Maternal Dietary Intake and Associated Pregnancy Outcomes in the United Arab Emirates

The Dietary Subcohort of the Mutaba'ah Study

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“لطالما آمنت أن الأمهات هن بناة الأوطان ..فبداخل كل أم وطن نابض بالحب و الأصالة”

أم الإمارات سمو الشيخة فاطمة بنت مبارك

“I have always believed that mothers are the backbone of nations... Inside every mother is a nation full of love and authenticity”

Mother of the Nation H.H. Sheikha Fatima Bint Mubarak

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ABSTRACT

This thesis aimed to assess dietary intake and its associations with pregnancy outcomes in the United Arab Emirates (UAE). Within the *Mutaba'ah* Study, 1556 pregnant women were recruited into a dietary subcohort. Data collection using a semi-quantitative food frequency questionnaire (FFQ) was performed during antenatal care visits throughout the pregnancy. The relative validity of the FFQ was assessed using a 24-hour dietary recall as a reference method. Adherence to dietary patterns (Alternate Healthy Eating Index for Pregnancy [AHEI-P], Alternate Mediterranean Diet [aMED], Dietary Approaches to Stop Hypertension [DASH]) were identified, and ultra-processed food (UPF) intake was assessed. Gestational weight gain (GWG) was calculated as the difference in weight between the first and the last recorded weight, and excessive GWG (EGWG) was defined according to the Institute of Medicine guidelines, based on the first trimester body mass index. Gestational diabetes mellitus (GDM) diagnosis was based on the National Institute for Health and Clinical Excellence criteria.

Paper I showed that the FFQ overestimated intake of most nutrients and food groups but could be used to rank the pregnant women based on some aspects of their dietary intake. **Paper II** showed that the three dietary indices (AHEI-P, aMED, DASH) were moderately correlated. Some differences were observed in what distinct aspects of dietary intakes they captured. In **paper III**, the prevalence of EGWG was 29%. No associations were found between aMED and GWG or EGWG. However, intake of some aMED components (fruit, vegetables, ratio of monounsaturated fatty acids to saturated fatty acids) showed associations with GWG and/or EGWG. In **paper IV**, UPF intake was associated with lower diet quality but not with GDM. Further, no association was found between aMED and GDM. These findings show that the FFQ estimates intakes of nutrients and food groups with poor to acceptable validity. Adherence to healthy dietary patterns was associated with a favorable intake of nutrients and food groups, while high UPF intake was associated with poorer intake. Further research is needed to clarify the role of dietary intake in pregnancy outcomes.

Keywords: food frequency questionnaire, 24-hour dietary recall, dietary pattern, Mediterranean diet, pregnancy

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SAMMANFATTNING PÅ SVENSKA

Avhandlingen syftade till att estimera kostintag och dess samband med graviditetsutfall bland gravida kvinnor i Förenade Arabemiraten (UAE). Inom *Mutaba'ah-studien* rekryterades 1556 kvinnor till en dietär subkohort. Datainsamling med hjälp av ett semikvantitativt kostfrekvensformulär (FFQ) utfördes under mödrahälsovårdsbesök under hela graviditeten. Den relativa validiteten av FFQ:n bedömdes med en 24-timmars recall som referensmetod. Följsamhet till kostmönster (Alternate Healthy Eating Index for Pregnancy [AHEI-P], Alternate Mediterranean Diet [aMED], Dietary Approaches to Stop Hypertension [DASH]) identifierades och intaget av ultra-processad mat (UPF) utvärderades. Viktuppgång under graviditeten (GWG) beräknades som skillnaden i vikt mellan den första och den senast registrerade vikten under graviditeten. Överdriven GWG (EGWG) definierades enligt Institute of Medicine riktlinjer på GWG samt första body mass index i första trimestern. Graviditetsdiabetes (GDM) definierades enligt National Institute for Health and Clinical Excellence kriterier.

Delarbete I visade att FFQ:n överskattade intaget av de flesta av näringsämnena och livsmedelsgrupper men kunde användas för att rangordna delar av de gravida kvinnornas kostintag. **Delarbete II** visade att de tre kostindexen (AHEI-P, aMED, DASH) var måttligt korrelerade. Vissa skillnader observerades i vilka distinkta aspekter av kostintaget de fångade. I **delarbete III** var prevalensen av EGWG 29%. Inga samband hittades mellan aMED och GWG eller EGWG. Intag av vissa aMED-komponenter (frukt, grönsaker, kvoten mellan intag av enkelomättade fettsyror och mättade fettsyror) visade dock samband med GWG och/eller EGWG. I **delarbete IV** var UPF-intag associerat med lägre kostkvalitet men inte med GDM. Vidare hittades inget samband mellan aMED och GDM. Dessa fynd visar att FFQ:n estimerade intag av näringsämnen och livsmedelsgrupper med låg till acceptabel validitet. Följsamhet till hälsosamma kostmönster var associerat till ett mer gynnsamt intag av näringsämnen och livsmedelsgrupper, medan UPF-intag var associerat med generellt sämre intag. Ytterligare forskning behövs för att klargöra kostens betydelse för graviditetsutfall.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. **Almulla AA**, Ahmed LA, Hesselink A, Augustin H, Bärebring L.

The relative validity of a semi-quantitative food frequency questionnaire among pregnant women in the United Arab Emirates: The Mutaba'ah study.

Nutr Health. 2024 Jan 31:2601060231224010. doi: 10.1177/02601060231224010.

II. **Almulla AA**, Augustin H, Ahmed LA, Bärebring L.

Dietary patterns during pregnancy in relation to maternal dietary intake: The Mutaba'ah Study.

PLoS One. 2024 Oct 22;19(10):e0312442. doi: 10.1371/journal.pone.0312442.

III. **Almulla AA**, Augustin H, Ahmed LA, Bärebring L.

Adherence to a Mediterranean-style dietary pattern during pregnancy in relation to gestational weight gain: The Mutaba'ah Study. *Submitted for publication*.

IV. **Almulla AA**, Augustin H, Ahmed LA, Bärebring L.

Is intake of Ultra-Processed Food or adherence to the Mediterranean Diet associated with the development of Gestational Diabetes Mellitus in the United Arab Emirates? The Mutaba'ah Study. *Submitted for publication*.

CONTENTS

ABBREVIATIONS

24-HDR	24-Hour Dietary Recalls
AHEI	Alternate Healthy Eating Index
aMED	Alternate Mediterranean Diet
BMI	Body Mass Index
BMR	Basal Metabolic Rate
COVID-19	Coronavirus Disease 2019
DASH	Dietary Approaches to Stop Hypertension
EGWG	Excessive Gestational Weight Gain
FFQ	Food Frequency Questionnaire
GCC	Gulf Cooperation Council
GDM	Gestational Diabetes Mellitus
GWG	Gestational Weight Gain
HEI	Healthy Eating Index
IADPSG	International Association of Diabetes and Pregnancy Study Groups
IOM	Institute of Medicine
MUFA	Monounsaturated Fatty Acids
NICE	National Institute for Health and Care Excellence
OGTT	Oral Glucose Tolerance Test
OR	Odds Ratio

PUFA	Polyunsaturated Fatty Acids
REE	Resting Energy Expenditure
SD	Standard Deviations
SFA	Saturated Fatty Acids
TEE	Total Energy Expenditure
UAE	United Arab Emirates
UPF	Ultra-Processed Food
USDA	The United States Department of Agriculture
WHO	World Health Organization

INTRODUCTION

PHYSIOLOGICAL CHANGES IN PREGNANCY

The term “pregnancy” refers to the process in which an embryo or fetus, or sometimes more than one offspring, develops inside a woman’s uterus [1]. Pregnancy, also known as the gestation period, typically lasts about 40 weeks, starting from the first day of a woman’s last menstrual period [2]. Pregnancy is divided into three stages, each lasting about three months: the first trimester (up to around 13-14 weeks), the second trimester (from around 14 to 26 weeks), and the third trimester (from around 27 to 40 weeks) [3, 4]. A total gestational period of 39-40 weeks is defined as a full-term pregnancy, while delivery at 37-38 weeks is classified as early term, and delivery before the completion of 37 weeks is considered preterm birth [5, 6].

Pregnancy begins with the fertilization of an egg, which occurs in the fallopian tube, forming a single cell that divides as it travels to the uterus; there, it implants into the uterine lining and begins to grow [7]. The embryo undergoes organogenesis, forming major organ systems, and is termed a fetus after 8 weeks post-implantation or 10 weeks gestational age until birth [7, 8]. Around 5 days post-fertilization, the blastocyst develops, with the outer layer (trophectoderm) destined to become the placenta [9]. The placenta supports pregnancy by producing human chorionic gonadotropin to sustain progesterone levels and enables the exchange of nutrients, oxygen, and waste between mother and fetus. In addition, the placenta protects the fetus from infections and secretes hormones like placental growth factor and human placental lactogen to promote fetal growth (e.g., by decreasing maternal insulin sensitivity, and making more glucose available for the fetus) and breast development [10-14].

The pregnant body undergoes substantial physiological changes to support the fetus's growth and prepare for childbirth [15]. These changes affect nearly every organ system, including the cardiovascular, renal, respiratory, and endocrine systems, ensuring increased nutrient supply, oxygenation, and waste elimination [1]. For example, cardiovascular adaptations include an increased in cardiac output by the second trimester, with tachycardia and an increased heart rate, while respiratory adjustments involve diaphragm elevation and hyperventilation, increasing oxygen demand to accommodate fetal needs. In addition, gastrointestinal changes often result in nausea, vomiting, and acidity, and hematological system adaptations cause increased blood volume, increased production of blood cells, and changes to clotting factors [2].

Energy requirement during pregnancy includes both maternal and fetal energy expenditure while also accounting for the energy needed to support the growth of maternal tissues, such as fat stores, breast tissue, placenta, and fetal development [16, 17]. According to Butte and King [18], a pregnant woman's energy requirement is “the level of energy intake from food needed to balance her energy expenditure while maintaining a body size, composition, and physical activity level consistent with good health”. This requirement also includes the energy demands associated with tissue deposition necessary for achieving an optimal pregnancy outcome and is determined by maternal weight gain and the energy cost associated with tissue deposition, including fat and protein [18, 19]. On average, Total Energy Expenditure (TEE) increases across trimesters, with a median rise in Resting Energy Expenditure (REE) of 5.3% (72 kcal) in the first trimester, 9.9% (153 kcal) in the second, and 18% (252 kcal) in the third trimester [20]. The energy costs during pregnancy arise from the growth of the fetus, placenta, uterus, breasts, and amniotic fluid, along with increases in blood volume, extracellular fluid, and adipose tissue [16, 19].

PREGNANCY COMPLICATIONS

GESTATIONAL WEIGHT GAIN

Weight gain during pregnancy is a natural and essential process that supports the growth and development of the fetus [21]. For a normal-weight woman, an approximate typical distribution of a total pregnancy weight gain of 12.5 kg is shown in Figure 1, with the largest variations in birth weight, fat stores, and edema [16, 22, 23]. This distribution reflects the minimum weight gain needed for a healthy pregnancy and underscores how specific components, such as fluid retention or placenta weight, may relate to pregnancy outcomes like pre-eclampsia or small-for-gestational-age [22]. In 2009, the Institute of Medicine (IOM) (renamed the National Academy of Medicine in 2015 [24]) revised its 1991 guidelines on Gestational Weight Gain (GWG) to provide updated recommendations aimed at minimizing adverse health risks for both the mother and the infant [16]. The 2009 guidelines considered infant outcomes such as fetal growth, gestational duration, neonatal morbidity and mortality, and pregnancy complications, such as postpartum weight retention and lactation [16]. The recommendations propose GWG ranges for women with singleton fetuses based on pre-pregnancy Body Mass Index (BMI), with lower BMI categories advised to gain more weight (Table 1). For women carrying twins, the IOM committee offered provisional guidelines for GWG for normal weight women (17-25 kg), overweight women (14-23 kg), and obese women (11-19 kg) at term [16].

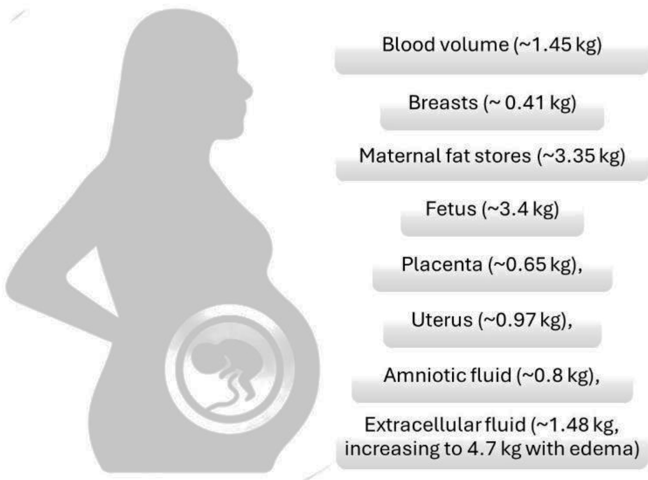

Figure 1. Approximate distribution of total pregnancy weight gain of around 12.5 kg for a woman with a normal weight [16, 22, 23]. Image adapted, modified, and licensed from Shutterstock. Copyright 2025 by Shutterstock [25]

Table 1. Institute of Medicine weight gain recommendations for pregnancy [16]

Pre-pregnancy BMI	**Total weight gain (kg)**
Underweight (<18.5 kg/m^2)	12.5–18
Normal weight (18.5–24.9 kg/m^2)	11.5–16
Overweight (25.0–29.9 kg/m^2)	7–11.5
Obese (≥30.0 kg/m^2)	5–9

BMI: Body mass index.

EXCESSIVE GESTATIONAL WEIGHT GAIN

Both insufficient (below the IOM recommended range) and Excessive Gestational Weight Gain (EGWG) (above the IOM recommended range) have been associated with adverse outcomes [16, 26]. Insufficient weight gain is associated with a higher risk of small-for-gestational-age, low birth weight, and preterm birth [26, 27]. EGWG is associated with a higher risk of complications such as large-for-gestational-age, fetal macrosomia, cesarean delivery, Gestational Diabetes Mellitus (GDM), pre-eclampsia, postpartum weight retention, gestational hypertension, depression, increased birth weight, and increased risk of childhood overweight or obesity [21, 26, 28, 29]. Risk factors for EGWG include high pre-pregnancy BMI, reduced physical activity, and increased food intake [30-32]. Risk factors for insufficient GWG are short maternal stature (<145 cm), tobacco smoking, multiparity, and low food intake during pregnancy [33-35]. A Cochrane review of 65 randomized trials found strong evidence that diet, exercise, or both reduce the risk of EGWG [36].

GESTATIONAL DIABETES MELLITUS

GDM is characterized by glucose intolerance leading to hyperglycemia of varying severity, with onset or first diagnosis during pregnancy [37], regardless of whether it is managed with insulin or dietary changes and whether it resolves after pregnancy. GDM diagnosis does not rule out the possibility that diabetes may have been undiagnosed prior to or developed alongside the pregnancy [38]. GDM screening and diagnosis lack international uniformity, with varying approaches used across countries and healthcare systems [39]. GDM diagnostic testing commonly includes a 75- or 100-gram Oral Glucose Tolerance Test (OGTT), with different diagnostic cut-offs used for blood glucose response [40]. According to the American College of Obstetricians and Gynecologists, all pregnant women should be screened for GDM, whether or not known risk factors are present, at 24–28 weeks of pregnancy with a 50-gram glucose challenge test. If the 1-hour blood glucose is higher than 130-140 mg/dL, a 100-gram 3-hour OGTT is recommended [41]. GDM is then diagnosed in women who have two or more abnormal values on the 3-hour OGTT [41]. However, the International Association of Diabetes and Pregnancy Study Groups (IADPSG) and the American Diabetes Association recommend a 1-step screening approach for GDM using a 2-hour 75-gram OGTT [42, 43]. According to these guidelines, a woman would be diagnosed with GDM when any single threshold value is equal to or exceeds these cut-offs: fasting value ≥5.1 mmol/l, 1-hour value ≥10.0 mmol/l, or 2-hour value ≥8.5 mmol/l [42]. Moreover, the United Kingdom National Institute for Health and Care Excellence (NICE) recommends that women with risk factors (e.g., BMI >30 kg/m2, previous diagnosis with GDM, family history of diabetes, and previous macrocosmic baby (≥4.5 kg) to undergo a 2-hour 75-grams OGTT at pregnancy weeks 24–28. GDM diagnosis here is defined by either a fasting value of ≥5.6 mmol/l or a 2-hour value of ≥7.8 mmol/l [44].

EGWG can result in greater maternal fat accumulation, which may reduce insulin sensitivity and beta-cell function, which increases the risk of GDM [16, 45]. GDM is linked to a higher risk of adverse outcomes, including pre-eclampsia, cesarean delivery, and macrosomia [46, 47]. Additionally, women with a history of GDM face an increased risk of developing GDM in subsequent pregnancies, as well as type 2 diabetes and cardiovascular disease later in life [48, 49]. Moreover, several risk factors have been identified for GDM, including advanced maternal age (≥25 years), pre-pregnancy overweight or obese, family history of diabetes, and history of fetal macrosomia [50, 51]. A meta-analysis of 18 randomized controlled trials found that dietary improvements after GDM diagnosis effectively reduce fasting and postprandial glucose levels and lower infant birth weight [52]. Maintaining appropriate weight gain during pregnancy is crucial to reduce the risk of GDM and its associated complications.

NUTRITION IN PREGNANCY

A balanced dietary intake – including a high intake of nutrient-rich foods like fruit, vegetables, whole grains, and sources of unsaturated fat while limiting intake of processed foods, refined grains, and sources of saturated fat – offers the greatest likelihood of a healthy pregnancy and optimal perinatal outcomes [53]. The United States Department of Agriculture (USDA) dietary guidelines recommend pregnant women to follow a healthy diet based on a variety of nutrient-dense, whole foods, such as vegetables, fruit, whole grains, eggs, fish, unsalted nuts and seeds, and low-fat or fat-free dairy products while reducing consumption of foods and beverages high in saturated fat, added sugars, and sodium [53, 54]. Similarly, the 2023 Nordic Nutrition Recommendations targeted to the general population, including pregnant women, recommend a "predominantly plant-based diet high in vegetables, fruit, berries, pulses, potatoes, and whole grains, nuts, fish, with moderate low-fat dairy, limited red meat and poultry, and minimal processed meats and food" [55]. It is important to consider that pregnant women might experience changes in their dietary habits resulting from cravings, changes in appetite, health beliefs, changed food preferences, social pressure, and recommendations [56-60]. In addition, maternal requirements differ based on individual characteristics, and alongside dietary quality before pregnancy, considerations should include maternal age, body size, gestational age, multiple pregnancies, activity level, and any existing health conditions [53]. The World Health Organization (WHO) defines good nutrition as "the intake of food required for optimal growth, function, and health that involves a well-balanced diet and provides all essential nutrients in the right amounts and proportions", while poor nutrition refers to a diet lacking nutrients due to insufficient or excessive intake [61]. A healthy diet should also consist of foods that are accessible, cost-effective, safe, culturally suitable, and primarily whole foods consumed in moderation [53].

A mother's nutritional status before conception and during pregnancy is critical for the well-being of the mother and her child and may affect pregnancy and child outcomes by influencing early development and nutrient availability [62-64]. Adequate micronutrient intake may support healthy placental development and function by reducing the risk of developing abnormal placentation (ex., pre-eclampsia), maternal-placental interface (ex., premature delivery), and fetal growth restriction [63, 65]. Inadequate intake of essential macro- and micronutrients can negatively affect pregnancy and neonatal outcomes, especially given the increased nutrient demands during pregnancy [66, 67]. Macronutrient deficiencies, such as insufficient protein or fat intake, impair fetal tissue growth, muscle development, and brain formation [62], and micronutrient deficiencies can result in severe consequences [62, 67]. For instance, folic acid deficiency increases the risk of neural tube defects and anemia, iron deficiency can lead to anemia which affects oxygen delivery to the fetus, calcium deficiency can contribute to osteopenia, muscle cramps, and delayed growth, and iodine deficiency can impair brain development, causing cognitive deficits and growth retardation [62, 67]. Nutrient deficiencies are linked to low birth weight, preterm delivery, and long-term health issues for the child, such as obesity, cardiovascular diseases, and cognitive deficits [62, 68]. It is, therefore, crucial to identify and address nutritional deficiencies in pregnant women to prevent adverse health outcomes.

DIETARY ASSESSMENT METHODS

Dietary assessment methods can be categorized into objective and subjective (self-reported) measurements [69]. Objective measurements, such as dietary biomarkers, are biochemical indicators that reflect recent or long-term dietary intake [70, 71] and are broadly defined as "any biological specimen that is an indicator of nutritional status with respect to intake or metabolism of dietary constituents" [71]. Dietary biomarkers are useful for validating or calibrating self-reported dietary assessment methods, estimating recent or long-term dietary intake, and assessing diet-disease risk [72]. However, they are often expensive and may impose a significant burden on participants, such as in the case of a 24-hour urine collection [73]. Nutritional biomarkers can be categorized as exposure, status, or functional biomarkers, which provide insights into nutrient intake, body levels, and physiological or behavioral responses, respectively [74]. However, their application often overlaps, as illustrated by Gao et al.'s framework [75], where biomarkers are classified into exposure (indicating dietary intake or nutrient exposure, e.g., nutrient concentrations in blood), effect (measuring physiological responses, e.g., plasma glucose levels), and susceptibility (assessing disease risk or response to exposure) biomarkers depending on the research objective, with many biomarkers serving multiple roles, such as indicators of both nutrient intake (exposure) and deficiency risk (susceptibility) [75].

Self-reported measures are divided into short- and long-term assessment methods and are commonly used to evaluate nutritional intake [76]. Short-term methods include 24-Hour Dietary Recalls (24-HDR) and food records, while the Food Frequency Questionnaire (FFQ) is an example of a long-term method [70].

The 24-HDR is a method that collects detailed information, including all foods and beverages consumed in the previous twenty four hours through an interview [77]. There are several techniques to perform a 24-HDR, in either an interviewer-administered or automated tool. One example is the Automated Multiple-Pass Method, developed by the USDA [78, 79], which enhances the accuracy of dietary recalls using a five-step process (Figure 2). The 24-HDR provides reliable quantitative estimates of dietary intake and can assess habitual intake at the group level with a large sample size or at the individual level with multiple recalls on different days and across seasons. However, it is limited by memory bias and cannot estimate usual dietary intake distributions [73, 77].

Food records can be estimated or weighed and involve participants recording all foods and drinks consumed over a specific period, depending on the study's requirements and variation in food and nutrient intake, but should include both weekdays and weekends to reflect different eating patterns [74, 77]. Food records provide accurate portion size estimates without relying on memory, where participants measure all items using a scale and describe foods and drinks precisely, including, when possible, details like brand names or recipes [77]. However, it depends on participants' active cooperation and consistent effort to record their intake accurately [73].

Figure 2. The Automated Multiple-Pass Method, developed by the United States Department of Agriculture [78]

FFQ's gather information on how often specific foods or food groups are consumed often over a defined period, such as a week, month, or year [74]. It can be self-administered or conducted through a standardized interview and may include portion size estimates to provide information on energy or nutrient intake [74, 80]; see Table 2. The FFQ is considered as a suitable method for assessing habitual dietary intake and is often used to rank individuals, separating those with low intakes from those with high intakes [81, 82]. It is a simple, inexpensive, non-invasive tool that can capture usual long-term dietary habits [73, 83, 84]. It is currently the most commonly used method for estimating dietary intake in large epidemiological studies on nutrition [84, 85].

All self-reported assessment methods need to be analyzed using nutritional analysis software that incorporates food composition databases to assess energy and nutrient intake. The USDA has been a leader in developing food composition databases, recognized globally as a gold standard for food and nutrition research [86]. These databases are part of the USDA Food Data Central and consist of five data types: the National Nutrient Database for Standard Reference Legacy Release, the USDA Global Branded Food Products Database, the Food and Nutrient Database for Dietary Studies, Foundation Foods, and Experimental Foods, and among these, the Standard Reference Legacy Release is the most comprehensive, covering 7793 foods and 149 food measures [87].

Table 2. Description of different types of FFQ based on portion size options

Portion size option	Type of FFQ	Description
No portion size included	Food Propensity Questionnaire [88, 89]	- A qualitative FFQ - Can be used along with the 24-HDR to assess long-term food intake, accounting for variation and frequency of food group intake
Specific standard reference portion size for each food	Semi-quantitative FFQ [77, 90]	- Used to ask respondents to measure how often specific quantities of food are consumed. - Useful when ranking individuals according to food or nutrient intake and can target foods in their standard units. - A good tool for studying the associations between dietary habits and disease. - Portion sizes should be tailored to the study population. It can be affected by age, gender, activity level, individual appetite, household tools used, and where and when the food was eaten.
Discrete portion size for each food item	Quantitative FFQ [90]	- Used to ask respondents to report their usual portion size using a specified measure. - Longer but offer a clear presentation of portion size and remove the uncertainty of the reported amount consumed.

FFQ: Food Frequency Questionnaire, 24-HDR: 24-hour dietary recalls.

These subjective measures of dietary intakes share common limitations, as they are prone to biases such as underreporting, where energy intake is reported as lower than actual, and selective misreporting due to social desirability, where participants report what they perceive as healthier choices [91, 92]. A summary of the uses and limitations of selected dietary assessment methods is presented in Table 3. The selection of an appropriate dietary assessment method depends on the study's objectives, whether estimating mean nutrient intake, determining the inadequacy percentage at risk, ranking individuals by intake, or assessing usual intakes [77] (Table 4). To characterize the average usual intake of a large group, a single 24-HDR or food record is a suitable method. To determine the prevalence of inadequate nutrient intakes within a population, multiple observations are required, whereas to rank individuals according to their dietary intake, multiple 24-HDR or food records or an FFQ can be used. If the aim is to obtain reliable estimates of the usual food or nutrient intakes of individuals, an even larger number of measurement days are needed [74, 77] (Table 4). The number of days depends on the day-to-day variations (within-subject variation) to the specific food or nutrient of interest and the level of precision needed. Thus, the number of days needed can be affected by the study population, dietary method, and seasonal changes [74, 77].

Table 3. Uses and limitations of selected dietary assessment methods used to assess individual food intake [73, 74, 77, 93-95]

Assessment methods	**Uses and benefits**	**Limitations**
Biomarkers	- Provide objective measures of nutrient intake, status, and function - Help detect nutrient deficiencies or excesses - Monitor responses to dietary interventions - Support public health research and initiatives by linking diet to health outcomes	- Interpretation can be complex due to biological variability (e.g., genetics, health status, environmental factors) - Technical limitations and the need for specialized equipment can make analysis costly and resource-intensive - Biomarkers may not always reflect long-term dietary patterns, focusing instead on recent intake or status
24-HDR	- Effective for assessing average dietary intake in large populations, provided the sample is representative and covers all days of the week - Useful for international comparisons of nutrient intake and its relationship to health and chronic disease risk - Less respondent burden - Suitable for individuals with low literacy - Less likelihood of participants altering their eating habits - Accuracy and detail - Provide reliable quantitative estimates of dietary intakes	- Single 24-HDR may miss food consumed infrequently - Relies on memory (recall bias) - Multiple recalls are needed to better capture the variability in an individual's diet and usual intake estimation - Need well-trained interviewers

Table 3 continued. Uses and limitations of selected dietary assessment methods used to assess individual food intake [73, 74, 77, 93-95]

Assessment methods	Uses and benefits	Limitations
Food records	- Can assess both actual and usual dietary intake, depending on the number of measurement days - Accurate and intake is quantified	- Time-consuming and requires a setting that allows for precise weighing - Participants may alter their usual eating habits by making weighing easier or impress researchers - Needs motivated and cooperative participants - Costly - Challenging for illiterate participants
FFQ	- Provide descriptive data on usual foods or nutrient intakes over long periods - Capture habitual intake - Useful in nutritional epidemiological studies to rank individuals into broad categories of specific foods or nutrients as low, medium, and high intakes and compare these with disease prevalence or mortality rates - Can identify dietary patterns linked to inadequate intake of specific nutrients - Efficient to administer, with minimal participant burden - Lower cost and time-effective - Fewer resources to analyze	- Less accurate and not as quantifiably precise (less detail on portion sizes) - Memory dependence and recall bias - Limited food list: overestimation or underestimation - Validated FFQ to use in different countries, affecting accuracy: commonly consumed food, unused or new food items - Requires literate population

FFQ: Food Frequency Questionnaire, 24-HDR: 24-hour dietary recalls.

Table 4. Selection of appropriate methods to assess nutrient intake in relation to four possible levels of objectives [74, 77]

Objective level	Information obtained	Appropriate methods
One	Nutrient mean intake of a group	- Single 24-HDR or - Single-weighted or estimated record - Large sample size and representation of all days of the week
Two	Prevalence of population "at risk"	- Replicates 24-HDR or - Replicates weighted or estimated one-day food record
Three	Individuals' usual intake of nutrients for ranking within a group	- Multiple replicates of 24-HDR or food records or - FFQ
Four	Individuals' usual intake of nutrients or foods for counseling or correlation or regression analysis	- Larger number of recalls or records or - FFQ or - Diet history

MEASUREMENTS ERRORS

Each dietary assessment method is subject to measurement errors, broadly categorized as random or systematic, depending on the method used [96]. Random error occurs when daily variations in an individual's food intake differ from their habitual dietary intake, and this can be minimized by increasing the number of assessed days [77]. On the other hand, systematic errors can arise when certain food groups are omitted from a questionnaire or when inconsistencies occur in interviews, such as differences in interviewers' questioning styles or interpretation of responses [77]. Random errors result in imprecision, while systematic errors introduce bias [77]. Therefore, the dietary assessment method must be valid, capturing the intended dietary intake, whether habitual, specific to a particular day, or focused on certain foods or nutrients, depending on the study's objective [77, 97]. A valid tool should closely reflect true intake and be reliable by providing consistent results over time if dietary intake remains unchanged [77]. Assessing the absolute validity of a dietary method is time-consuming, challenging to implement, involves few participants, and covers a short time frame [77]. However, the relative validity of a dietary method can be evaluated in both short- and long-term studies by comparing the "test" dietary method to a reference method known for its accuracy, reproducibility, and ability to measure similar parameters over the same period of time [77]. Dietary assessment is reproducible if it gives consistent results under the same conditions, though influenced by measurement errors, daily intake variation, and confounding factors (e.g., age, sex, season, illness, or dieting) [77]. True reproducibility cannot be fully determined due to between- (differences in usual daily food intake) and within-individual variability (the true day-to-day variations in dietary intake of a person), which should be statistically estimated rather than minimized [77]. A measurement with good reproducibility does not ensure validity, whereas a measurement with good validity cannot have poor reproducibility [98].

Misreporting in dietary assessment (under- or overreporting) affects the estimation of energy intake and other nutrients [99]. Under-reporters of total energy intake often report higher energy percentage of protein intake and lower percentage of fat intake in their diets [100], leading to bias in reported intake of macronutrients, which suggests a bias also in food and micronutrient intake. A recent study showed that more than 50% of dietary reports in large surveys (National Diet and Nutrition Survey and National Health and Nutrition Examination Survey) had implausible energy intakes and inaccurate intake of macro- and micronutrients [100]. Energy adjustment helps minimize artificial interindividual variation caused by misreporting of food intake, thereby reducing the impact of dietary measurement errors [101].

ENERGY ADJUSTMENTS

Adjustment for total energy intake, as outlined by Walter Willett [102], is crucial in epidemiological analysis for three key reasons. First, controlling for confounders can result in biased reporting if total energy intake is associated with disease risk, possibly because of differences in body size, physical activity, or metabolic efficiency. The second reason is the removal of variation in nutrient intake that is dependent on energy intake. A third reason is to simulate the impact of a dietary intervention by focusing on dietary composition instead of absolute intake (e.g., substitution analyses where increased intake of one dietary factor calls for a decreased intake of one or more other dietary factors). Walter Willett discussed several approaches to address the effect of total energy intake on analyses of specific nutrient intakes [102]. A standard statistical approach to control for energy intake can be explained as the effect of increasing the nutrient by one unit while keeping the energy intake constant. The residual method can be used to remove the variation caused by energy intake using a regression analysis. From the regression, the residuals represent the variation between each individual's actual intake and the intake predicted by their total energy intake. Another common approach is the nutrient density method, which utilizes the diet's composition and is often expressed as a percentage of energy or intake per 1000 kcal [102]. Various methodological issues exist with statistical methods for total energy adjustment in epidemiologic analyses. For example, the nutrient density model may introduce confounding when nutrient intake and disease risk are both related to total energy intake, leading to misleading conclusions and obscure interpretations [84, 103]. Tomova et al. have evaluated different methods of energy adjustment and further found issues with the most used methods [103].

DIETARY PATTERNS

Nutritional science explores dietary exposures by examining the consumption of specific foods, nutrients, and overall dietary patterns [104]. Dietary patterns are characterized by the types and combinations of foods they include, as well as their distribution of macro- and micronutrients, which can vary significantly [105]. For example, both plant- and animal-based foods provide protein, but their nutrient compositions differ [104]. A dietary pattern refers to the combination and proportions of foods and beverages habitually consumed, reflecting overall dietary behaviors rather than focusing on individual nutrients or food. Thus, dietary patterns capture the synergistic effects of diet as a whole on health outcomes [104, 106]. Dietary patterns also capture the usual quantities and consumption frequencies of foods and beverages over specific time periods or life stages (e.g., during the past year, during pregnancy) and can be tailored to particular eating occasions, such as breakfast or snacks [107]. These patterns reflect cultural and population norms influenced by food availability, food processing methods, cooking practices, agricultural techniques, socioeconomic conditions, marketing, and religious beliefs [108]. Dietary patterns can be used to assess and promote diet quality, reflecting food and beverage choices that support health and reduce chronic disease risk [109-111].

Dietary patterns can be identified using a priori, a posteriori, or hybrid approaches. A priori patterns are hypothesis-driven and predefined based on a concept of dietary score/index that is based on pre-defined scoring criteria [112, 113]. These scores can be used to assess adherence to dietary recommendations, cultural eating habits, or dietary quality and to analyze diet-health relationships [104, 114]. A posteriori patterns are data-driven, using statistical methods, for example, principal component analysis or cluster analysis, to identify patterns based on actual intake data [112, 114, 115]. However, these may lack generalizability and alignment with dietary guidelines [116, 117]. Hybrid approaches combine both methods, which combine aspects of the a priori and a posteriori approaches [113], using prior knowledge of disease mechanisms [114, 117].

An example of a priori-derived dietary score is the Healthy Eating Index (HEI), which evaluates how closely an individual's diet aligns with the United States Dietary Guidelines by scoring foods, nutrients, or components based on their health-promoting value [117]. Scores are determined using predefined criteria, such as cutoff values or sex-specific medians, and summed to provide an overall adherence score [118]. These methods are beneficial for their simplicity, reproducibility, ability to analyze diet-disease relationships across populations, and are based on existing and well-established patterns that capture multiple aspects of the diet within a single score [117, 119]. However, they also have limitations, such as focusing only on specific dietary components, introducing subjectivity when adapting patterns for cultural variations, and facing challenges in categorizing adherence scores since similar total scores can represent different combinations of dietary components [111, 117]. The most used methods to derive data-driven a posteriori approaches are factor analysis, which is based on intercorrelations between different dietary variables ("Prudent" and "Western" dietary patterns), and cluster analysis, which is based on the difference in the mean intakes of dietary components among individuals ("healthy" and "unhealthy" clusters) [112]. Factor analysis identifies principal components or factors with high loadings, representing dietary patterns [118], while cluster analysis groups participants with similar dietary intakes into exclusive clusters [115]. These methods allow for greater specificity in identifying food or food group combinations than a priori approaches [117]. However, they involve subjectivity in the classification of patterns and the selection of factor numbers, making it difficult to reproduce and compare patterns across populations, and the derived patterns are often population-specific and may not be generalizable to other studies [117]. The most used analysis in the hybrid pattern approaches is reduced rank regression, where a combination of food predictors (for example, food groups) explains the variation of some intermediate response variables (for example, nutrients or biomarkers) [112]. It uses prior knowledge of nutrient-disease associations to identify dietary patterns linked to health outcomes, making its findings easier to interpret and communicate for public health; however, its limitations include subjectivity in selecting dietary patterns, uncertainty about key food group drivers, and reliance on well-studied response variables, which may miss other important nutrients [120]. Additionally, dietary patterns can be analyzed using methods other than those described above, for example, Ultra-Processed Foods (UPF). UPF intake classifies food at the level of processing rather than nutrient or food intake, most commonly by the NOVA food classification system [121].

HEALTHY AND UNHEALTHY DIETARY PATTERNS

Several indices have been developed to assess overall dietary quality. The HEI, introduced by the USDA in 1995, was significantly updated in 2005 through a collaboration with the National Cancer Institute to align with the revised Dietary Guidelines for Americans [122]. The HEI has been updated every five years to reflect updates in dietary guidelines. The HEI-2005 emphasized whole grains and diverse vegetable subgroups, while the HEI-2010 added seafood, plant proteins, and fatty acid ratios [122]. The HEI-2015 introduced added sugars as a component, addressing their role in chronic disease, and the HEI-2020 aligns with the 2020–2025 Dietary Guidelines, emphasizing dietary patterns across life stages [104, 122]. In 2002, the original HEI was revised into the Alternate Healthy Eating Index (AHEI), which predicts more accurately the risk of cardiovascular and major chronic diseases (cancer or non-trauma related death) [123]. An updated version of the AHEI was released in 2010 (AHEI-2010), which involved additional dietary information and was more closely linked to chronic disease risk, such as coronary heart disease and diabetes [124]. Similarly, another widely used healthy dietary index is the Mediterranean Diet score [125], which emphasizes high intake of plant-based foods, fresh and minimally processed ingredients, olive oil as the primary fat source, moderate intake of dairy, fish, and poultry, and low red meat intake [126]. It was adapted and modified into the Alternate Mediterranean Diet (aMED) score [127, 128] by excluding potato products, separating fruit and nuts, removing dairy, focusing on whole grains, limiting the meat group to red and processed meats, and assigning one point for alcohol intake of 5–15 grams per day. These modifications were based on eating behaviors and dietary patterns constantly linked to lower chronic disease risk in clinical and epidemiologic studies [127]. In addition, the Dietary Approaches to Stop Hypertension (DASH) diet, initially designed to lower blood pressure [129], also has a corresponding index [130]. This diet is high in fruit, vegetables, and plant proteins and low in sodium and animal protein, effectively reducing blood pressure and low-density lipoprotein cholesterol [131-133].

Several studies, including randomized controlled trials, systematic reviews, and meta-analyses, have shown that the AHEI [124], aMED [128], and DASH [130] indices are inversely associated with risks of cardiovascular disease, cancer, and all-cause mortality [132-143]. Moreover, the Dietary Guidelines for Americans 2020-2025 incorporate principles from the HEI, Mediterranean Diet, and DASH diet, highlighting their shared focus on promoting nutrient-rich foods and reducing the risk of chronic diseases [54]. These 2020–2025 Dietary Guidelines provide four overarching guidelines [111, 117] (Figure 3).

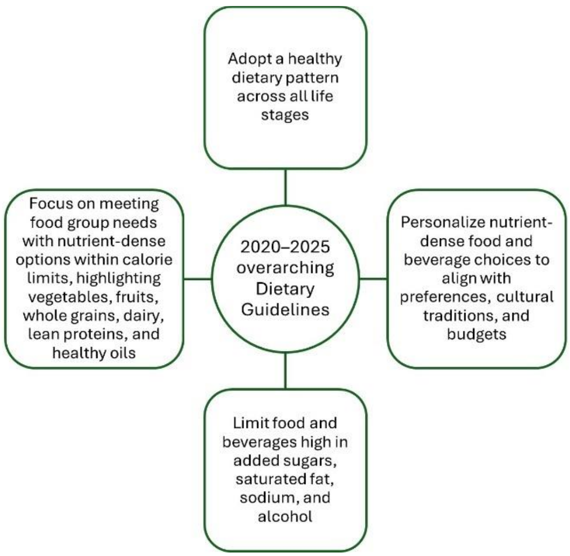

Figure 3. The four overarching guidelines of the 2020–2025 Dietary Guidelines [111, 117]

An unhealthy diet is often marked by high consumption of energy-dense, processed foods and nutrient-poor foods (e.g., salty or sugary snacks) [144]. An example of an unhealthy dietary pattern is the Western diet, marked by high consumption of energy-dense, low-nutrient foods like fast foods, sugary drinks, and processed items high in added sugars, salt, and unhealthy fats [145]. The Western diet is linked to higher consumption of UPF like sweets, sugary drinks, processed meats, potato and maize products, high-fat dairy, and animal fats [145]. UPF intake is a defining feature of the Western diet with similar unhealthy eating patterns, characterized by the high intake of calorie-dense, industrially produced foods with low nutritional value [146]. UPF are foods with industrial formulations made mostly from ingredients that undergo multiple industrial processes, including chemical modifications, and contain added additives like flavors, colors, emulsifiers, and sweeteners to enhance taste, appearance, and long shelf life [147]. Common UPFs include soft drinks, packaged snacks, sweets and candies, instant noodles, ready-to-eat meals, and fast food [147, 148]. The NOVA food classification system is the most widely used for defining ultra-processed foods in research [149], and it classifies all food and food products based on the nature, extent, and purposes of the industrial processes into four groups [148]. Group one is unprocessed and minimally processed foods, including natural food, for example, edible parts of plants (including fruit, leaves, seeds, and roots), and animal products (such as muscle meat, eggs, and milk). Group two is processed culinary ingredients (oils, butter, sugar, and salt) derived from group one foods through industrial processes such as pressing, refining, and extracting. Group three is processed foods, which includes, for example, canned or brine-preserved vegetables and legumes, syrup-preserved fruit, processed meats, freshly baked bread, and salted simple cheeses, and group four is UPF [147, 148]. High consumption of UPF and Western-style diet has been associated with various negative health outcomes in adults, including an increased risk of obesity, cardiovascular diseases, type 2 diabetes, breast cancer, and all-cause mortality [145, 150-154].

DIETARY PATTERNS IN PREGNANCY

A healthy diet during pregnancy, defined by the WHO as one that provides adequate energy, protein, vitamins, and minerals through a variety of foods such as vegetables, fruit, meat, fish, beans, nuts, and pasteurized dairy products, is essential for maternal and child health [155]. Poor dietary intake during pregnancy is associated with negative health outcomes; this includes a higher risk of pre-eclampsia, gestational diabetes, and EGWG, adverse birth outcomes (premature birth and low birth weight), and it can have long-term impacts in childhood and adult life, increasing the likelihood of chronic diseases such as diabetes and coronary heart disease [63, 156, 157].

A high-quality diet during pregnancy, characterized by a nutrient-dense profile, is associated with improved fetal health and growth and reduced risk of maternal complications such as preterm birth and EGWG [53, 158-161]. Maintaining a healthy maternal dietary pattern before and during pregnancy reduces maternal and fetal health complications and the risk of long-term adverse health outcomes for both [68, 162]. The 2020-2025 Dietary Guidelines for Americans emphasize the importance of maintaining healthy dietary patterns to support both maternal well-being and fetal development throughout pregnancy and lactation [54, 163] and conclude that “consuming a healthy dietary pattern before and/or during pregnancy may modestly reduce the risk of gestational diabetes, hypertensive disorders, EGWG, and preterm birth" [54, 164]. These patterns are often characterized by a higher intake of vegetables, fruit, whole grains, nuts, legumes, fish, and vegetable oils and a lower intake of red and processed meat, refined grains, and added sugar and are associated with a reduced risk of adverse pregnancy outcomes such as gestational hypertension, pre-eclampsia, GWG, GDM, and preterm birth [111, 165, 166]. In this context, healthy dietary patterns, such as Mediterranean-style diets, DASH, "prudent" diets, and AHEI, were associated with lower risk for GDM, gestational hypertension, pre-eclampsia, preterm birth, and preterm delivery. In contrast, unhealthy dietary patterns, such as the Western pattern and diets rich in UPF, were associated with increased risks. These associations were observed among pregnant women from the United States [167-171], Australia [172], Denmark [173], the Netherlands [174], Norway [175, 176], Spain [177], and China [178], using different dietary pattern methods and definitions.

ANTENATAL CARE IN THE UNITED ARAB EMIRATES

In the United Arab Emirates (UAE), government facilities offer a free healthcare to UAE nationals and a low-cost option for non-nationals [179], with a mandatory health insurance for all citizens and residents covered by employers [180]. Routine antenatal checks, including weight, blood pressure, urine dipstick, and fetal heart rate monitoring, are performed at every visit starting from the initial booking visit (ideally by 10 weeks) and continuing throughout pregnancy, with increasing visit frequency in the third trimester [181]. Additional tests are conducted at specific intervals: blood tests, including complete blood count and antibody screening, are done at the first visit, repeated at 28 and 36 weeks, while OGTT for gestational diabetes is performed for all women between 24 and 28 weeks [181]. A fetal anomaly scan is done between 18 and 23 weeks, ideally around 20 weeks, to check for structural abnormalities. In high-risk pregnancies (e.g., diabetes, hypertension, multiple gestation), growth scans begin between 24 to 26 weeks and are repeated every 2 to 4 weeks. For low-risk pregnancies, growth is monitored with fundal height measurements during routine visits starting at 28 weeks [181]. For low-risk pregnancies, most visits are performed by midwives and/or obstetricians; consultant obstetricians and multidisciplinary teams are involved for high-risk pregnancies.

NUTRITION IN THE UNITED ARAB EMIRATES

The UAE is a federation of seven emirates with Abu Dhabi as its capital, Dubai, Sharjah, Ajman, Umm Al-Quwain, Fujairah, and Ras Al Khaimah (Figure 4). As of 2022, the UAE's total population was approximately 10.28 million, with a literacy rate of 98.5% among the population aged 25 to 64 years [182]. As of 2023, Abu Dhabi Emirate has a total population of approximately 3.79 million, with 1.01 million live in Al Ain City [183]. The UAE is part of the Gulf Cooperation Council (GCC) countries besides the Kingdom of Saudi Arabia, Kuwait, Qatar, Bahrain, and Oman and shares similar political and cultural identities [184] (Figure 4). Since the discovery of oil, the GCC countries have undergone rapid economic growth, rising incomes, extensive trade globalization, and rabid urbanization, leading to significant shifts in diet and lifestyle habits [185, 186]. The transition in dietary intake includes increased consumption of energy-dense, high-fat and high-sugar food, animal products, and a lifestyle with high rates of physical inactivity, resulting in increasing rates of obesity and other metabolic diseases [185, 187-190]. According to the WHO, 16% of adults worldwide were obese in 2022, with obesity rates more than doubling since 1990 [191]. The GCC region has seen alarming prevalence estimates in obesity rates ranging from 17% to 48% among women [192], in type 2 diabetes ranging from 16.7% to 31.6% among adults [193], and in hypertension ranging from approximately 26% to 40% among adults [194]. In the UAE, it has been observed that approximately 22% of women are obese [195], 23% have type 2 diabetes [196], and 17% have hypertension [197].

Pregnant women in the GCC, including the UAE, face several nutritional challenges and health risks. Iron deficiency anemia is a major concern, affecting 30% to 54% of pregnant women in the region [198], and low birth weight prevalence ranges from 8.8% in Qatar to 11.5% in the UAE [199]. The prevalence of GDM in the GCC countries increased from 11.9% to 15.9% over a span of two decades [200], and ranges from 5.1% to 37.7%, indicating significant regional variation [201].

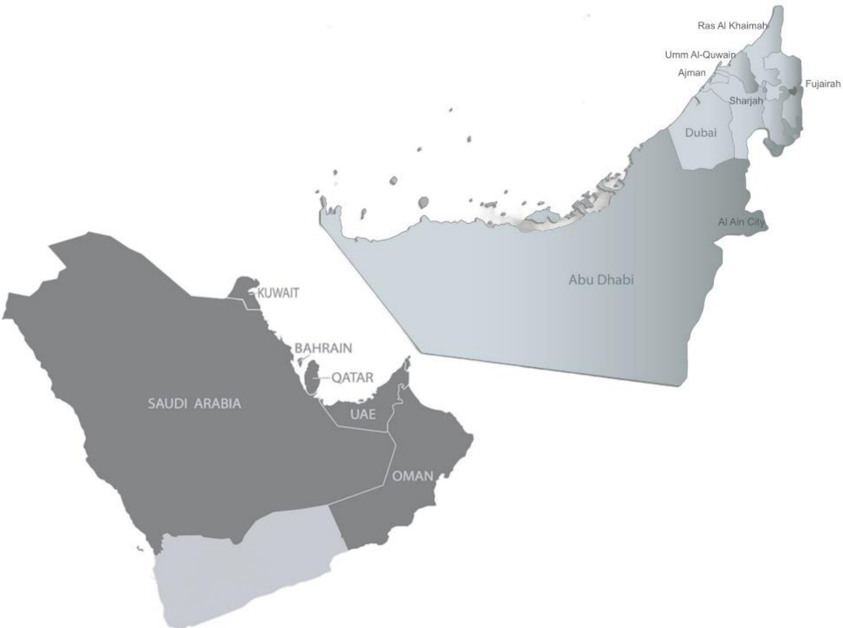

Figure 4. The Gulf Cooperation Council countries and the United Arab Emirates map. Image adapted, modified, and licensed from Shutterstock. Copyright 2025 by Shutterstock [202]

The nutrition transition in the UAE has shifted dietary practices away from traditional foods, such as dates, milk, rice, high-fiber bread, fish, and traditional spices toward more Westernized diets characterized by processed, high-fat, sugary foods, and high-caloric snacking [203-207]. Dates are rich in fiber, vitamins, and minerals, such as calcium, magnesium, iron, zinc, potassium, phosphorus, selenium, and amino acids [208, 209], and Emirati traditional spices are known for their antioxidant and anti-inflammatory benefits [206]. Among pregnant women in the UAE, 3% have Vitamin A deficiency (plasma vitamin A $<$20 µg/dL) [214], and 26% have Vitamin D deficiency ($<$10 ng/mL) [210]. Among obese women, 15% underwent a cesarian section, and 33% had macrosomia (birth weight $>$4000 grams) [211]. A 2-year Mother Infant Study Cohort of Emirati and Arab women from UAE reported that 59% had a pre-pregnancy BMI ≥25 kg/m2, 71% had inadequate GWG (around 32% insufficient and 40% EGWG), and 19% reported having GDM [212]. The same cohort investigated GWG in association with different dietary patterns, showing that the "Western" pattern was associated with EGWG and GWG rate, while the "Diverse" pattern decreased the risk of inadequate GWG and GWG rate [213], and higher adherence to the Mediterranean diet linked to reduced odds of insufficient and EGWG and lower postpartum weight retention [214]. A randomized trial of 63 high-risk pregnant women in the UAE found that a 12-weeks lifestyle intervention, including diet, physical activity, and behavior counseling, reduced the risk of GDM by 41% compared to usual care [215]. Another randomized controlled trial among 162 pregnant women found that supplementation with 2000 and 4000 International Units of vitamin D in the second and third trimester of pregnancy increased maternal and cord blood 25-hydroxyvitamin D levels when compared to supplementation with 400 International Units per day [216].

KNOWLEDGE GAP

The physiological changes that occur during pregnancy can contribute to a woman's increased susceptibility to significant weight gain during this period. This can impact future pregnancies and maternal health in the long term. The nutritional status of pregnant women in the UAE is inadequately documented, and there is a lack of data evaluating the dietary patterns among the Emirati population. Maintaining a healthy, balanced, and varied diet before, during and after pregnancy is challenging without adequate knowledge of the current nutritional intake of Emirati pregnant women, assessed through valid dietary methods. It is also important to address the related lifestyle factors that could affect maternal nutrition, such as family history, pre-pregnancy BMI, physical activity, diet quality, dietary supplementation, educational level, health literacy, and socioeconomic status. This would facilitate the implementation of successful strategies and intervention plans for pregnant women to prevent any related health complications for the mother and her child. Research in the UAE on the effects of structured nutrition programs during pregnancy on GWG and GDM is lacking. There is a scarcity of designated research on dietary practices during pregnancy in the UAE, with a small number of previous studies including small sample sizes that are not nationally representative. Healthy lifestyle counseling should be prioritized within antenatal care health programs with regular follow-up sessions. Little is known about the nutritional status and the association of different dietary patterns of pregnant women in the UAE and the impact on specific maternal outcomes. Examining these dietary patterns in the UAE is crucial for exploring diet-disease relationships, preventing adverse pregnancy outcomes, and promoting a long-term healthy life pattern.

AIM

The overall aim of this thesis was to evaluate the overall dietary intake and its association with pregnancy outcomes in a prospective longitudinal cohort study of pregnant women in the UAE.

The specific aims of each paper in this thesis were:

I. To assess the relative validity of a semi-quantitative FFQ in evaluating absolute and relative intake of nutrients and food groups using a 24-HDR as a reference method.

II. To relate adherence to healthy dietary patterns, evaluated by three dietary indices (Alternate Healthy Eating Index for Pregnancy (AHEI-P), aMED, and DASH), to intake of nutrients and food groups.

III. To investigate the associations between adherence to the Mediterranean diet and its components with GWG and EGWG.

IV. To evaluate the association between UPF intake and adherence to the Mediterranean diet with GDM.

PARTICIPANTS AND METHODS

STUDY DESIGN AND RECRUITMENT

Data used in this thesis are part of the *Mutaba'ah* Study [217], an ongoing prospective mother and child cohort study investigating maternal and early life determinants of infant, child, and adolescent health. *Mutaba'ah* means "follow up" in Arabic. The study employs a consecutive sampling strategy initiated in May 2017 and aims to recruit 17000 mother and baby pairs and to follow the children until the age of 18 years (2032-2043). The recruited sample as of October 2024 was around 15800 pregnant women. The recruitment was conducted in three major hospitals within the Emirati of Abu Dhabi in Al Ain City (UAE): two public hospitals (Al Ain Hospital and Tawam Hospital) and one large private hospital (Kanad Hospital). The inclusion criteria in the *Mutaba'ah* Study were pregnant women from the Emirati population aged 18 years or older, residents in Al Ain City, and able to provide informed consent. All eligible pregnant women were asked to participate in the *Mutaba'ah* Study during the antenatal visits throughout the pregnancy.

Data on more than 2000 parameters, including sociodemographic, lifestyle and behavioral, environmental, physical, and clinical factors, are collected through self-reported sequential questionnaires during pregnancy and from medical records of the mothers and their babies after birth. No biological samples have been collected yet. All questionnaires were translated from English to Arabic and back-translated by separate groups of study researchers. The full protocol of the *Mutaba'ah* Study can be found here [217]. Pregnant women recruited between December 9, 2019 and August 26, 2022 were invited to provide dietary data, constituting a dietary subcohort within the *Mutaba'ah* Study.

The recruitment staff were present in the waiting areas of the obstetrics clinics. While pregnant women waited to be seen by the obstetrician or gynecologist, they were introduced to the *Mutaba'ah* Study through verbal information. If a pregnant woman agreed to participate, she would receive an information sheet and a consent form to sign and return to the recruitment staff. Initially, a short questionnaire would be administered to collect basic sociodemographic data. After completing this, the pregnant women were invited to join a dietary subcohort by answering a semi-quantitative FFQ, for which another consent was obtained. All questionnaires were completed using digital tablets that were protected with access codes. The completed forms and consent sheets were then securely stored in a locked cabinet in the research department.

Primary data were obtained from medical records, including weight measurements, height, gravida and parity status, type of pregnancy, OGTT results, and delivery dates or instances of miscarriage. One hospital was in the process of transitioning from paper-based medical records to electronic records, which led to some difficulties and delays in obtaining data. Additionally, some cases of inaccurate or missing data were identified. To address these issues, the relevant variables were manually verified by accessing the participants' medical records to extract or correct any missing or incorrect data.

DATA COLLECTION AND DIETARY ASSESSMENT

Data collections were performed during the antenatal visits throughout the pregnancy. Data collections were suspended between March 6, 2020 and October 24, 2020 due to restrictions and challenges posed by the Coronavirus Disease 2019 (COVID-19) pandemic. A baseline questionnaire, administered at inclusion to the *Mutaba'ah* Study, was used to obtain maternal demographic characteristics and included, among others, maternal age, gestational age, education level, employment/occupation status, husband smoking during the current pregnancy, and physical activity before and during the current pregnancy.

Dietary intake among pregnant women was assessed using a self-administered semi-quantitative FFQ. For paper I-IV, the FFQ was completed at recruitment to the *Mutaba'ah* Study during antenatal care visits at any stage during pregnancy and captured habitual dietary intake up to that point. A subset of women was invited to complete a single 24-HDR interview, preferably during the same day or month as the FFQ. Data collection for the 24-HDR were administered during the second or third trimester and performed between February and June 2022. No data collections were administered for paper I during the month of Ramadan between March and April 2022. For paper II-IV, data collection for the FFQ were continued even during the month of Ramadan.

THE SEMI-QUANTITATIVE FFQ

The FFQ used in this thesis was adapted from a previous FFQ by Dehghan et al. [218, 219] that was developed to measure dietary intake among adults from the UAE and Kuwait [218, 219]. The FFQ was originally constructed based on the Harvard FFQ [218] and validated among Kuwaiti adults (n=68, mean age 37 years old) using two 24-HDR conducted over four months [219]. For the study included in the current thesis, the FFQ was adapted by a dietitian (A.A.A.), who refined it by removing specific traditional food items consumed mostly among the Kuwaiti population and specifying other food items by using the particular dish name instead of a general term. The detailed description of the FFQ is shown in paper I.

The final FFQ utilized in this thesis included 146 food items (Appendix 5). Women were asked how often during pregnancy, on average, they consumed each food item or beverage and chose their average consumption frequency of the specified serving size from one of nine frequency categories (never or less than once/month, 1-3/month, 1/week, 2-4/week, 5-6/week, 1/day, 2-3/day, 4-5/day, >6/day). The midpoint of the reported frequency category for each food item was used to compute the daily intake of food items (for example, the response "5–6/week" was calculated as 5.5/week or 0.73 times/day). The FFQ took approximately 20-30 minutes to complete, and we used the Photographic Atlas of Food Portions for the Emirate of Abu Dhabi to assist women in determining the average specified serving size for each food item and to display some uncommon food items with photographs [220].

THE 24-HDR

The 24-HDR was used only in paper I as a reference method to validate the FFQ and was administered after the FFQ, most often during the same day. Each woman in the validation study completed a single 24-HDR interview administered face-to-face by a dietician (A.A.A.) and took around 25-30 minutes to complete (Appendix 6). The 24-HDR was conducted using the USDA Multiple-Pass Approach [79, 221], which employs multiple memory prompts to assist women in recalling all consumed foods. The 24-HDR was not specified for any day of the week and covered both the weekdays (n=109, 81%) and the weekends (n=26, 19%) (Figure 5). We also used the Photographic Atlas of Food Portions for the Emirate of Abu Dhabi [220], and some usually used household measures (bowls and cups) to accurately estimate portion sizes.

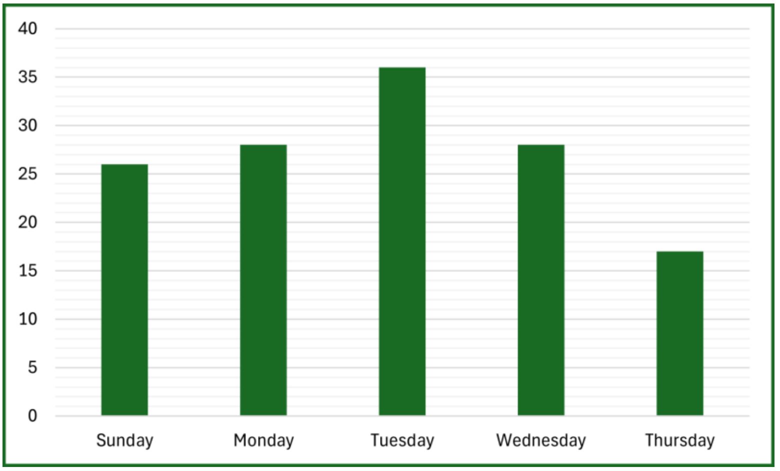

Figure 5. The distribution number of the 24-HDR throughout the week

NUTRITIONAL DATABASE

All food items from both the FFQ and the 24-HDR were entered into the software program Dietist Net Pro (Kost och näringsdata), which incorporated the latest release of the USDA National Nutrient Database to obtain all nutritional data [87]. Nutrient contents retrieved from the Dietist Net Pro program are shown in Figure 6.

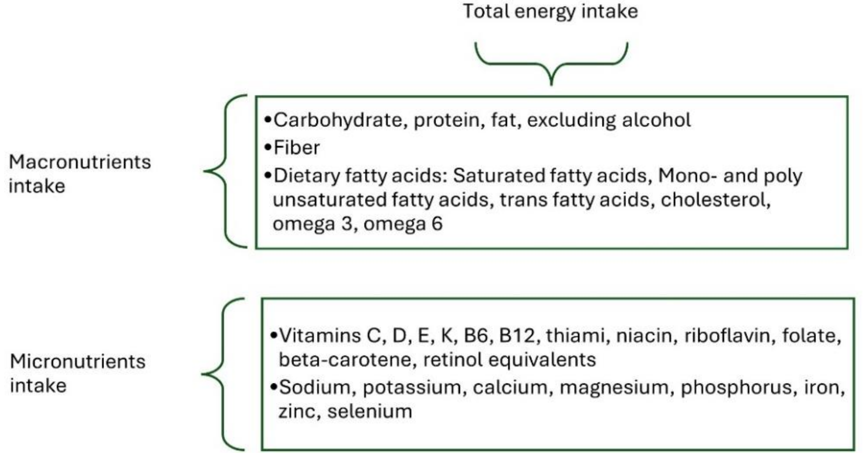

Figure 6. Nutrients obtained from the Dietist Net Pro program. Total energy intake was expressed as kcal or MJ per day. Macronutrients intakes were expressed as percent of total energy/day and/or g or mg per day. Micronutrients intakes were expressed as mg or µg per day

Nutrient intakes were determined by multiplying the nutrient content of the specified portion size by the intake frequency in the FFQ. For local mixed dishes, recipes from regional cookbooks were used [222-225]. Vitamins, minerals, and nutritional supplements were not included in nutrients calculations. Food groups included in paper I and paper IV were defined as shown in Figure 7.

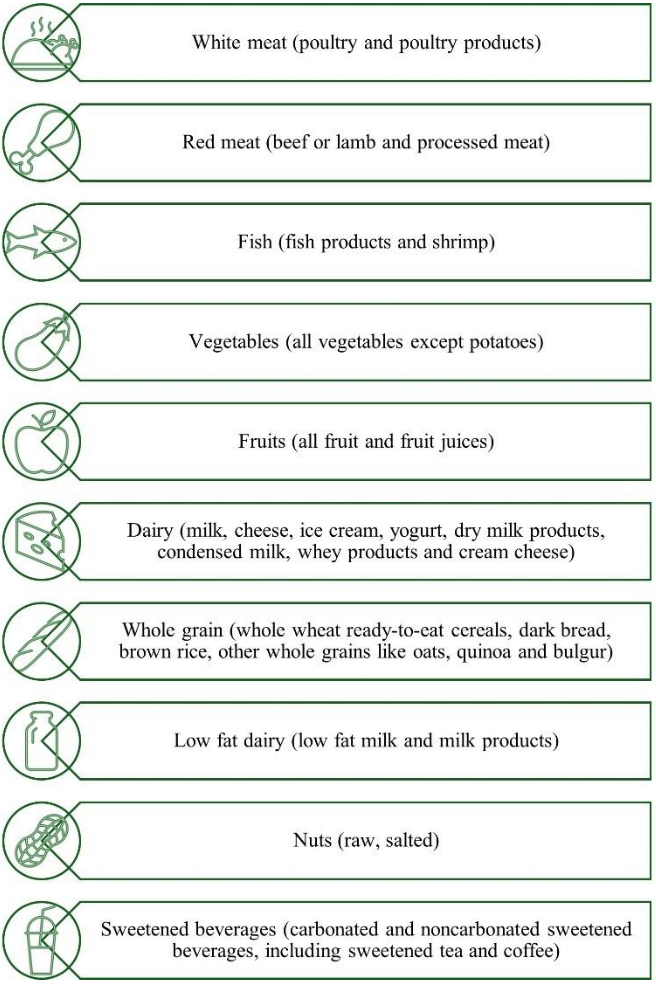

Figure 7. Classification and definitions of the food groups

DIETARY INDICES

In paper II, three dietary indices were calculated: AHEI-P [171], aMED [125, 128], and DASH [130]. These dietary indices were used to assess adherence to healthy dietary patterns, and intake data from the FFQ was used to calculate their scores. The AHEI-P index is a pregnancy-modified version of the AHEI [123, 171] and consists of nine components. Each component is scored on a scale of 0 (minimum adherence) to 10 (maximal adherence) based on adherence to the USDA dietary recommendations [54]. The aMED index is based on the Mediterranean Diet score [125, 128, 168] and consists of eight components scored based on the median intake within the study sample. For healthy components, intake equal to and above the median was scored as 1, and intake below the median was scored as 0, unhealthy components were scored reversely. The DASH index [130, 168], consists of eight components scored based on quintiles of intake within the study sample. A scale of 1 (least healthy) to 5 (most healthy) was used to score the components. All three indices excluded alcohol to support a healthy diet for pregnant women [226], and intakes from nutritional supplements were not included. To note, several components are similar across the three indices, such as vegetables, fruit, whole grain, nuts, legumes and red/processed meat (Table 5). Higher scores in all three indices represent a healthier diet. A detailed description of the three indices is published in paper II.

The aMED index was further used in papers III-IV. In paper IV, we also used the NOVA system to classify UPF intake in servings/day [121, 147]. Energy adjustment using the residual method [102] was used for the intake of nutrients and food in paper I, for the intake of micronutrients in the AHEI-P index in paper II, and for the UPF intake in paper IV. Also, energy adjustment using the density model was used in papers II- IV for the aMED index (2000 kcal per day) [227] and in papers I, II, and IV for nutrients intake (1000 kcal per day or as a percentage of total energy intake).

Table 5. Components of the dietary indices used in this thesis

Components*	**Foods included**	**Evaluation**	**Inclusion in Dietary indices**		
			AHEI-P	**aMED**	**DASH**
Vegetables	All vegetables (raw, cooked), tomato products, yams, legumes, excluding potatoes	Healthy	Yes	Yes	Yes
Fruit	All fruit (raw, dried, canned) and 100% fruit juices	Healthy	Yes	Yes	Yes
Whole grain	Whole-grain ready-to-eat cereals, cooked cereals, crackers, dark breads, brown rice, other grains, wheat germ, bran	Healthy	No	Yes	Yes
Ratio of white to red meat, g/d	White meat: poultry or fish. Red meat: beef or lamb and processed meat	Healthy	Yes	No	No
Sweetened beverages	Carbonated and noncarbonated	Unhealthy	No	No	Yes
Nuts and legumes	Nuts and peanut butter, dried beans, peas, tofu	Healthy	No	No	Yes
Nuts	Nuts, peanut butter	Healthy	No	Yes	No
Legumes	Tofu, string beans, peas, beans	Healthy	No	Yes	No
Red/processed meat	Hot dogs, deli meat, hamburger, beef and processed meat	Unhealthy	No	Yes	Yes
Fish	Fish and shrimp, breaded fish	Healthy	No	Yes	No
Low-fat dairy	Skim milk, yogurt, cottage cheese	Healthy	No	No	Yes
Fiber, g/d		Healthy	Yes	No	No
MUFA/SFA ratio		Healthy	No	Yes	No
PUFA/SFA ratio		Healthy	Yes	No	No

Table 5 continued. Components of the dietary indices used in this thesis

Components*	**Foods included**	**Evaluation**	**Inclusion in Dietary indices**		
			AHEI-P	**aMED**	**DASH**
Trans fat, E%		Unhealthy	Yes	No	No
Sodium, mg/d		Unhealthy	No	No	Yes
Calcium, mg/d		Healthy	Yes	No	No
Folate, µg/d		Healthy	Yes	No	No
Iron, mg/d		Healthy	Yes	No	No
UPF, servings/d	Formulated products containing minimal whole foods and typically include additives such as flavorings, colorings, preservatives, and emulsifiers	Unhealthy			

AHEI-P: Alternate Healthy Eating Index for pregnancy; aMED: Alternate Mediterranean Diet; DASH: Dietary Approaches to Stop Hypertension; MUFA: Monounsaturated fatty acids; SFA: Saturated fatty acids; PUFA: polyunsaturated fatty acids; E%: percent of total energy/day; UPF: ultra-processed food. *Units for the components of the AHEI-P presented as servings per day for vegetables and fruit, and are scored based on reference values according to the Dietary Guidelines for Americans 2020-2025 [54]. Units for the components of the aMED are presented as grams per day and are scored by women's distribution relative to the median intake level of the study sample. Units for the components of DASH are presented as servings per day and are scored in quintiles within the study sample.

PREGNANCY OUTCOMES

Data regarding weight during pregnancy, height, parity, gravidity, and pregnancy progress and outcomes were obtained from medical records. BMI was calculated as kg/m2 and classified based on the criteria from the WHO [228] as underweight (<18.5 kg/m2), normal weight (18.5-24.9 kg/m2), overweight (25-29.9 kg/m2), and obesity (≥30 kg/m2). Parity was defined as nulliparous or multiparous, and gravidity was defined as primigravid or multigravida [229]. Harris-Benedict equation was used to predict the Basal Metabolic Rate (BMR) [230] of women with singleton pregnancy and by adding the median increase in REE during the first trimester of the pregnancy ((655.0955+(9.5634*weight (kg))+(1.8496*height (cm))–(4.6756*age)+ 72)) [19, 20], and to calculate the food intake level (total energy intake/BMR). The current dietary intake of the pregnant women included in this thesis with singleton pregnancy was examined and compared with the recommended intakes during pregnancy according to the Dietary Guidelines for Americans 2020-2025 [54].

GESTATIONAL WEIGHT GAIN

GWG was calculated as the difference between the first recorded weight of the pregnant women at the first prenatal visit (gestational week ≤14) and the last weight recorded before delivery (gestational week ≥37). Adequate GWG was defined as 12.5–18 kg for underweight, 11.5–16 kg for normal weight, 7–11.5 kg for overweight, and 5–9 kg for obese women, based on the first trimester BMI and according to the IOM guidelines [16]. Insufficient GWG was defined as weight gain below the recommended ranges according to the IOM guidelines, and EGWG was defined as weight gain above these ranges.

GESTATIONAL DIABETES MELLITUS

As part of routine antenatal care at the study hospitals, all pregnant women were advised to undergo GDM screening using a 75-gram 2-hour OGTT between weeks 24-28 of pregnancy [231]. The GDM diagnosis was based on the NICE 2015 criteria. The cutoff points for the NICE 2015 criteria were set as a fasting value of ≥5.6 mmol/L or a 2-hour value of ≥7.8 mmol/L [44, 232]. At least one glucose value equal to or above the cutoffs was used for the diagnosis of GDM.

STATISTICAL ANALYSIS

It was planned to recruit a sample size of 2000 pregnant women for the dietary subcohort (~20% of the whole *Mutaba'ah* cohort) to allow the detection of an odds ratio as low as 1.31 for a relatively common outcome of 20% in the unexposed group (e.g., GDM), or an odds ratio of 1.73 for a relatively less common outcome of 5% in the unexposed group, with 80% power at a 0.05 significance level. However, we assumed an outcome proportion of about 25% to 30% in the unexposed group, a cohort of about 1100 pregnant women would allow the detection of an increase or decrease in the odds ratios of approximately 19% to 23% in the exposed group compared to the unexposed group (80% power and 5% alpha). Calculations were based on the G*Power software version 3.1.9.7 [233]. For paper I, according to Willet et al. [84] and Cade et al. [83], a sample size of 100-200 individuals is recommended for a validation study.

The statistical methods used in the thesis are shown in Table 6. Descriptive statistics were used to summarize and present women's characteristics and to characterize the distribution and main features of the study population. Normality was examined for all papers by histograms. In papers III and IV, correlations were checked between the independent variables to check for collinearity, and in paper II, to see how closely the three dietary indices relate to each other in terms of dietary components or scoring. In paper I, agreement analyses were used to assess the relative validity at both the group and individual levels to measure how closely the FFQ aligns with the reference method (24-HDR). In paper II, the associations between the three indices in both tertiles and medians and maternal dietary intake were assessed using the Kruskal-Wallis test and multivariable logistic regression models. In papers II-IV, potential confounding was identified by prior knowledge and guided by a Directed Acyclic Graph [234]. In papers III and IV, the aMED dietary score (both as a continuous and tertiles of intake) and its components were used to assess its relation to GWG, EGWG, and GDM using multivariable linear and logistic regression models. Further, in paper IV, multivariable logistic regression analysis was used to assess the association between UPF intake (both as a continuous and tertiles of intake) and UPF food groups with GDM. All our models were carefully checked, and the assumptions for linear and logistic regression were met, confirming their validity. In the FFQ, we used imputation for missing responses to single items (applied in the sweets and baked goods category) by replacing the missing value with the mean of the available responses for that item. Moreover, missing values from the questions about husband smoking and physical activity were imputed with the most frequent reply.

Table 6. Overview of the statistical methods performed in this thesis

Statistical methods	**Paper I**	**Paper II**	**Paper III**	**Paper IV**
Descriptive analysis				
Mean± standard deviations	✓	✓	✓	✓
Median (25th-75th percentile)	✓	✓		
n (percent)	✓	✓	✓	✓
Agreement, correlation, group comparisons				
Kruskal-Wallis test		✓	✓	✓
Chi-square test			✓	✓
Mann-Whitney U tests			✓	✓
Correlation, Spearman's rank	✓	✓	✓	✓
Cross-classification	✓			
Kappa (Cohen's Kappa)	✓			
Wilcoxon Signed-Rank Test	✓			
Mean percent difference	✓			
Bland-Altman Analysis	✓			
Regression analysis				
Linear regression			✓	
Logistic regression		✓	✓	✓

In this thesis frame, additional analyses were performed to identify differences in demographics and nutritional data: first, between pregnant women who completed the FFQ during the month of Ramadan and those who completed it during other months, and second, between women with singleton and multifetal pregnancies, using the Mann-Whitney and Chi-Square tests. Moreover, a Wilcoxon rank test was used to compare pregnant women who completed the FFQ twice during the same pregnancy (FFQ1 vs. FFQ2). Each woman's first completed FFQ (FFQ1) was included in all papers. In addition, based on the data from the validation study (paper I), we used a different energy adjustment method (density model) to compare some results with paper I. We also examined the associations between GWG (continuous variable) with aMED and some selected components in each trimester separately using multivariable linear regression analysis.

Sensitivity analysis was conducted in Paper III to examine any differences among women excluded due to missing body weight measurements or due to implausible energy intakes using a Mann-Whitney or Chi-Square test and the inverse probability weights. In addition, we excluded women with insufficient GWG from the reference group in the logistic regression analysis. Moreover, in Paper IV, sensitivity analysis was performed to evaluate the robustness of the study results and included only women who completed the FFQ before the time of GDM screening (week 24 of pregnancy). In all analyses, a p-value of <0.05 was considered significant. All statistical analyses were conducted using Statistical Package for Social Sciences version 28.0 (IBM SPSS Statistics for Windows, Armonk, New York, United States of America).

ETHICAL CONSIDERATIONS

The study procedures followed the guidelines of the Declaration of Helsinki [235]. Ethical approvals for the *Mutaba'ah* Study were obtained from the UAE University Human Research Ethics Committee and the Abu Dhabi Health Research and Technology Ethics Committee [(ERH-2017-5512) and (DOH/CVDC/2022/72), respectively] [217]. Informed written consent was obtained from all women before performing any data collection. It included simple and clear information about the study's purpose, methods, voluntary participation, and the right to withdraw at any time. Data collectors also briefly explain the study, assuring participants that their identity will only be accessible to the research team. Participants then signed and received a copy of the consent form and an information booklet about the *Mutaba'ah* Study. Participants didn't receive payments, and no blood sampling was drawn for this study's purposes. Ethical approvals were also obtained from the Swedish Ethical Review Authority (2023-00338-01) to conduct the research included in this thesis (i.e., analyze the data).

RESULTS

STUDY PARTICIPANTS

The overall participant response rate for the *Mutaba'ah* Study cohort is 87%. Between the period from December 9, 2019 to August 26, 2022, pregnant women were introduced to provide dietary data in the form of an FFQ with a subset of the participants to provide a single 24-HDR (between February and June 2022), thus formed a dietary subcohort within the *Mutaba'ah* Study. The participation flow of the dietary subcohort for the inclusion process for all the papers in the thesis is shown in Figure 8. Out of 5620 pregnant women recruited in the *Mutaba'ah* cohort during that period, 2157 were invited, and 601 declined, citing reasons such as feeling unwell, being tired, lack of time, or without providing any specific reason, resulting in an overall response rate for the dietary subcohort from the FFQ of 72%. N=1556 were enrolled in the dietary subcohort. For the validation study presented in paper I, N=300 pregnant women were invited to participate, and 165 declined, resulting in a response rate of 45%.

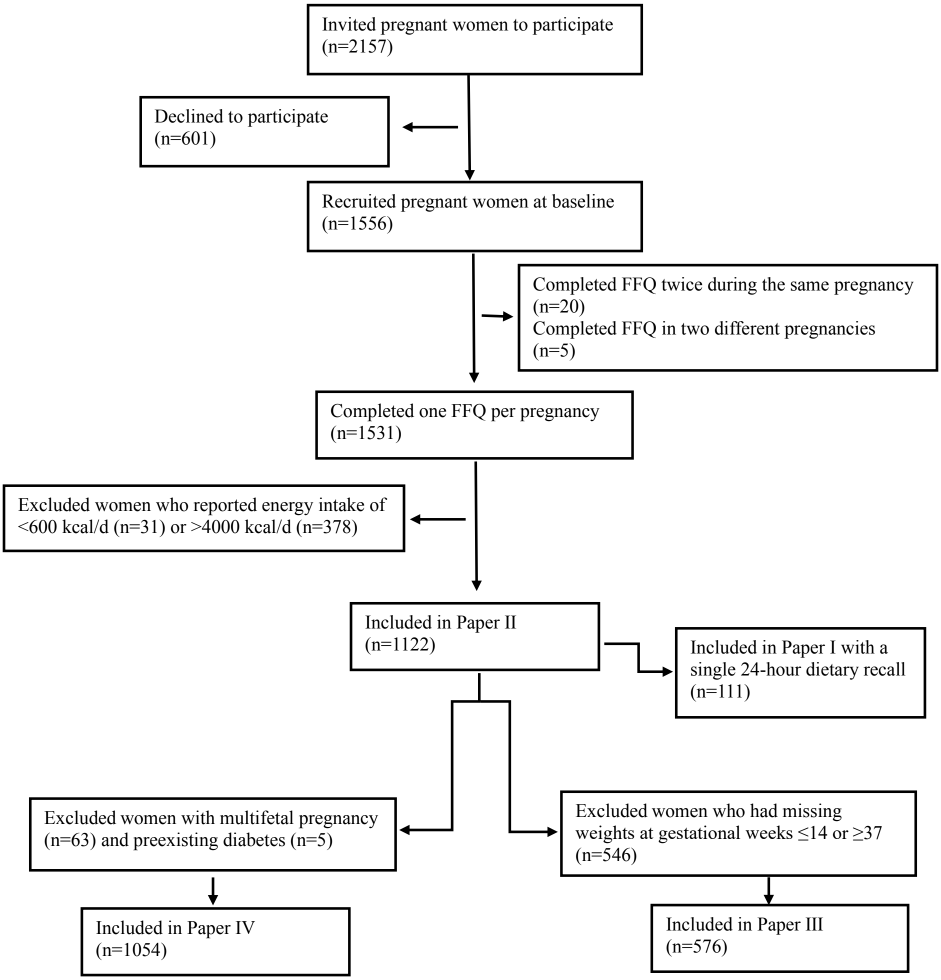

Figure 8. Participants flow in the dietary subcohort within the Mutaba'ah Study

There were no differences in the characteristics between women in the dietary subcohort compared to the whole cohort (*Mutaba'ah* Study), as shown in Table 7. In the dietary subcohort (n=1122), the mean±SD age of the pregnant women was 31 years old, and the mean gestational age was 6.5 months at the time of the FFQ completion. Most women were recruited in their third trimester (58%), 71% were multiparity, 53% were housewives, and 48% had a university level education. The mean first trimester BMI was 27±6 kg/m2.

Table 7. Characteristics of pregnant women from the whole cohort of the Mutaba'ah Study based on the available data as of October 2024 (n=13404)

Characteristics	N (valid values)	Mean (SD)
Age	13 404	30.9 (6.1)
Gravidity	12 896	3.6 (2.4)
		N (%)
Gravida groups	12 896	
First pregnancy (primiparous)		3 430 (26.6)
2-3 pregnancies		3 530 (27.4)
4-5 pregnancies		3 186 (24.7)
> 5 pregnancies		2 750 (21.3)
Education level	12 349	
Secondary school or less		5 623 (45.5)
Higher than secondary school		6 726 (54.5)
Employment status	12 321	
Unemployed		8 291 (67.3)
Employed		4 030 (32.7)
Passive smoking (secondhand smoking)	12 622	
No		6 589 (52.2)
Yes		6 033 (47.8)
Physical activity before pregnancy	10 542	
No		6 148 (58.3)
Yes		4 394 (41.7)
Physical activity during pregnancy	10 604	
No		6 871 (64.8)
Yes		3 733 (35.2)

The mean±SD of food intake level was 1.47±0.6, and for the calculated first trimester BMR was 1538±147 kcal/day. Women with higher BMI tended to underreport their energy intake, as indicated by a negative correlation between BMI and food intake level. Figure 9 and Table 8 display the median intakes in the study compared to the recommended intakes according to the Dietary Guidelines for Americans 2020-2025 among pregnant women standardized to an energy intake of 2200 kcal. Intakes of vegetables, whole grains, and dairy are below the recommended intake ranges, and fruit intake is above (Figure 9). Median intakes of fiber, omega 6, calcium, iron, vitamins E and D, and folate were below the recommended intakes. In contrast, the intake of SFA E% exceeded the recommended intake in both the FFQ and the 24-HDR (Table 8).

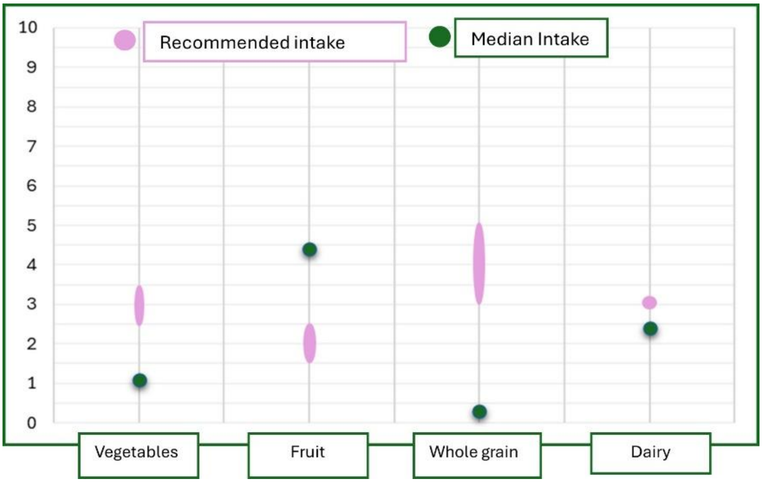

Figure 9. Median intake of selected food groups (servings/day) among 1054 pregnant women and the recommended intake ranges according to the Dietary Guidelines for Americans 2020-2025

Table 8. Median intake of selected nutrients among pregnant women from both the FFQ and the 24-HDR

Nutrients	Recommended intake ranges	Median absolute intake (FFQ) N=1054	Median absolute intake (24-HDR) N=111
Protein, E%	10-35	16	15
Carbohydrates, E%	45-65	49	54
Fiber (g)	31	26*	16*
Total fat, E%	20-35	37	31
SFA, E%	<10	12	11
Omega 6 (g)	13	10*	6*
Omega 3 (g)	1.4	1.6	1
Calcium (mg)	1000	771*	782*
Iron (mg)	27	14.9*	12*
Sodium (mg)	2300	2128	2000
Zinc (mg)	11	11	8
Vitamin E (mg)	15	9*	6*
Vitamin D (mcg)	15	3*	2*
Vitamin C (mg)	85	165	114
Niacin (mg)	18	23	20
Vitamin B6 (mg)	1.9	2.4	1.8
Vitamin K (mcg)	90	119	118
Folate (mcg)	600	468*	376*

E%: percent of total energy/day; SFA: Saturated fatty acids. *Indicates a median intake that is less than the recommended intake based on the Dietary guidelines for Americans 2020-2025.

PAPER I

This paper aimed to assess the relative validity of the FFQ in evaluating absolute and relative nutrient and food intakes using a 24-HDR as a reference method. A summary of the findings from paper I is shown in Tables 9 and 10, highlighted with different colors to illustrate the agreement level between the FFQ and the 24-HDR both at the individual and group levels. The green color refers to good agreement, the yellow refers to acceptable agreement, and the red refers to poor agreement between the two methods (Tables 9 and 10). Overall, the FFQ performed good or acceptably in ranking women based on their nutrient intake. At the group level, the FFQ overestimated some nutrients (e.g., fat, fiber, fruit, vegetables, fish, nuts, vitamin E, folate, and iron). However, the estimation of average intakes was good to acceptable for some nutrients (e.g., carbohydrate, protein, whole grain, white meat, beta-carotene, and selenium).

Table 9. Interpretation criteria for the statistical tests presented in table 10

Relative validity at the individual level [82, 236]	**Good**	**Acceptable**	**Poor**
Correlation absolute intake- Spearman's r	>0.5	0.2-0.49	<0.2
Cross-Classification/same quartile	≥50%		<50%
Cross-Classification/opposite quartile	≤10%		>10%
Weighted Kappa	>0.61	0.2-0.59	<2.0
Relative validity at the group level [236, 237]	**Good**	**Acceptable**	**Poor**
Wilcoxon signed-rank test	p>0.05		p≤0.05
mean % difference	0-10.9%	11-20%	>20%
Bland-Altman/correlations	p>0.05		p≤0.05

Table 10. Summary of the statistical test interpretation for nutrients and food groups from the FFQ compared with the 24-HDR

Nutrient/food	Relative validity at the individual level					Relative validity at the group level		
	Correlation	Same quartile	Same/adjacent quartile	Opposite quartile	Kappa	Wilcoxon signed-rank	Mean % difference	Bland-Altman
Energy (kcal)								
Carbohydrate (g)								
Protein (g)								
Fat (g)								
Fiber (g)								
SFA (g)								
MUFA (g)								
PUFA (g)								
Trans fatty acids (g)								
Fruit (g)								
Vegetables (g)								
Total Dairy (g)								
Sweetened beverages (g)								
Vitamin C (mg)								
Vitamin D (μg)								
Beta-carotene (μg)								
Thiamine (mg)								
Niacin (mg)								
Vitamin B6 (mg)								
Vitamin B12 (μg)								
Folate (μg)								
Sodium (mg)								
Potassium (mg)								
Calcium (mg)								
Iron (mg)								
Selenium (mg)								

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

PAPER II

We aimed in this paper to relate adherence to different healthy indices to the intake of nutrients and food groups. Higher adherence to all three indices (AHEI-P, aMED, and DASH) was significantly associated with higher intakes of healthy components such as vegetables, fruit, legumes, nuts, fiber, and PUFA and lower intakes of unhealthy components such as red meat, sweetened beverages, and SFA. Fat quality was captured by the three indices (PUFA and SFA), and the carbohydrate quality was best captured by aMED and DASH (whole grain), while fiber intake was captured only by AHEI-P.

PAPER III

This paper aimed to examine the association between the aMED score and its components and both GWG and EGWG. Based on the first trimester BMI, the highest percentage of EGWG was among overweight and obese pregnant women (35% and 37%, respectively) (Figure 10). The total aMED score showed no associations with GWG and EGWG. Three components of the aMED showed significant associations with GWG and EGWG. Positive associations were shown between fruit intake and GWG and EGWG; however, negative associations were shown between MUFA/SFA ratio and GWG and between vegetables intake and EGWG. The sensitivity analysis, in which we excluded women with insufficient GWG from the reference group in the logistic regression analysis, showed similar results. However, no significant association with fruit intake was found.

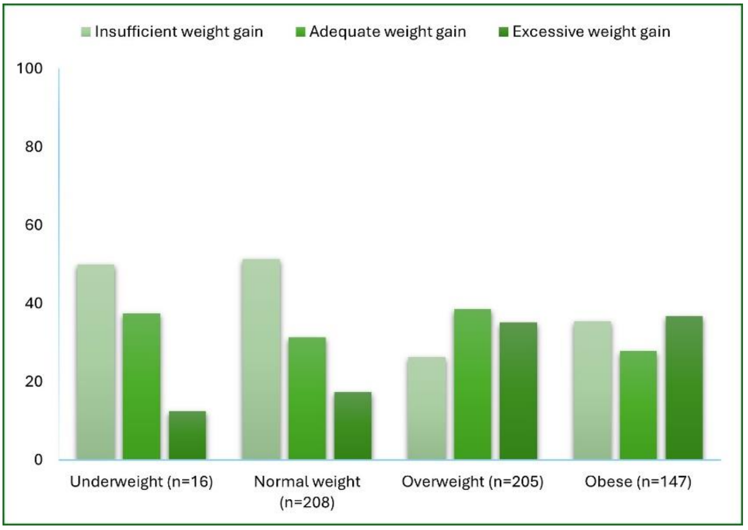

Figure 10. Distribution of gestational weight gain by the first trimester body mass index categories as per the Institute of Medicine guidelines (%) (n=576)

PAPER IV

The main aim of this paper was to examine the associations between UPF intake and its food groups, aMED and its components, and GDM. The median total intake of UPF among pregnant women was 9.2 servings per day, and the median total score of aMED was 4. The overall diet quality differed significantly among those with higher UPF intake. The largest contribution expressed as servings per day to UPF intake was UPF bread (38%), and the smallest was UPF mixed dishes (12%) (Figure 11). The sensitivity analysis where women who completed the FFQ before week 24, when the OGTT test is usually performed, showed no significant associations between UPF or aMED with GDM.

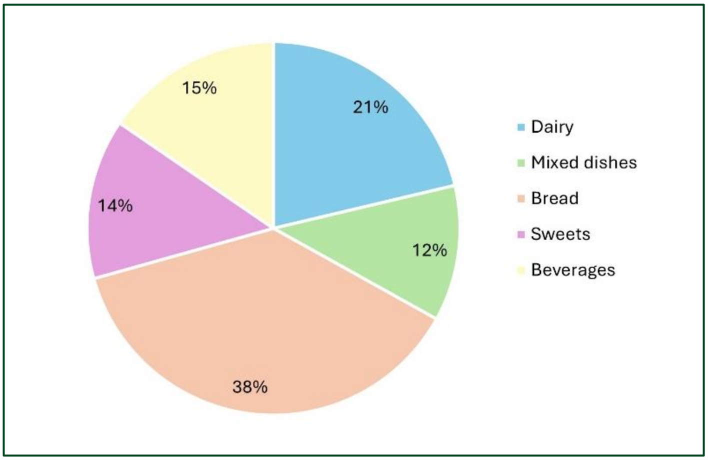

Figure 11. Ultra-processed food groups contribution to the total ultra-processed food intake (% serving per day)

ADDITIONAL ANALYSIS

THE MONTH OF RAMADAN

In total, 1122 pregnant women were included in the main analyses after applying a cut-off for energy intake levels of <600 kcal/day or >4000 kcal/day to remove reports with implausible intakes [238, 239]. Out of 1122 pregnant women, n=56 completed the FFQ during the month of Ramadan. Overall, the demographic characteristics and dietary intake of the pregnant women who were recruited (completed the FFQ) during the month of Ramadan were not significantly different compared to those recruited during other months, except for education level, fish intake, and AHEI-P score (Tables 11 and 12). Those recruited during the month of Ramadan had a lower proportion of university education (41% vs. 49%, p=0.005), lower intake of fish (0.3 vs. 0.5 servings/day, p=0.01), and lower AHEI-P score (60 vs. 63 points, p=0.02), Tables 11 and 12.

Table 11. Comparison between maternal demographics characteristics of pregnant women during the month of Ramadan and other months

	Other months		Ramadan	
Continuous variables	**N (valid values)**	**Mean± SD**	**N (valid values)**	**Mean± SD**
Age, years	1066	31±6	56	31±6
Gestational age (months)	1066	6.5±2.1	56	6.7±2.2
First trimester BMI (kg/m^2)	724	27±6	44	27.6±4.9
Categorical variables		**N (valid %)**		**N (valid %)**
First trimester BMI (kg/m^2)	724		44	
Underweight <18.5		30 (4)		1 (2)
Normal weight 18.5-24.9		239 (33)		13 (29.5)
Overweight ≥25		247 (34)		21 (47.7)
Obese ≥30		208 (28.7)		9 (20.5)
Parity	1065		56	
Nulliparous		304 (28.5)		18 (32)
Multiparous		761 (71.5)		38 (68)
Education level	1000		51	
≤Primary school		41 (4)		7 (13.7)
High school or diploma		473 (47)		23 (45)
University level		486 (49)		21 (41)*
Employment status	998		50	
Student		80 (8)		4 (8)
Housewife		528 (53)		28 (56)
Seeking employment		97 (10)		3 (6)
Employed		293 (29)		15 (30)

BMI, Body mass index; SD, Standard deviation. *Mann-Whitney test or Chi-Square test.

Table 12. Comparison between maternal dietary intake of pregnant women during the month of Ramadan (n=56) and other months (n=1066)

Dietary Intake	**Other months**	**Ramadan**
	Mean± SD	**Mean± SD**
Energy intake, kcal/d	2245±815	2124±769
Carbohydrates, E%	49.3±8.9	50.3±8.2
Protein, E%	16.3±3.3	15.6±2.9
Fat, E%	37.4±7.0	37.1±5.9
PUFA, E%	6.9±2.4	6.4±2.0
MUFA, E%	14.8±3.4	14.5±2.9
SFA, E%	12.2±3.1	12.7±3.0
Fiber, g/d	29.0±14.5	26.2±11.5
Vegetables, serving/d	1.6±1.8	1.2±0.9
Fruit, serving/d	5.2±3.9	5.1±2.9
Dairy, serving/d	2.9±2.4	2.8±1.9
Wholegrain, serving/d	0.5±0.5	0.4±0.4
Fish, serving/d	0.5±0.6	0.3±0.3*
Red meat, serving/d	0.4±0.4	0.4±0.3
Legumes, serving/d	0.5±0.6	0.4±0.3
Nuts, serving/d	0.7±0.9	0.6±0.7
Sweetened beverages, serving/d	1.8±1.4	1.6±1.3
AHEI-P	62.5±7.8	60.4±5.5*
aMED	4.0±1.5	3.8±1.3
DASH	22.9±4.1	22.3±3.5
UPF	9.5±4.3	9.4±5.0
UPF	9.5±4.3	9.4±5.0

SD: Standard deviation; AHEI-P: Alternate Healthy Eating Index for pregnancy; aMED: Alternate Mediterranean Diet; DASH: Dietary Approaches to Stop Hypertension; SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; E%: % of total energy/day; UPF: ultra-processed food. *Mann-Whitney test.

SINGLETON AND MULTIFETAL PREGNANCY

Pregnant women with multifetal pregnancy had significantly higher mean first trimester BMI (29 vs. 27, p=0.006), were significantly more often obese (44% vs. 28%, p=0.02) (Table 13), and had higher DASH score (24 vs. 23, p=0.04) (Table 14) compared to women with single pregnancy.

Table 13. Comparison between maternal demographics characteristics of pregnant women with singleton and multifetal pregnancies

	Singleton pregnancy		Multifetal pregnancy	
Continuous variables	**N (valid values)**	**Mean± SD**	**N (valid values)**	**Mean± SD**
Age, years	1054	31±6	63	32±6
Gestational age at inclusion (months)	1054	6.5±2.1	63	6.1±1.8
First trimester BMI (kg/m^2)	793	27.2±5.8	52	29.4±5.6*
Categorical variables		**N (valid %)**		**N (valid %)**
First trimester BMI (kg/m^2)	793		52	
Underweight <18.5		31 (3.9)		1 (1.9)
Normal weight 18.5-24.9		268 (33.8)		8 (15.4)
Overweight ≥25		272 (34.3)		20 (38.5)
Obese ≥30		222 (28)		23 (44.2)*
Parity	1054		63	
Nulliparous		300 (28.5)		18 (28.6)
Multiparous		754 (71.5)		45 (71.4)
Education level	985		61	
≤Primary school		45 (4.6)		3 (4.9)
High school or diploma		466 (47.3)		26 (42.6)
University level		474 (48.1)		32 (52.5)
Employment status	982		61	
Student		83 (8.5)		1 (1.6)
Housewife		523 (53.3)		28 (45.9)
Seeking employment		92 (9.4)		8 (13.1)
Employed		284 (28.9)		24 (39.3)

BMI, Body mass index; SD, Standard deviation. *Mann-Whitney test or Chi-Square test.

Table 14. comparison between maternal dietary intake of pregnant women with singleton (n=1054) and multifetal pregnancies (n=63)

Dietary Intake	**Singleton pregnancy**	**Multifetal pregnancy**
	Mean± SD	**Mean± SD**
Energy intake, kcal/d	2237±814	2276±822
Carbohydrates, E%	49.4±8.9	48.7±8.1
Protein, E%	16.2±3.3	16.5±3.2
Fat, E%	37.4±6.9	37.8±6.6
PUFA, E%	6.8±2.4	7.1±2.5
MUFA, E%	14.8±3.4	15.0±3.3
SFA, E%	12.2±3.1	12.1±2.6
Fiber, g/d	28.8±14.3	30.5±14.7
Vegetables, serving/d	1.6±1.8	1.7±1.3
Fruit, serving/d	5.2±3.9	5.2±3.4
Dairy, serving/d	2.9±2.4	2.8±1.8
Wholegrain, serving/d	0.5±0.5	0.4±0.5
Fish, serving/d	0.5±0.6	0.5±0.5
Red meat, serving/d	0.4±0.4	0.4±0.3
Legumes, serving/d	0.5±0.6	0.5±0.4
Nuts, serving/d	0.7±0.9	0.9±1.1
Sweetened beverages, serving/d	1.8±1.5	1.4±1.0
AHEI-P	62.3±7.7	63.2±8.2
aMED	4.0±1.5	4.2±1.6
DASH	22.8±4.1	23.9±4.4*
UPF	9.4±3.4	9.5±3.8

SD: Standard deviation; E%: percent of total energy/day; PUFA: polyunsaturated fatty acids; MUFA: Monounsaturated fatty acids; SFA: Saturated fatty acids; AHEI-P: Alternate Healthy Eating Index for pregnancy; aMED: Alternate Mediterranean Diet; DASH: Dietary Approaches to Stop Hypertension; UPF: ultra-processed food. *Mann-Whitney test.

DUPLICATE ADMINISTRATION OF THE FFQ

The mean gestational age at the time of the FFQ administration for women excluded (FFQ2) was 6.05±2.2, and for women included (FFQ1) was 6.3±2.1 months. Fiber intake and total AHEI-P score were significantly higher among the included compared to the excluded women (29 g/day vs. 25 g/day, p=0.04 and 64 vs. 59, p=0.002, respectively) (Table 15).

Table 15. Comparison of dietary data between pregnant women who completed the FFQ twice during the same pregnancy

Dietary Intake	**FFQ1 (n=20)**	**FFQ2 (n=20)**
	Mean± SD	**Mean± SD**
Energy intake, kcal/d	2139±743	2051±871
Carbohydrate, E%	50.1±6.4	48.6±12.2
Protein, E%	16.1±2.0	17.0±4.6
Fat, E%	36.8±5.9	37.2±8.4
PUFA, E%	6.9±2.4	6.2±2.2
MUFA, E%	14.8±2.9	14.0±3.5
SFA, E%	11.6±2.7	13.4±4.4
Fiber, g/d	28.5±14.5	25.1±18.0*
Vegetables, serving/d	1.4±1.4	1.1±1.1
Fruit, serving/d	5.0±2.6	4.8±4.3
Dairy, serving/d	2.2±1.2	3.2±2.9
Wholegrain, serving/d	0.5±0.4	0.4±0.5
Fish, serving/d	0.4±0.4	0.4±0.5
Red meat, serving/d	0.3±0.2	0.4±0.3
Legumes, serving/d	0.5±0.4	0.4±0.4
Nuts, serving/d	0.9±1.2	0.6±0.8
Sweetened beverages, serving/d	2.1±1.5	1.6±1.3
AHEI-P	64±9	59±9*
aMED	4.4±1.8	3.7±1.8
DASH	23±3	22.3±3

SD: Standard deviation; E%: percent of total energy/day; PUFA: polyunsaturated fatty acids; MUFA: Monounsaturated fatty acids; SFA: Saturated fatty acids; AHEI-P: Alternate Healthy Eating Index for pregnancy; aMED: Alternate Mediterranean Diet; DASH: Dietary Approaches to Stop Hypertension. *Wilcoxon rank test.

ENERGY DENSITY METHOD

There were statistically significant differences in energy-adjusted intake using the density method between the FFQ and 24-HDR, except for the SFA. Spearman’s correlations between the FFQ and 24-HDR were statistically significant for all nutrients and food groups except for protein, SFA, and MUFA (Table 16).

Table 16. Energy-adjusted intakes using the density method of nutrients and food groups from the FFQ compared with the 24-HDR (n=111)

Nutrient/food	**Energy-adjusted intake (density method, per 1000 kcal)**		
	FFQ	**24-HDR**	**Spearman's rs**
	Median (25th-75th)	**Median (25th-75th)**	
Carbohydrate (g)	113.8 (103.3-125.8)	135.8 (118.3-148.3)*	0.25**
Protein (g)	41.8(36.9-45.9)	37.7 (29.8-46.4)*	0.16
Fat (g)	44 (40.1-49.3)	34.8 (30.7-42.5)*	0.21**
Fiber (g)	11.8(9.7-13.9)	8.3(6.1-11.5)*	0.29**
SFA (g)	13.2 (11.8-14.8)	12.7 (9.8-14.9)	0.08
MUFA (g)	17.9 (15.9-20.2)	12.9 (10.5-15.6)*	0.16
PUFA (g)	7.9 86.6-10.2)	5.5(4.2-7.4)*	0.2**
Vegetables (g)	50.9 (28.5-73.7)	69.7 (16.6-148.6)*	0.39**
Fruit (g)	195.7 (122.4-310.5)	84.8 (12.7-169.2)*	0.39**
Dairy (g)	84.6 (45.6-139.7)	24.0 (4.6-123.7)*	0.22**
Wholegrain (g)	8.3 (3.4-18.1)	0 (0-23.7)	0.22**
Fish (g)	17.2 (7.8-37.9)	0 (0-0)*	0.20**
Red meat (g)	14.9 (6.5-23.9)	0 (0-0)*	0.22**
Sweetened beverages (g)	181.2 (106.4-288.9)	118.7 (0-179.7)*	0.47**

FFQ: semi-quantitative food-frequency questionnaire; 24-HDR: 24-hour dietary recall; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids. *Wilcoxon signed-rank test. **Spearman's rank correlation.

GWG AND AMED BY TRIMESTER

The regression analysis between GWG and aMED score with selected components among women in the third trimester showed similar results to the analysis, including women from all trimesters in paper III (Table 17). No associations were found between GWG and aMED among women in the second trimester. However, women in the first trimester showed a positive significant association with GWG (β=0.94, 95% CI: 0.009-1.86) (Table 17).

Table 17. Multivariable linear regression model for the associations between GWG (continuous variable) with aMED by each trimester

	Dietary Intake assessed in different trimesters of pregnancy								
	First trimester Crude: n=67, adjusted: n=64			**Second trimester** Crude: n=184, adjusted: n=174			**Third trimester** Crude: n=325, adjusted: n=299		
	Beta Coefficient	**95 % CI**	**P value**	**Beta Coefficient**	**95 % CI**	**P value**	**Beta Coefficient**	**95 % CI**	**P value**
aMED (tertiles)									
Model 1, crude									
Tertile 1	Ref			Ref			Ref		
Tertile 2	0.33	-3.14-3.81	0.85	-0.61	-2.56-1.34	0.54	0.06	-1.19-1.30	0.93
Tertile 3	3.21	-0.85-7.28	0.12	-0.68	-3.11-1.76	0.58	-0.92	-2.61-0.77	0.29
Model 2, adjusted[1]									
Tertile 1	Ref			Ref			Ref		
Tertile 2	-0.53	-3.83-2.78	0.75	0.02	-1.89-1.94	0.99	0.45	-0.76-1.66	0.47
Tertile 3	2.76	-1.39-6.90	0.19	-0.04	-2.39-2.31	0.97	-0.45	-2.07-1.16	0.58
aMED (continuous)									
Model 1, crude	1.14	0.22-2.06	**0.016**	-0.43	-0.99-0.13	0.13	-0.19	-0.58-0.19	0.32
Model 2, adjusted[1]	0.94	0.009-1.86	**0.048**	-0.09	-0.65-0.45	0.73	-0.17	-0.55-0.20	0.36
Vegetables (25 g/d)									
Model 1, crude	0.18	-0.33-0.69	0.48	-0.20	-0.39- -0.02	0.034	-0.11	-0.27-0.05	0.17
Model 2, adjusted[1]	0.21	-0.29-0.72	0.41	-0.09	-0.29-0.11	0.38	-0.10	-0.25-0.04	0.17
Fruit (25 g/d)									
Model 1, crude	0.09	-0.06-0.24	0.23	0.002	-0.06-0.06	0.94	0.04	-0.01-0.09	0.09
Model 2, adjusted[1]	0.07	-0.09-0.25	0.39	0.02	-0.03-0.08	0.43	0.05	0.003-0.09	**0.038**
MUFA/SFA ratio (g/d)									
Model 1, crude	-0.34	-2.60-1.92	0.76	-1.28	-2.48- -0.08	0.037	-1.31	-2.19- -0.43	**0.004**
Model 2, adjusted[1]	0.18	-2.17-2.54	0.88	-0.91	-2.16-0.33	0.15	-1.09	-1.94- -0.25	**0.011**

GWG: gestational weight gain; aMED: alternate Mediterranean diet; CI: confidence interval; MUFA/SFA: mono- to saturated fatty acids ratio.
[1]Adjusted for maternal age, first trimester BMI, gestational age at first and last visits, parity, and education. All intakes are energy adjusted to 2000 kcal/day.

DISCUSSION

SUMMARY OF THE MAIN FINDINGS

The overall findings of this thesis show that adherence to different healthy dietary patterns, assessed by different indices, was associated with beneficial dietary intake, but the patterns captured somewhat different aspects of the diet. There were no associations between adherence to the Mediterranean diet or UPF intake and gestational outcomes. However, the validity of the study FFQ was relatively poor, which could have weakened diet-health relationships.

DISCUSSION OF THE RESULTS

PAPER I. THE VALIDATION OF THE FFQ

Direct comparisons between validation studies are complicated due to the variations in the use of reference methods (e.g., 24-HDR, food records, biomarkers), number of replicates, number of food items in the FFQ, nutrients, and foods of interest, nutritional supplementations inclusion or exclusion, gestation time of the FFQ, food culture, and the statistical analysis performed.

VALIDATION AT THE INDIVIDUAL LEVEL

The validity of the FFQ at the individual level showed an acceptable agreement. The correlation coefficient for absolute intakes showed acceptable agreement for most nutrients and food groups. However, the correlation coefficients decreased for some nutrients and foods after energy adjustment using the residual method. Only the correlation coefficient for sodium increased after energy adjustment to reach an acceptable agreement. Previous studies have also shown that the correlation coefficients decreased after energy adjustment for most nutrients and food groups [4, 13], and our study's overall absolute ranges of correlations were comparable or lower than other studies [240, 241]. According to Willett, energy adjustment improves or increases correlation coefficients for most nutrients and food groups when the variability of food consumption is correlated with energy intake. However, it might decrease when the variability relies on systemic errors of over- or underestimation [84]. The decrease in correlation coefficients in our study might be explained by the highly correlated measurement error between reported dietary intakes and energy intake. In addition, both methods may also have similar measurement errors because both capture the same inaccuracies that could result from memory bias, social desirability, portion size misreporting, seasonal variation, and respondent fatigue.

Despite the weak correlation coefficients in our results, cross-classification provides a clearer picture of how well the two methods perform in classifying levels of intake [83]. According to Lombard et al., a good agreement can be considered when 50% or more of participants are classified into the same quartile, and 10% or less are classified into the opposite quartile [236]. In our study, no nutrient or food group fulfilled the criteria of 50% being classified into the same quartile, but most were classified in the same or adjacent quartile. In addition, a few nutrient and food group intakes were misclassified into the opposite quartile in >10% of participants (on average 6%), indicating acceptable agreement between the two methods. These results are in line with validation studies showing high proportions of pregnant women from Finland [242], Jordan [243], Brazil [244], China [245], and Canada [246], classified into the same or adjacent quartile with low average proportions in the opposite quartile. We further used Cohen's weighted kappa to account for chance agreement [82]. None of the nutrients or food groups showed good agreement in the kappa statistics but acceptable agreement for many nutrients and food groups. Overall, the FFQ is useful for ranking intakes of some nutrients and food groups.

VALIDATION AT THE GROUP LEVEL

We found that the FFQ validity at the group level was acceptable in estimating the average intake of certain nutrients and foods. However, the FFQ overestimated most nutrients and food intakes compared to the 24-HDR. In general, the overestimation of the FFQ is comparable to many validation studies conducted among pregnant women using the 24-HDR or food records as the reference method [240, 242, 243, 247, 248]. Possible explanations for the overestimation, as discussed in these studies, might partly be due to inaccurate estimating of the portion size consumed or the large number of food items listed incorporated in the FFQ [83, 249]. In our FFQ, the food items list included 146 food items with fixed portion sizes and a wide range of frequency choices for each food item. A specific possible explanation for the overestimation of our FFQ might be women's potentially inaccurate reporting of frequency of consumption and/or the specified portion size estimation that might not reflect the amount they usually consume. The long food list of some food groups might also explain the overestimation of certain nutrients and food groups. However, low intakes were reported in the 24-HDR for some nutrients and food groups. A single 24-HDR cannot accurately reflect the intake of rarely consumed food items. Therefore, repeated 24-HDR might increase precision but could result in a low response rate with a high burden and might be affected by dietary intake changes during pregnancy [250]. Moreover, underreporting in the 24-HDR is likely caused by social desirability bias, often leading to underestimated intake of unhealthy food [84]. Likewise, social desirability bias may also have been present in the FFQ data collection, as it was supervised by a dietitian. However, on the group level, since most days of the week were represented in our data, we do not believe that the 24-HDR underestimated foods as much as the FFQ overestimated the intakes. In addition, the Bland-Altman analysis indicated that for some nutrients and food groups, the differences between the FFQ and the 24-HDR increased with increasing intake. This indicates a systematic bias that increases with increased intake, showing that women who reported higher intakes reported more errors. Overall, the group level validity of the FFQ is quite poor for many nutrients and food groups and should be used with this in mind.

PAPER II. THE HEALTHY DIETARY INDICES

We found that the healthy dietary indices (AHEI-P, aMED, DASH) were moderately correlated with each other. However, their associations with the overall dietary intake were somewhat different among pregnant women from the UAE. Interestingly, each index captured different aspects of dietary intake in terms of fat and carbohydrate quality. Fat quantity in terms of total fat intake was captured only by the AHEI-P index, and in terms of fat quality, intake of SFA and PUFA were captured in all three indices. However, MUFA was only captured by the aMED. Moreover, dairy intake was associated with lower adherence to AHEI-P and aMED indices but higher adherence to DASH. This might be explained by dairy components being only included in the DASH index (low-fat dairy) and the possibility of a high SFA content [251, 252]. Moreover, fish intake was associated with lower adherence to DASH and higher adherence to AHEI-P and aMED indices. Carbohydrate quantity in terms of total carbohydrate intake was captured by AHEI-P and DASH indices, and in terms of carbohydrate quality, intake of whole grain was captured by aMED and DASH, while all three indices captured intake of fiber and sweetened beverages. These differences could be explained by the specific component of each index and the way it is scored. Another explanation that could affect these associations was that we used both tertiles and medians of intake to assess adherence to the three indices to better evaluate the variation of intake within the study sample [253]. However, in our study, the associations were relatively similar when we applied the three indices with tertiles and medians.

Dietary patterns vary across regions, populations, and cultural food traditions [254]. It is common to use dietary patterns in nutritional epidemiological studies to reflect the overall dietary habits of a population and may offer significant associations between habitual dietary intake and disease risk [116, 162, 255]. Hence, evaluating eating habits is more important for health than single nutrient intake [256, 257]. However, significant physiological changes occur during pregnancy for the pregnant body to support the growing fetus and prepare for childbirth [15]. These changes may challenge healthy eating during pregnancy, especially gastrointestinal changes that often result in nausea, vomiting, and acidity, as well as food aversions, cravings, fatigue, and hemorrhoids [2, 258]. Even though these challenges exist, pregnant women appear to improve their dietary intake and are motivated by healthier choices to promote positive health outcomes for the baby [259, 260].

The USDA dietary guidelines are applied as the primary source of dietary recommendations in the UAE. The additional analysis performed in the thesis showed that median intakes (derived from the FFQ) of vegetables, whole grains, and dairy were below the recommended intake according to the USDA dietary guidelines, and fruit intake was above. This is comparable to results from a study among pregnant women assessing the adherence to the USDA's dietary guidelines in five Arab countries (Lebanon, Palestine, Jordan, Saudi Arabia, and Bahrain) [261], showing higher intakes of fruit and lower intakes of vegetables and dairy products. Moreover, high fruit intake was seen among Turkish pregnant women [262] and Polish pregnant women, who also had an insufficient intake of vegetables and milk products [263]. In contrast to our study, among Norwegian women, fruit intake did not meet the recommended daily intake according to the Norwegian Food-Based Dietary Guidelines [264]. Furthermore, in our study, median intakes of macronutrients (carbohydrate, protein, and fat) obtained from the 24-HDR aligned with the USDA dietary guidelines for pregnant women. However, the total fat percent from the FFQ (37 E%) was higher than the recommended range of intake (20-35 E%). SFA E% intake from both the FFQ and the 24-HDR were above the recommended intake. Moreover, as assessed by both the FFQ and the 24-HDR, fiber intake was below the recommended intake. A systematic review and meta-analysis included 90 studies from different parts of the world, including the United States of America, Canada, Europe, Australia, and Japan, based on country-specific national dietary guidelines during pregnancy, showed that energy and fiber intakes were below the recommendations, while total fat and SFA were above the recommendations [265]. Inadequate calcium, iron, vitamin E, vitamin D, and folate intake among our pregnant women were observed from the FFQ and the 24-HDR. This is consistent with studies in pregnancy from different countries, including the United States, Saudia Arabia, and some European countries, with inadequate folate, iron, and vitamin D intake during pregnancy due to low diet quality intakes [264-268]. Another study among adults from 10 Arab countries, including the UAE, showed that most food groups, including fruit, dairy, nuts, and legumes, were consumed less frequently (lower than or equal to 4 times a week), indicating poor dietary diversity [269].

Dietary guidelines vary worldwide, and each country adapts certain guidelines to suit its specific needs [270-272]. Different national and international dietary guidelines promote dietary quality during pregnancy, e.g., the USDA dietary guidelines, Nordic Nutrition Recommendations, the Swedish National Food Administration, and the Institute of Obstetricians and Gynecologists (Royal College of Physicians of Ireland). These guidelines jointly indicate the amount of nutrients and food recommended during pregnancy, including, amongst others, fruit, vegetables, whole grains, and protein sources [54, 55, 273, 274].

In the UAE, there is no national dietary guidelines exist specifically for pregnant women; however, national food-based dietary recommendations targeted to the general population authorized by the Ministry of Health and Prevention in the UAE and endorsed by the Food and Agriculture Organization of the United Nations were developed using the USDA dietary guidelines as a reference recommendation [275]. The UAE national food-based dietary guidelines recommend a healthy diet for the general population based on food group intake [275]. Moreover, these recommendations consider food availability and cultural acceptance within the country and include some recommendations that align with the Mediterranean diet, such as vegetables, fruit, legumes, nuts, fish, unsaturated fatty acids, and olive oil [275-277]. With its economic growth, the UAE has attracted a multiethnic and multicultural population, leading to a diverse and abundant food environment [203]. This diversity has led to the impact of the Mediterranean diet, cuisine, and dishes transformed and adopted within the country, with citizens originally coming from these countries (e.g., Syria, Lebanon, Palestine, Jordan, and Egypt) [278, 279]. Moreover, traditional foods have shifted toward more Westernized diets characterized by processed, high-fat, sugary foods and high-caloric snacking [203-207].

Based on the impact of these factors, both the aMED and the AHEI-P indices might be relevant for evaluating dietary adherence among pregnant women in the UAE. There is very limited data regarding adherence to healthy dietary patterns among pregnant women in the UAE. A recent study among Saudi pregnant women showed that 32% (out of n= 774) of the participants had high adherence to the Mediterranean diet [280]. The AHEI is an essential index for assessing adherence to recommendations, as it is based on actual recommendations and not a dietary pattern. Moreover, the application of the Mediterranean diet in a non-Mediterranean population is challenging. Colao et al. have advocated that vegetables, fruit, cereals, and unsaturated fat sources available in non-Mediterranean countries may be combined to design evidence-based local nutritional standards that still capture the health benefits of the Mediterranean diet [271, 281]. We also need to consider that some nutrients and food in our study had poor validity and might give inaccurate estimates. Therefore, choosing the proper index will be based on their validity, variation in nutritional profile, and the specific study objective. Consequently, this will facilitate the assessment of diet-health relationships and improve future dietary guidelines among pregnant women.

PAPER III. THE MEDITERRANEAN DIET AND GWG

We found a high prevalence of EGWG among pregnant women from the UAE, with the highest proportions among overweight and obese women. This aligns with other studies conducted among pregnant women from the Brazil, Sweden, and UAE [158, 212, 282, 283]. Although women with pre-pregnancy overweight or obesity may be particularly prone to EGWG [284], studies estimate that about 22–30% of women with normal weight also exceed recommended guidelines [158, 285]. Moreover, according to the IOM guidelines, obesity is defined as a BMI of 30 or above and does not differentiate between different classes of obesity (Class I-III) [16]. There is inadequate scientific evidence to provide specific guidelines for obesity classes or to reduce the recommendation for GWG of 5-9 kg [16, 286]. However, a recent Swedish study indicated that weight gain less than recommended, according to the IOM guidelines, was safe for pregnant women with obesity classes 1 and 2 and might be positive for those with obesity class 3, given that nutritional balance is maintained [287]. The findings suggest that a reevaluation of existing weight gain guidelines for pregnant women with obesity may be warranted [287]. This underscores the importance of including women across all BMI classes in research and clinical interventions to manage GWG using evidence-based approaches leading to more effective guidelines for pregnancy care.

Several health implications can arise from EGWG, for example, increased risk of postpartum weight retention, which is a significant contributing factor to obesity in women [288]. A systematic review of 9 studies showed that women with EGWG retained around 3 and 5 kg more weight after 3 years and ≥15 years postpartum than women who gained weight within the IOM guidelines [289]. Moreover, EGWG might lead to midlife obesity and increase the risk of non-communicable disease in women over the long term [290, 291]. As discussed in the introduction, there are high prevalence rates of obesity among women from the GCC [192] and specifically in the UAE [195]. The Mediterranean diet has demonstrated protective effects against obesity, cardiovascular diseases, type 2 diabetes, overall cancer incidence, and breast cancer and this might be due to its nutrient profile as it is rich in antioxidants, low in SFA, high in PUFA and MUFA, and high in dietary fiber [292-294].

Recent studies among the adult population in the GCC and UAE showed low adherence rates to the Mediterranean diet [279, 295-297], and among those who had higher adherence, a significant decrease in two indicators of obesity was observed (BMI and hip circumference) [279]. Studies among Spanish pregnant women showed varying associations between adherence to the Mediterranean diet and GWG with higher adherence to the Mediterranean diet was associated with lower GWG [298], higher adherence to the Mediterranean diet was associated with higher GWG [299], and no association between adherence to the Mediterranean diet and GWG [300], which is in line with our study showing no associations between aMED and GWG. The association between the Mediterranean diet and GWG has also been reported in intervention studies. In a multicenter United Kingdom-based trial, pregnant women with obesity, hypertriglyceridemia, or chronic hypertension who were randomized to a Mediterranean-style dietary pattern had lower GWG compared to the control group [301]. However, a clinic-based single-center trial in Spain aimed to evaluate the effect of the intervention diet on GDM incidence, with GWG as a secondary outcome, reported no significant differences in GWG between the intervention (Mediterranean diet with supplementation of extra virgin olive oil and pistachios) and control groups (only Mediterranean diet) [302]. In contrast to our finding that no associations were found between EGWG and aMED index, a study from UAE showed that higher adherence to the Mediterranean diet was associated with lower odds of both insufficient and EGWG [214]. These conflicting findings might be due to differences in the definitions of the Mediterranean diet, which might complicate the comparison between studies with regard to GWG [303-305].

Interestingly, some components of the aMED index were associated with both GWG and EGWG. Both GWG and EGWG showed positive associations with fruit intake, which aligns with the findings among pregnant Chinese women [306]. However, among pregnant women from the United States of America, no associations between intakes of fruit or vegetables with GWG and EGWG have been shown [307, 308], and it was shown that those with higher fruit and vegetables consumption were less likely to have EGWG [309]. This aligns with our findings that the lower vegetables intake was associated with higher EGWG. Vegetables and fruit play a crucial role in the diet of pregnant women [263]. One possible explanation for our results might be the high intake of some specific fruit, such as dried fruit (mostly dates), that contributed 20% of the energy intake from total fruit intake. The average intake of dried dates among our pregnant women was 23 g/day, and the average intake of fresh and dried dates was 37 g/day. However, it has been shown that consuming approximately seven dates (around 70 g) daily among Algerian healthy adults was not associated with weight changes based on their BMI at the end of the three-week study period [310]. Another study among Saudi men and women showed a weak association between date consumption and weight gain and showed that the consumption of dates was not responsible for weight gain [311]. Daily date intake among adults from the UAE ranges from 80-114 g per day [312, 313], and the average consumption of dates is 122 g per day in Saudi Arabia [314]. Dates are rich in dietary fiber and potassium, low in sodium, a good antioxidant source, and their energy content is between 278-301 kcal/100 grams [315, 316]. These estimations of date intake are different in terms of the type of dates (fresh, dried) as the weight will be different, the country sources of these dates, and the different subtypes of the dates (different palm trees). Therefore, we cannot conclude that dates as a source of high energy intake were associated with EGWG in our study. Further analyses separating dried and fresh fruit might better estimate the association between the subtypes of fruit and GWG.

In addition, the sensitivity analysis showed no significant associations between fruit intake and EGWG when we excluded women with insufficient GWG from the reference group. A possible explanation might be related to the different responses in fruit intake among those with insufficient GWG compared to those with adequate GWG or EGWG. Moreover, it was shown that women with low energy intake are more likely to have inadequate weight gain during pregnancy [317]. Another important finding was that a higher MUFA/SFA ratio was associated with lower GWG. This is in line with previous studies showing that high-quality fat intake is associated with lower GWG and EGWG [158, 307]. Therefore, it is essential to consider specific components in the diet as they may contribute significantly to the overall dietary intake. However, assessing dietary patterns as a whole instead of single components or nutrients is better in order to reflect overall diet behavior and better capture diet's effects on health outcomes, and to promote a high-quality diet [104, 106, 109-111].

The additional analysis performed stratified by each trimester showed similar results that were found in paper III among women in the third trimester. However, a positive association was found among women in the first trimester between aMED and GWG in the adjusted model. These results might be due to the very small number of pregnant women included in the first trimester, which could result in inconclusive results. A higher proportion of women in our study was in the third trimester (56%). Therefore, their results were similar to the analysis with all pregnant women from all the trimesters included. In addition, we performed sensitivity analyses for those excluded from the analysis in Paper III due to missing weight measurements or implausible energy intake. We found no significant difference between them and women included in the paper. However, we found that women with implausible energy intake had a lower GWG (by about 2 kg) and a lower aMED score (by about 0.5), but there was no difference in the first trimester BMI. A possible explanation might be that we did not have enough data on their first trimester BMI (n=68), as those were excluded primarily due to missing weight measurements. Overall, participants were probably not missing completely at random, which may have introduced selection bias that could have impacted the results. However, the sensitivity analysis utilizing the inverse probability weight did not show significant changes in the results compared to the main analyses.

PAPER IV. UPF, THE MEDITERRANEAN DIET, AND GDM

This study showed that UPF intake is a major contributor to total energy intake among pregnant women from UAE, with UPF bread intake being the largest contributor. Moreover, we found that high UPF intake was associated with lower food quality (assessed using the aMED index) and negatively associated with food and nutrient intake. These results are consistent with previous studies assessing UPF in relation to diet quality and nutrient intakes [318-320]. We found no association between UPF intake and GDM. This finding was similar to a study among Brazilian pregnant women using the same UPF classification system as ours (NOVA system) [321]. Moreover, two systematic reviews concluded that intake of some UPF subtypes during pregnancy is associated with an increased risk of GDM [322, 323]. To our knowledge, no previous studies conducted in the UAE assessed UPF intake among adults or pregnant women. One study among Saudi adults using a simple questionnaire assessing their knowledge of processed food and its relation to colorectal cancer [324], based on this statement, "Soft drinks, sweetened juices, dairy drinks, juice powders, energy drinks, natural sugar substitutes, sausages, pepperoni, mortadella, frozen chicken and fish, and other pre-prepared frozen dishes. Do you know what kind of these foods are?"[324]. They found that 84% of participants consumed UPF [324].

We also examined UPF food group intake and their associations with GDM risk and found no relationships. A study among adult French assessing UPF intake and its subtypes with type 2 diabetes found that UPF was associated with an increased type 2 diabetes risk, with proportions of UPF in beverages, sugary foods, fats and sauces, and dairy products specifically associated more with the increased risk of type 2 diabetes [325]. It was found that increased energy intake from UPF is associated with greater GWG and neonatal adiposity [326]. Moreover, pregnant women with higher UPF intake have been found to be three times more likely to be obese compared to those with lower UPF consumption [321]. Observed associations are supported by results from Hall et al., who identified a significant effect of UPF intake on increased energy consumption in a controlled trial among adults [327].

The conflicting results of UPF intake among pregnant women and its association with GDM risk might be explained by the differences in definitions, classifications system used to classify UPF intake, and the criteria used to diagnose GDM. We used the NOVA classification system in our study as it is the most widely used for defining UPF in research [149], and it captures a wide range of different food products available in the UAE food supply. However, NOVA's broad categorizations may oversimplify food quality, resulting in inconsistencies in diet-health associations between studies [328, 329]. For example, according to NOVA definitions, in Drewnowski et al.'s analysis, beans and nuts were classified as ultra-processed [330], and another example, commercially baked bread is categorized as UPF, whereas homemade bread, despite having similar ingredients, is classified as processed [331]. Therefore, it is necessary to explore the effects of UPF intake on health during pregnancy with more precise dietary assessment tools and classification systems. The underlying mechanisms for these potential associations should also be studied.

We also investigated the association between aMED intake and its components and GDM risk and found no relationship. Similar to our findings, there were no significant associations between aMED score and GDM among Chinese and Tunisian pregnant women [332, 333]. However, higher adherence to a Mediterranean dietary pattern was inversely associated with the risk of GDM in 10 Mediterranean countries [334] and in a United States cohort of pregnant women [168]. To our knowledge, there are no studies regarding adherence to the Mediterranean diet and its association with GDM risk in the UAE. One study among Saudi pregnant women showed that those who have gestational diabetes (n=23) have a lower tendency to adhere to the Mediterranean diet assessed using a standardized tool without taking into account all foods such as dairy products and cereals [280]. The Mediterranean diet has significantly reduced the risk of GDM in different populations, including non-Mediterranean countries [335]. These conflicting results might be due to different dietary habits between countries, the diagnostic criteria for GDM and the cut-off used, and the definition of the Mediterranean diet. However, the Mediterranean diet is recognized to have a potential preventive effect against GDM [303, 336], and further investigation is warranted to assess its association with GDM risk and its impact on GDM prevention in the UAE.

STUDY POPULATION

RECRUITMENT

The dietary subcohort did not differ from the whole cohort (*Mutaba'ah* Study) in terms of age, gravida status, education, and employment level. The study hospitals where the recruitment took place are considered referral centers from other cities in the UAE, thus minimizing selection bias. In addition, the Emirati population benefits from comprehensive healthcare insurance, which ensures that pregnant women can access the same quality of care at any hospital throughout the UAE. As a result, the participants in the *Mutaba'ah* Study likely represent women from the general Emirati population, particularly in Al Ain City. However, more studies covering different parts of the country would be warranted to give a better overall estimate and generalizability. We do not have information on how many women visited these clinics during the study period, and thus, no data on the overall participation rate.

THE MONTH OF RAMADAN

We performed additional analysis to investigate if there is a difference in demographic characteristics and some nutrients and food intake among women who completed the FFQ during Ramadan compared to the other months. We found a small number of women who participated in the FFQ during Ramadan, and we are unsure if those women did actually fast. Even though women who did not complete the FFQ during Ramadan, their dietary intake may still have influenced their responses, particularly if the FFQ was administered shortly after Ramadan. From a religious perspective, healthy pregnant women are exempt from fasting if they believe it may risk their health or their fetus [337, 338]. Fasting has a conflicting impact on healthy pregnant women. Some studies among healthy pregnant women have shown no harmful fasting impacts on the baby or on the mother, including, for example, birth weight and fetal anthropometrics measurement, the serum lipid profile of the mother, or maternal ketonemia [338-342]. On the other hand, other studies found some effects in terms of higher levels of serum lipids, including triglycerides and low-density cholesterol levels, among fasting pregnant women and increased risk for low birth weight compared to non-fasting women [343-345].

In our study, we found that those recruited during Ramadan had a lower proportion of university education, lower intake of fish, and lower AHEI-P score. However, a study among Lebanese pregnant women showed no significant difference between education level and fasting [346]. Moreover, fasting among pregnant women can affect their dietary habits [337], which might explain the lower score of AHEI-P. The macronutrient intake was shown to alter during fasting; for example, lower protein intake was observed among fasting Indonesian pregnant women [347], and higher carbohydrates and fats were observed among fasting Iranian and Emirati adults [348, 349], while lower protein intake was shown among Saudi fasting adults [350]. It is important to note the cultural differences and fasting periods between different countries during Ramadan. Moreover, investigating the effects of fasting on dietary intake among pregnant women is warranted to understand how fasting during this specific month affects the nutrient composition and consumption and its subsequent impact on health outcomes for the mother and the child in both short- and long-term outcomes. Furthermore, healthcare providers should guide pregnant women on fasting by providing culturally sensitive, evidence-based guidance and offering individualized recommendations, while supporting those who fast with medical advice and closer monitoring [351].

SINGLETON AND MULTIFETAL PREGNANCY

Additional analysis was performed to examine if there is a significant difference in demographic characteristics, nutrients, and food intake among pregnant women with single and multifetal pregnancies. We found that women with multifetal pregnancies had higher mean first trimester BMI and DASH score. The number of women with multifetal was small compared to women with single pregnancy, and therefore, this could make the comparison inaccurate. According to the IOM guidelines, women carrying twins have different recommendations for GWG based on their pre-pregnancy BMI, as two additional kilograms in GWG to account for the additional components of a twin gestation in terms of fetus, placenta, and amniotic fluid weight [16]. Moreover, the IOM guidelines acknowledge that data are insufficient to determine the amount of GWG that women with multifetal (triplet and higher) gestations would gain [16, 352]. In our study, women with multifetal pregnancies were all carrying twins and were only included in the analysis of paper II.

REPRODUCIBILITY

Initially, pregnant women who completed the FFQ twice were included in the analysis only for their first FFQ completion, as their second FFQ was assumed to be unintentional. However, in this thesis, additional simple analyses were performed for those who completed the FFQ twice during the same pregnancy. The difference in the mean gestational age at the time of the FFQ between women included (FFQ1) and women excluded (FFQ2) was around 3 months. Only fiber intake and total AHEI-P score were significantly higher among women with FFQ1. One explanation for this difference might be that women with FFQ1 were motivated to answer the questionnaire and tried to report their intakes accurately. Then, in FFQ2, they repeated the FFQ as they thought it was different and were curious to complete it. Women with FFQ2 were excluded from all our analyses, as only women who completed the first FFQ (FFQ1) were included to ensure the independence of the data selected. However, there might be a risk of unintentional selection bias when participants provide duplicate answers. In our study, only 20 women provided two FFQs, which is a limitation of the analyses.

STUDY DESIGN

Based on the moderate validity of our FFQ and the identified indices, the results of the papers discussed in this thesis might be impacted. Therefore, it is important to note that some specific nutrients or food should be interpreted cautiously, as this may introduce random errors and attenuate true associations, leading to an underestimation of effects. Moreover, systematic misreporting could result in biased or misleading associations. Intake of legumes and nuts was included in both aMED and DASH, and these intakes showed poor agreement at both levels. All three indices included red meat, which showed poor agreement at the individual level. It is important to consider the validity level of the components of the dietary indices as it might explain the reduced predictive ability of the dietary indices.

We used three predefined dietary indices (a priori patterns), as these are based on dietary score/index that relies on preexisting scoring criteria [112, 113] and are useful in assessing adherence to dietary recommendations or dietary quality and to analyze diet-health relationships [104, 114]. Moreover, we aimed to assess adherence to specific dietary guidelines and test predefined hypotheses commonly used among pregnant women. In contrast, posterior patterns, such as principal component analysis or cluster analysis, are used to identify patterns based on actual intake data and may lack generalizability and associations with dietary guidelines [112, 114-117]. Using priori allows better comparability with other studies and can easily be translated into a specific country or cultural nutritional recommendations [112]. However, it may not describe the overall diet as it is based on selected aspects of the diet [250] and may not capture unique dietary habits or eating practices if the predefined indices are based on different populations. The data-driven methods might extract dietary patterns that describe how the study sample really eats. However, this may not accurately report healthy and unhealthy dietary habits, may not align with the most recognized eating behaviors, and the analytical choices introduce some subjectivity [112]. If we combine both approaches, we might have a comprehensive understanding of dietary behaviors among pregnant and their health implications.

The FFQ was collected throughout the pregnancy with the possibility that pregnant women might change their dietary intake during pregnancy to adjust their GWG based on their perception of whether they are gaining adequately. Thus, this might result in reverse causation, where adherence to the aMED index might be influenced by the GWG rather than the reverse situation.

However, in our analysis, we adjusted the gestational age at the time of the FFQ. Additional concerns are regarding the calculation of the GWG, as it was according to the IOM guidelines that are based on the pre-pregnancy BMI; however, we used the first trimester BMI to estimate the GWG. We used the first trimester BMI due to the difficulty in obtaining an accurate pre-pregnancy weight. It was shown that weight in the first trimester closely correlates with self-reported pre-pregnancy weight [257] and is based on the assumption that weight gain in the first trimester is considered minimal (0.5–2 kg). Early pregnancy weight gain mostly corresponds to maternal fat deposition rather than fetal or placental tissue or excess fluid [16, 45, 353]. Still, the assumption that first trimester weight equals pre-pregnancy weight is inaccurate, and our GWG might be underestimated [354].

Moreover, in paper III, we excluded those with missing weight at ≤14 weeks or ≥37 weeks of gestation and those with implausible energy intakes. This could introduce selection bias and might not reflect the characteristics of the general population or the cohort. We did not use any imputation for the missing data, and this might lead to potential bias and limit generalizability if the data were not missing completely at random. We were unable to assess other confounding factors that could affect the association between the Mediterranean diet and GWG, such as physical activity level and other health-related conditions such as thyroid function, hyperemesis gravidarum, and specific diets.

In paper IV, we used the NICE-2015 criteria (based on a fasting value of ≥5.6 mmol/L or a 2-hour value of ≥7.8 mmol/L) [44], as previous research identified it as one of the most inclusive criteria for GDM assessment in the UAE along with the IADPSG criteria [231]. A moderate agreement was found between the two criteria (NICE-2015 and IADPSG), with NICE-2015 criteria identified as a strong contender criterion for GDM assessment in the UAE [231]. We had available data regarding fasting and 2-hour values, with less missing data compared to the data from the 1-hour values. All these readings were extracted from the medical records. GDM diagnosis was set at a single time point, which limited the competence to recognize early and late-onset GDM, and the FFQ was sometimes collected after the diagnosis of GDM and may have adjusted their dietary habits accordingly, which could have influenced the overall results. However, the sensitivity analysis performed for women who completed the FFQ before the time of the OGTT test showed the same results. Additionally, we were unable to consider other factors that could have contributed to plasma glucose and glucose intolerance, such as GWG or genetic factors. Moreover, the misclassification of UPF intake might be due to the FFQ used, which is not designed to measure UPF intake levels.

METHODOLOGICAL CONSIDERATIONS

DIETARY ASSESSMENT METHODS

In paper I, we used the 24-HDR as a reference method to assess the validity of the FFQ. Both methods are retrospective methods relying on participants recalling their past dietary intake, which could introduce recall bias and over- or underreporting of food intakes [73, 84]. A 24-HDR is commonly used as a reference method to assess the relative validity of an FFQ, as they are open-ended records unrelated to a limited food list or fixed portion sizes [355, 356]. Moreover, based on what was feasible during data collection and the expected compliance of our pregnant women, a single 24-HDR was considered appropriate compared to diet records for this study. Moreover, a single 24-HDR is useful in representing the average dietary intake in a population [73] and has been previously utilized in FFQ validation studies among Chinese and Indian adults [357, 358]. Moreover, in a validation study of an FFQ among Lebanese pregnant women (n=128), only n=43 participants provided a second 24-HDR [248]. This suggests that the limitations of a 24-HDR are less significant for group-level comparisons than for individual-level assessments. Multiple 24-HRDs administered several times during pregnancy were preferred as a reference method. However, that was not feasible due to the high respondent burden, limited resources, varying levels of motivation and collaboration, time frame limitations, and the progression of the women's pregnancy. Moreover, data collection delays due to the COVID-19 pandemic caused the research team to pause and restart several times during the FFQ (December 2019 to August 2022) and 24-HDR (February and June 2022) data collection periods. The pandemic might also have contributed to changes in dietary habits during the study period [359, 360]. All these factors might also explain the higher disagreement between the FFQ and the 24-HDR.

There is no golden standard dietary assessment method. Biomarkers can be chosen for their strong direct relationship with dietary intakes and ability to independently assess specific nutrients [173]. While biomarkers-based assessment could provide more information for the validity of the FFQ and objective measures of dietary intake, it was not included in this dietary subcohort. However, biomarker's ability to capture habitual dietary intake is questionable [74], with the absence of biomarkers indicating the overall dietary intake and may be considered unfeasible due to the high costs and increased respondent burden [73, 361].

Improving the quality of FFQ validation studies among pregnant women may help minimize these effects and improve accuracy. For example, combining multiple reference methods, such as 24-HDR with biomarkers, increasing the sample size with a diverse study population to enhance generalizability, and using digital tools for dietary assessment might help reduce respondent burden and include pregnancy-specific dietary behaviors and specific nutrients. A web-based FFQ adapted to the Emirati adult population using data from the 2009–2010 national nutrition survey was validated using three non-consecutive 24-HDR over a month (n=60, aged 18-60 years old) and showed an acceptable validity [362]. Nutritional epidemiology focuses on linking dietary intake levels to health outcomes, indicating that the acceptable ranking of individuals in relation to their intake levels is more significant than the absolute intake [363, 364].

As discussed in the introduction section, the FFQ is commonly used to assess habitual dietary intake over extended periods and rank individuals based on their dietary intakes [81-83]. Therefore, FFQs are considered valid and reliable for studying maternal nutrition and its impact on pregnancy outcomes and identifying dietary intake changes during periconceptional and gestational periods [248, 365-369]. However, some challenges may occur during pregnancy connected with problems assessing their dietary intake due to the large within-individual variations [370], which may compromise the accuracy of FFQ responses, such as changes in appetite, food preference, and dietary patterns due to cravings or aversions [56-60]. Furthermore, the dietary intake of pregnant women may change during pregnancy and vary between trimesters [250], and the FFQ may not fully account for these changes. Finally, the self-reported nature of the FFQ raises concerns about recall bias due to the retrospective recall of dietary intake and misreporting of the types and amounts of foods consumed, which can induce substantial systematic error [96, 99, 356]. However, epidemiological studies have used self-reported data, demonstrating strong consistency and validity in predicting different outcomes [371].

When assessing dietary intake, diet variation is a natural occurrence that can be influenced by seasonal variation, meal patterns, household composition, food availability and takeaways, special days and events, and disease states [372]. There are two main types of variation: within-individual (day-to-day variations for the same individual) and between-individual (differences in dietary intake between different individuals) variation. Variation between individuals is often smaller than within individuals [372]. Moreover, for some nutrients, there is more variability within subjects than between subjects, which complicates the ranking of individuals and the assessment of the absolute intake of an individual [373]. However, to improve estimates and increase the precision of the within-individual variation, the between-individual variation, or both, more repeated dietary assessments are needed for the same participants and large sample sizes [372]. The selection of the dietary method is also important to consider; for example, FFQ can assess between-individual variation and habitual diet. However, 24-HDR can assess between-individual variation and, if completed on multiple days, within-individual variation and habitual diet [77, 372]. Two or more non-consecutive 24-HDR are required to estimate usual dietary intake distributions and correct for within-subject nutrient intake variability [374, 375]. There is no method for providing a complete correction and handling misreporting, which lies with the researcher, who must decide and consider any risks that could occur with misleading findings and the potential loss of statistical power if observations are excluded [376]. Moreover, selecting the appropriate dietary assessment method depends on the study's objectives, as discussed in the introduction section, considering the factors that could affect the selection method, such as population characteristics and seasonal changes [77].

ENERGY ADJUSTMENT METHODS

In paper I, there were significant differences in almost all selected examined nutrients between the FFQ and 24-HDR, except for SFA and whole grain after energy adjustment using the density method, showing good agreement for the SFA compared to poor agreement when we used the residual adjusted method. The correlation coefficients result from the energy-adjusted method using residual methods did not differ from the energy-adjusted method using the density method for the selected nutrients. However, for some food groups, the energy-adjusted correlations using the density method between the FFQ and 24-HDR did not decrease and remained significant with an acceptable agreement. These food groups showed poor agreement after energy adjustment using the residual method.

Energy adjustment is frequently used in validation studies of FFQs and generally shows a higher correlation between methods than non-energy-adjusted analyses [377]. In our validation study, when using the residual energy adjusted method, the correlation decreased for some nutrients and food groups, while using the density model, the same results for some nutrients were observed, while for food groups, the correlations increased compared to non-adjusted intakes. In addition to the previously discussed possible explanations for the modest correlations, another explanation could arise from the way each method adjusts for energy intake. The density method expresses nutrient intake relative to energy intake (e.g., grams per 1000 kcal). The main problem with this method is that when total energy intake is associated with disease risk, nutrient intake will be confounded by total energy intake, and isolating total energy intake will introduce a reverse confounding effect [102]. This might lead to a complex estimate combining the effect of the nutrient and the opposite effect of the total energy intake, potentially masking true associations [103]. Maybe this is why the correlations increase for the food groups, as the density method did not account for the total intake per se and preserves the energy-dependence of nutrient intake if both methods are biased similarly in overestimating or underestimating intakes.

On the other hand, the residual method removes the effect of energy intake by regressing nutrient intake on total energy intake (part of the variation in nutrient intake not explained by total energy intake), and the residuals are uncorrelated with total energy intake [102]. The residual method is mathematically equivalent to the standard model, targeting the effect of substituting nutrient exposure with other caloric sources while keeping total energy intake constant [103]. The residual method focuses on the variability in nutrient intake independent of energy, so the correlation between the two methods might decrease if one of these methods estimates energy intake differently or has high variability. Different validation studies among pregnant women used different energy adjustment methods, most commonly the residual method that has been used among Finish [242], Brazilian [244], Jordanian [243], Canadian [246], and Chinese pregnant women [245]. In a validation study among pregnant women from England, no adjustment for energy was performed [240]. An FFQ validation study among Norwegian pregnant women using multiple reference methods (4-days weighed food diary, a motion sensor, one 24-hour urine collection, and a venous blood sample) used the energy density method (intakes amount per 10 MJ) [368].

Energy adjustment is valuable in analyses of diet-disease associations, almost always used when an FFQ is the main dietary assessment method, as it accounts for measurement error based on the assumption that individuals tend to misreport their dietary intake [377]. What energy adjustment method to use will depend on the research questions; for example, to evaluate the effect of substituting specific nutrients for other nutrients, the standard model or the residual model is suitable. To represent the effect of increasing the percentage of a nutrient while keeping total energy intake constant, the density model is appropriate, and it is characterized as a version of substitution methods. The "all-components model" has recently been recommended by Tomova et al., arguing that it offers a flexible, accurate approach to adjusting energy intake and reducing confounding bias and measurement error in observational nutrition studies [103, 378]. This model is almost similar to the partition model that estimates the effect of adding food or nutrients while keeping all other sources of energy constant and does not entirely control for total energy intake [103, 379]. However, according to Willett et al., the "all-components model" does not align with the hypothesis commonly focused on in nutritional epidemiology on how isocaloric diet composition affects health outcomes [379]. Moreover, Tomova et al. explained that the "all-components model" includes all components of energy intake, making it isocaloric, and since the standard and "all-components model" contain the same exposure, other factors such as normality and correlation with confounders can be analyzed in the same way independent of the model used [378]. The compositional nature of dietary data is complicated; for example, when we adjust for total energy intake, we evaluate the substitution effects of one nutrient for another while keeping total energy constant, and we know that multiple dietary components influence energy. It is also important to think about how practical it is to adjust for all the components that contribute to total energy intake, as it may result in a huge model with many components which would affect statistical power, standard errors and the precision of the results.

IMPLAUSIBLE ENERGY INTAKES

Misreporting, often underreporting, of energy and dietary intakes is associated with female sex, irregular meal habits, low education, older age, overweight, and obesity [380-383]. Specific cut-off criteria for implausible energy intakes during pregnancy are not universally established. Implausible reporting of energy intake has previously been examined based on <500 and >3500 kcal cutoffs in non-pregnant adults [384]. Some studies have used <600 kcal and >4500 kcal, accounting for the increased energy requirements in pregnancy [238, 385, 386], and some have considered >4000 kcal as implausible values for total energy intake [239]. Based on our study design and population, we set the threshold to <600 kcal and >4000 kcal to exclude those with inaccurate dietary reports and enhance accuracy, as some participants had extreme under- or over-reporting of intake, with some reporting values exceeding 40000 kcal/day or less than 30 kcal/day. We noticed more over-reporters than under-reports, mainly in the FFQ. This might be due to difficulties in portion size estimation, misinterpretation of questions (confusing frequency options), FFQ length, and the fact that they might have rushed to complete it, as well as recall bias.

The doubly labeled water method is a gold standard for measuring accurate TEE under non-laboratory conditions without interfering with participants' behavior and activities [387]. Combined with the measurement of BMR or REE, the TEE in activity can be estimated. Goldberg et al. suggested estimating TEE as the product of BMR and physical activity level, and the ratio between energy intake and the BMR could be used to determine criteria for under and over-reporting energy intake [388]. However, it was shown that the use of the Goldberg cutoffs is not a reliable method for eliminating bias [389]. BMR is defined as "the energy expenditure of an individual at physical and mental rest in a thermally neutral environment while in a fasting state" [19]. In our study, we used the Harris-Benedict equation to predict the BMR by adding the median increase in REE during the first trimester of the pregnancy [19, 20, 230]. The mean calculated BMR was lower than the reported energy intake among the pregnant women. This is because BMR corresponds to the minimum energy needed for basic life functions at rest, and total energy intake should typically exceed BMR. Moreover, the median increase in the REE for pregnant women and the calculated BMR might be confounded by other factors that are not considered, such as pre-pregnancy BMI, dietary intake, GWG, and physical activity level [19, 20]. In our study, we found that women with higher BMI were more likely to underreport dietary intake. This aligns with the fact that underreporting is generally more commonly seen among overweight and obese individuals [381], possibly due to social desirability bias or difficulties in estimating portion sizes. Moreover, among United States pregnant women, underreporting of dietary intake increases throughout pregnancy in women with a high BMI [390].

FOOD DATABASE

There is a lack of a local food composition database in the UAE; therefore, the USDA database was used to estimate all dietary information, including energy, macro, and micronutrients [87], as it has been shown to be relevant in the Emirati setting [218]. Moreover, the USDA database has been recognized globally as a gold standard for food and nutrition research, with a vast food composition database [86] and its extensive individual list of ingredients, accounting for their different forms, such as fresh or dried and different types of meat and poultry, and its large selection of generic food and branded items

[391]. Additionally, the UAE has a varied culinary landscape featuring Emirati main traditional dishes, Middle Eastern and international cuisines, and many fast food selections [391]. Furthermore, the country imports around 80–90% of its food worldwide, with major suppliers including the European Union, India, Brazil, and the United States [392]. A study on developing a nutrient dataset for a nutrition survey in the UAE reported that using a standardized approach, including the USDA database, successfully matched 97% of the reported foods [391].

In our study, we used the Dietist Net Pro software program (Kost och näringsdata) with the latest updated version of the USDA database. We ensured to report representative food recipes for the local mixed dishes that were entered in the software program; however, systematic error may occur based on the weight of the portion sizes stated in the FFQ; for example, in one medium chicken shawarma sandwich, there is variation in the weight of a medium sandwich, as the portion size can differ between recipes and restaurants; however, we estimate a realistic portion weight by purchasing different options from different restaurants and measuring the weight using a food scale. Another issue is that we were unsure about the enrichment levels of staple foods, such as flour, rice, or oil, as they may vary depending on the food source. However, we considered the fortification information presented on the branded foods labels, specifically from the 24-HDR, such as juices, dairy products, and breakfast cereals. According to the WHO, fortification is the deliberate addition of micronutrients to foods to improve nutritional quality, restore nutrients lost during processing, and help prevent and reduce micronutrient deficiencies [393]. For the FFQ data, we considered the most consumed products in the market and double-checked the food labels and information on added nutrients. For example, the flour in the UAE market is mainly enriched with iron and B vitamins such as niacin, thiamine, and folic acid. Moreover, local brands in the UAE usually fortify their products, such as flour enriched in iron and folic acid, and dairy products are fortified with vitamins A and D [394, 395]. However, food fortification practices in the UAE are mainly voluntary. In neighboring countries, such as Oman and Bahrain, fortification for wheat flour is mandatory while voluntary in the UAE. Fortification of salt with iodine is compulsory in the GCC, including the UAE [396, 397]. There is a lack of standard information available for fortification practices in the UAE, including legislation for fortification and the fortification level in food products. Therefore, fortification practices might differ among food brand companies. Several recent national food strategies and initiatives are being discussed and implemented in the UAE. The aim is to improve the population's nutritional status throughout the life cycle, ensure access to nutritious and sufficient food year-round, enhance local production, and to establish a sustainable nutritional system [398-400].

Nutrient deficiencies in pregnant women can be detrimental, with a negative health impact on both maternal health and fetal development. For instance, folic acid deficiency increases the risk of neural tube defects and anemia [62]. Among our pregnant women, inadequate intake of folate was observed. There is a lack of recent data about the prevalence of neural tube defects; a study between March and May 1998 recorded 4861 births, with a neural tube defect incidence of 0.62 per 1000 births in the UAE [401]. During almost the same period, higher rates were observed in Oman, with 1.25 per 1000 births [402], and in Saudia Arabia, with 1.09 per 1000 births [403]. A study in the UAE among pregnant women showed that 47% had precise knowledge about the role of folate in preventing neural tube defects [404]. The Centers for Disease Control and Prevention recommends that all pregnant women take 400 micrograms of folic acid daily [405]. Moreover, anemia is also prevalent in the UAE, affecting around 18% of women of reproductive age [406].

STATISTICAL ANALYSIS

For the validation study, we used different statistical analyses to assess the validity at individual and group levels, as one to three statistical tests may be insufficient to provide complete insights into various aspects of validity [236]. Missing data using the mean or mode imputation approaches assumes they were missing at random; however, this may underestimate variability in responses and introduce bias. This was done for three variables, and missingness in these variables was relatively low (13% of the women). However, alternative imputation strategies, such as multiple imputations, will be considered in future studies to enhance robustness.

In all regression models (linear and logistic), we presented both crude and adjusted models to account for any possible confounding factors. We did not want to overfit the models and considered the sample size. Sensitivity analyses were also conducted with almost similar conclusions. Multiple statistical tests were performed without correcting for multiple tests, such as the Bonferroni correction test [407]. Therefore, when interpreting the results, it is important to take into account that multiple tests can increase the likelihood of identifying associations by chance alone. Due to the observational design of the study, it limits our ability to determine causation.

Power calculations for the dietary subcohort were initially planned to recruit a sample size of 2000 pregnant women; however, this was not achieved due to the challenges posed by the COVID-19 pandemic. Therefore, we performed a post hoc power analysis, confirming that the sample size provided adequate statistical power to detect specific risks of common outcomes, such as GDM and GWG. However, in the adjusted model, the observations included in the analysis were reduced due to the missing data. A larger sample size would have provided more power and perhaps more statistically significant results.

ETHICAL REFLECTIONS

The first ethical approval of the study in 2017 was from the central ethics committee at that time (AAMD-HREC: ERH-2017-5512), and its validity depended on the submission of annual reports. Ethical approval was obtained before any data collection. In 2021, we applied for additional approval from the Abu Dhabi Health Research and Technology Ethics Committee (DOH/CVDC/2022/72) due to changes in the hierarchy of the Institutional Review Boards, and its validity depends on annual approvals. Moreover, ethical approval from the Swedish Ethical Review Authority (2023-00338-01) was also secured to analyze this project-related data in Sweden without any personal identification of the participants, as every participant is assigned with a code. Any additional questionnaire went through an amendment process prior to its administration. Moreover, we ensured we did not mislead any information or force participants to participate, as participation is voluntary and without pressure. The informed consent contained information on the overall research plan, the purpose, the methods, data protection, the contact information of the person responsible for the research, and the right to terminate their participation at any time, and we ensured that the participant understood this information. The study adhered to good research practices, emphasizing honesty in reporting, reliability in design and analysis, respect for colleagues and participants, accountability throughout the research process, and confidentiality in handling sensitive information [408].

As the dietary subcohort was mainly conducted in the waiting areas of the clinics, some ethical considerations might be made, including potential risks and benefits to the participants. Some main risks to participating might include time inconvenience as they expect to see their obstetricians, and answering dietary questionnaires may put them under stress. Moreover, there were privacy concerns in public areas as other women might overhear their responses, specifically when collecting the 24-HDR. However, we tried to minimize this risk by moving to a quieter area. Additionally, collecting dietary data during the COVID-19 pandemic might risk pregnant women in the waiting areas as it could increase exposure to the virus; however, precautions were applied with infection control measures like masking and distancing. Beyond health risks, other ongoing studies targeting pregnant women were conducted simultaneously during our recruitment in one of the hospitals, which may have added pressure and caused confusion among women. Moreover, in this dietary subcohort, we did not introduce or examine dietary intervention methods for pregnant women, as women's representation may vary depending on whether studies are interventions or observational [409]. On the other hand, participating in this dietary subcohort may increase women's awareness of their dietary intakes and nutritional choices. Moreover, the data collected leads to a better understanding and estimation of pregnant women's dietary intake, which will be presented as a base of nutritional information for Emirati pregnant women. Additionally, this will provide potential improvement in the dietary guidelines and early implementation of intervention programs targeting the well-being of future pregnant women.

NUTRITIONAL TRANSITION IN THE UAE

The UAE's rapid economic growth and urbanization, along with an increasingly multicultural population, has increased the variety of food choices and contributed to considerable changes in food habits, with high consumption of processed and fatty foods and reduced physical activity [203, 204]. The term “nutrition transition” has been principally used to characterize the shifts noticed in dietary intake, reflecting a broader global trend with larger food availability eroding traditional diets and gradually replacing them with Westernized pattern diets [205, 410]. This eventually leads to an increased risk of cardiovascular disease, obesity, diabetes, hypertension, and hyperlipidemia among both nationals and residents [295, 411]. The high rates of EGWG and GDM observed among pregnant women included in this thesis are concerning. Moreover, a high incidence of pre-pregnancy overweight and obesity (around 60%) has been reported among women from the *Mutaba’ah* Study [283].

Dietary pattern studies in the UAE are very limited, specifically among pregnant women. The Mediterranean diet is a good example of a healthy dietary pattern; however, its definition differs between studies, as discussed previously. Yet, compared to the Western diet, its definition and application are more consistent across studies. To clarify, some countries within the Mediterranean region (e.g., Spain and Lebanon) may share common characteristics of the Mediterranean diet, such as a high intake of vegetables, fruit, whole grains, olive oil, and lean proteins. However, some traditional patterns might differ and may not align with the typical Mediterranean dietary pattern [412]. A traditional dietary pattern was identified among healthy Emirati adults, including mixed dishes (mainly rice, red meat, and poultry), vegetables and fruit, and dairy and whole milk [412]. Adherence to this traditional Emirati diet was higher among older participants in comparison to the younger ones, providing evidence for nutrition transition in the country [412]. In the GCC, traditional diets comprised mostly of dates, wheat, barley, rice, meat, and yogurt products (e.g., Leben) [412]. Moreover, the diversity of food available in the UAE, influenced by the Mediterranean diet, has resulted in a culinary landscape that combines Mediterranean and Middle Eastern food cultures [278, 413, 414]. The health benefits of healthy dietary patterns such as the Mediterranean diet, the Nordic diet, DASH, and the HEI are characterized by a high intake of plant-based foods and a low intake of animal-based foods, which also supports environmental sustainability [415, 416]. Following the National Nutrition Strategy 2030 in the UAE that aims to establish a sustainable nutrition system and provide a safe and supportive nutritional environment to all age groups [398], integrating the beneficial effects of these diets among our pregnant women will help achieve these visions. A study among adult Emirati women investigated the association of adherence to the Mediterranean Diet with environmental footprints and showed that the Mediterranean diet might support environmental sustainability [297].

CONCLUSION

The results show that the FFQ is a useful method in ranking habitual diary intake at the individual level among pregnant women in the UAE. However, it overestimates the intake of most nutrients and food groups at the group level. Moreover, careful considerations should be taken with specific intakes of nutrients and food groups. Based on the FFQ, we identified adherence to healthy dietary patterns (AHEI-P, aMED, or DASH) that correlated with each other but showed different features of dietary intake with regard to carbohydrate and fat quality. Thus, the choice of the dietary index should be considered.

Adherence to the Mediterranean diet among pregnant women was not associated with GWG, EGWG, or GDM. However, some components of the Mediterranean diet show associations with both GWG and EGWG. Higher intake of fruit was associated with higher GWG and an increase in the odds of EGWG, higher vegetables intake was associated with a decrease in the odds of EGWG, and a higher MUFA/SFA ratio was associated with a reduction in GWG. Overall, this suggests that the intake of vegetables and high-quality fat may support healthy GWG. The intake of fruit needs further investigation. Additionally, the components of the Mediterranean diet show no associations with GDM. Pregnant women with high UPF intake had an overall poor diet quality, but no associations were observed between UPF intake and GDM.

FUTURE PERSPECTIVES

Data from this dietary subcohort addressed important aspects of dietary patterns among pregnant women, starting from the validation of FFQ, identifying adherence to different dietary patterns, and ending with dietary associations with common pregnancy outcomes. Dietary data are scarce in this population, and this thesis will integrate the building of both national and international nutritional databases for future investigations and collaborations. Our results fill a knowledge gap regarding the dietary situation in the country and how dietary intake could contribute to maternal health outcomes both in the short- and long-term effects. The results of this thesis have significant implications for policy and future project implementation among Emirati pregnant women and will add to the national strategies that the country recently initiated. Moreover, the dietary patterns included in this thesis have not been assessed previously among Emirati pregnant women. This could contribute to developing dietary recommendations and nutritional guidance focused on improving diet quality to support maternal health.

Although we did not find significant associations with pregnancy outcomes, that does not mean such associations do not exist. It would be effective to conduct well-designed research, including randomized controlled trials, which may help uncover potential relationships and causal links. This would provide substantial evidence to better understand the impact of a healthy diet during pregnancy and inform effective intervention strategies. Moreover, based on the results presented in this thesis, we encourage dietary counseling during antenatal care visits. This will offer a viable, long-term approach to optimize GWG while ensuring adequate nutrient intake during pregnancy and may help identify pregnant women at risk of developing GDM. There are no previous data regarding UPF intake and its related health effects among the Emirati population. This is concerning as this country has experienced a nutrition transition that has negatively impacted overall dietary intake and health. Specifically for pregnant women, this transition poses even greater challenges, as based on our data, pregnant women showed inadequate intake of important nutrients. This is concerning as poor nutritional intake during pregnancy can increase the risk of adverse maternal and fetal outcomes.

Furthermore, the *Mutaba'ah* Study is still ongoing, and the dietary subcohort is planned to investigate diet in the postpartum period further using the FFQ and its associations with women's and children's health. This will build on the dietary cycle we started, providing a comprehensive understanding of dietary transitions and their implications, particularly for future generations. Today's girls will become the next generation of women who experience pregnancy and associated nutritional challenges. Furthermore, we aim to improve and implement nutritional strategies that support maternal health across generations.

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