportion of missing offspring data, and the lack of appropriate analytical methods to address this. In fact, in many studies, offspring follow-up data were available for less than 50% of cases,<sup>26,32,36,39,47,51,56,61</sup> and in one study for only 8%.<sup>49</sup> Compliance with the intervention was also rarely reported, and only the dropout rate was provided. This is important considering that, when reported, attendance at the appointments or activities included in the trials was usually incomplete,<sup>24,34,56,58</sup> possibly leading to a poorer response.<sup>24,68</sup> This may cause bias, as participants discontinuing the trials may have had lower socioeconomic status and a higher rate of obesity.<sup>24,34,63</sup> Parent-reported outcome measures were often used; these are less reliable than those obtained by trained research staff.<sup>69,70</sup>

Even when appropriately executed, both the duration and intensity of the interventions were relatively low in many of the studies included. Some consisted of only a few appointments during pregnancy and/or the postpartum period.<sup>26,37,49</sup> One cannot expect these contacts to achieve major changes in either maternal or offspring outcomes. More intensive interventions with face-to-face meetings, longer duration of intervention, a greater number and longer duration of sessions, as well as group exercise in healthcare facilities compared with home-based exercise have been associated with lower GWG and a reduced prevalence of GDM.<sup>71,72</sup> Therefore, these interventions are also likely to be more effective in improving offspring outcomes. Finally, for ethical reasons, standard care for the control group typically included at least some lifestyle and exercise counseling during pregnancy, which may have reduced the anticipated impact of the intervention.

Despite the limited number and heterogeneity of the studies, our results suggest that at least for combined dietary and exercise interventions, more intense approaches are associated with more favorable maternal outcomes. No definite conclusions could be drawn regarding offspring outcomes. Only two interventions included the preconception period,<sup>39,54</sup> notably both of them improving maternal health, with one also showing a reduction in offspring weight gain and skinfold thickness.<sup>54</sup> However, further research employing standardized and comparable outcome measures is required to enable more reliable and generalizable conclusions.

In light of our findings, future research should focus on more intensive interventions, ideally initiated before pregnancy and sustained throughout as well as beyond it, in sufficiently large cohorts. Outcome reporting should be more consistent and include more comprehensive data on offspring metabolic health. Following the intention-to-treat principle and assessing the effect of partial participation or dropout on outcome measures are essential.<sup>68</sup> Furthermore, psychological aspects should be considered. Mental health has been linked to obesity and metabolic dysfunction, and higher BMI has been associated with maternal depressive symptoms and anxiety.<sup>73-75</sup> Moreover, mental health challenges may increase the dropout rate from lifestyle interventions.<sup>76</sup> Psychological interventions, such as cognitive behavioral therapy, may also improve weight management in adults, with particularly long-lasting effects.<sup>73</sup> Additionally, incorporating motivational strategies and behavioral techniques has been shown to improve the effectiveness of both maternal and childhood lifestyle interventions.<sup>18,66,77</sup> It would also be worth considering socioeconomic aspects. Lower parental education and socioeconomic status both increase the risk of childhood obesity and metabolic syndrome,<sup>78</sup> and also contribute to a higher dropout rate in intervention trials.<sup>24,63</sup>

The use of modern digital platforms could facilitate participant recruitment and the implementation of interventions. For example, mobile phone-based interventions have proven effective in reducing GWG and improving healthy maternal lifestyle habits,<sup>79,80</sup> particularly when both parents are involved.<sup>80</sup> These approaches could also be more acceptable to mothers with lower-than-average

socioeconomic status and higher BMI,<sup>81</sup> thereby increasing the participation rate and reducing the dropout rate. Additionally, mobile phone-based and other digital platforms offer novel opportunities to set individual goals and provide personalized support.

## 4.1 | Strengths and limitations

The strengths of this scoping review included the broad search strategy with carefully predefined inclusion criteria and precise adherence to the PRISMA Guidelines. There were also some limitations, primarily due to the heterogeneity among the studies included. In particular, considerable differences in the nature and duration of the interventions, a high risk of bias due to lacking offspring data, and the heterogeneity of reported offspring health outcomes hampered the interpretation of the results. We were also unable to estimate if there was significant publication bias, but this seems unlikely as many of the trials included reported negative results. Finally, due to the nature of a scoping review, the quality of the studies included was not assessed statistically. A further limitation is the lack of interventions conducted exclusively during the preconception period.

## 5 | CONCLUSION

Only a limited number of gestational intervention studies evaluated offspring health outcomes beyond the neonatal period. Many of these studies had small cohort sizes and lacked systematic offspring data, which increased the risk of bias. Many important metabolic outcomes were not assessed. Trials including psychological and behavioral components, as well as modern digital platforms, are particularly rare. Due to these limitations, the absence of long-term benefits should be interpreted with caution. In the future, more intensive interventions with longer duration, preferably from preconception to the postpartum period, and involving larger cohorts as well as wider-scale measurements of metabolic outcomes, are called for. Additionally, the role of psychology and the use of modern technologies should be more thoroughly considered.

### AUTHOR CONTRIBUTIONS

Guarantor of article: Kalle Kurppa, M.D., Ph.D. Tiina Pajuvirta and Linnea Aitokari: literature research, screening and reading of studies, drafting of the manuscript. Kalle Kurppa: study design, study supervision, critical revision of the manuscript. Anna Eurén, Sauli Palmu, Salla Kuusela, Hannele Laivuori, Kaija Nissinen, Kaija Puura: study design, critical revision of the manuscript. All authors approved the final version of the article.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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