Harokopio University
School of Health Sciences & Education
Department of Nutrition and Dietetics
Postgraduate Program "Applied Nutrition and Dietetics"
Discipline: Clinical Nutrition

Parental risk factors for Diabetes Mellitus type II and childhood obesity.

Master's Research Thesis

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Περίληψη

Εισαγωγή: Ο επιπολασμός της παιδικής παχυσαρκίας και των επιπλοκών που συσχετίζονται με αυτήν αυξάνονται συνεχώς. Συνεπώς, η πρόληψη της παιδικής παχυσαρκίας είναι υψίστης σημασίας, της οποίας σημαντικό συστατικό είναι ο προσδιορισμός των παραγόντων κινδύνου. Δεδομένου ότι τα γονικά χαρακτηριστικά έχουν καθοριστικό ρόλο στη διαμόρφωση της κατάστασης βάρους των απογόνων και δεδομένου ότι οι παράγοντες κινδύνου για Σακχαρώδη Διαβήτη τύπου 2 και παχυσαρκία είναι σε μεγάλο βαθμό κοινοί, ιδιαίτερο ενδιαφέρον έχει να διερευνηθεί σε ποιο βαθμό οι παράγοντες κινδύνου για ΣΔτ2 των γονέων μπορούν να προβλέψουν το υπέρβαρο και την παχυσαρκία των παιδιών.

Σκοπός: Ο στόχος αυτής της μελέτης είναι να εξετάσει την πιθανή συσχέτιση μεταξύ γονικών παραγόντων κινδύνου για ΣΔτ2 και του υπέρβαρου και της παχυσαρκίας στα παιδιά, σε ένα μεγάλο δείγμα από 6 ευρωπαϊκές χώρες.

Υλικά και Μέθοδος: 20.151 ενήλικες (10967 μητέρες και 9184 πατέρες) και τα παιδιά τους συμπεριλήφθηκαν στη μελέτη (στοιχεία από τη μελέτη Feel4Diabetes). Λογιστική παλινδρόμηση και καμπύλες λειτουργικών χαρακτηριστικών χρησιμοποιήθηκαν για την εκτίμηση της πιθανής συσχέτισης μεταξύ μητρικών, πατρικών και γονικών παραγόντων κινδύνου για σακχαρώδη διαβήτη τύπου 2 και του υπέρβαρου και της παχυσαρκίας των παιδιών.

Αποτελέσματα: Ο υψηλότερος Δείκτης Μάζας Σώματος (ΔΜΣ) και η περιφέρεια μέσης της μητέρας συσχετίστηκαν με υψηλότερο ΔΜΣ του παιδιού [3.127 95%C.I. (2.751-3.556), 2.402 95%C.I. (2.154-2.679) αντίστοιχα]. Η παρουσία τουλάχιστον ενός υπέρβαρου/παχύσαρκου γονέα σε μία οικογένεια συσχετίστηκε θετικά με υπέρβαρο ή παχυσαρκία απογόνων [4.510, 95%C.I. (3.852-5.280), 2.882 95%C.I. (2.471-3.361)]. Οι συσχετίσεις αυτές παρέμειναν στατιστικά σημαντικές ακόμη και ύστερα από προσαρμογή ως προς την περιοχή κατοικίας, την εκπαίδευση μητέρας/γονέων και όλες τις υπόλοιπες μεταβλητές. Επιπλέον, το υψηλό μητρικό και γονικό σκορ FINDRISC συσχετίστηκε σημαντικά με υπέρβαρους απογόνους [FINDRISC σκορ της μητέρας 1,698 95%C.I. (1.456-1.980), FINDRISC σκορ των γονέων 1.586 95%C.I. (1.385-1.816)]. Μη κατηγορηματικά ήταν τα αποτελέσματα σχετικά με τους υπόλοιπους παράγοντες κινδύνου που εξετάστηκαν. Επιπρόσθετα, ο μητρικός και πατρικός ΔΜΣ προέβλεψε σε μεγαλύτερο βαθμό από το μητρικό και το πατρικό FINDRISC σκορ το παιδικό υπέρβαρο και την παχυσαρκία [AUC-ROC: 0.638 (0.628-0.647)

για ΔΜΣ της μητέρας vs 0,586 (0.577-0.596) για FINDRISC σκορ της μητέρας και 0.632 (0.622-0.642) για ΔΜΣ του πατέρα vs 0.594 (0.584-0.604) για FINDRISC score του πατέρα]. Τέλος, ο ΔΜΣ της μητέρας και του πατέρα ήταν εξίσου ικανά να προβλέψουν το υπέρβαρο και την παχυσαρκία των απογόνων.

Συμπεράσματα: Υψηλότερος ΔΜΣ των γονέων, μεγαλύτερη περιφέρεια μέσης και υψηλότερο σκορ FINDRISC ήταν οι σημαντικότεροι προγνωστικοί παράγοντες της παιδικής παχυσαρκίας, εκ των οποίων ο πιο αξιόπιστος ήταν ο γονικός ΔΜΣ. Επειδή το αυξημένο βάρος κατά την παιδική ηλικία είναι ένα ανησυχητικό πρόβλημα δημόσιας υγείας σε όλο τον κόσμο, στο οποίο οι γονείς μπορεί να έχουν καθοριστικό ρόλο, συνιστάται οι στρατηγικές προώθησης της υγείας και τα προγράμματα παρέμβασης να απευθύνονται στην οικογένεια.

Λέξεις κλειδιά: παιδική παχυσαρκία, παράγοντες κινδύνου, Feel4Diabetes, ΣΔτ2

Abstract

Background: The prevalence of childhood obesity and obesity related complications is escalating. As a result, prevention of obesity is of utmost importance, whose vital component is the identification of childhood obesity risk factors. Since parental characteristics play a pivotal role in shaping the offspring's weight status and since risk factors for Diabetes Mellitus Type 2 and obesity are often common, it is of special interest to investigate the possible association between parental risk factors for Diabetes Mellitus Type 2 and childhood overweight and obesity.

Objectives: The aim of this study is to examine the possible association between parental risk factors for Diabetes Mellitus Type II and childhood overweight and obesity, in a large sample from 6 European countries.

Methods: 20,151 adults (10967 mothers and 9184 fathers) and their children were included in the study (data from the Feel4Diabetes study). Logistic regression analysis and receiver operating characteristic (ROC) analysis were used to assess the possible association between maternal, paternal and parental risk factors for Diabetes Mellitus Type 2 and childhood overweight and obesity.

Results: Child overweight and obesity were significantly associated with maternal and parental weight status [maternal: 3.127 95%C.I. (2.751-3.556) and parental 4.510, 95%C.I. (3.852-5.280)] and waist circumference [maternal 2.402 95%C.I. (2.154-2.679) and parental 2.882 95%C.I. (2.471-3.361)] These effects remained significant after adjusting for region, maternal/parental education and all other variables. Child overweight and obesity were associated with a maternal and parental moderate to very high risk of developing diabetes, according to the FINDRISC score [maternal FINDRISC 1,698 95%C.I. (1.456-1.980), parental FINDRISC 1.586 95%C.I. (1.385-1.816)]. Results were inconclusive for all other factors examined. In addition, maternal and paternal BMI were the most significant predictors of childhood overweight and obesity and succeeded at a greater degree than maternal and paternal FINDRISC score at identifying childhood overweight and obesity [AUC-ROC: 0.638 (0.628-0.647) for maternal BMI vs 0,586 (0.577-0.596) for maternal FINDRISC score and 0.632 (0.622-0.642) for paternal BMI vs 0.594 (0.584-0.604) for paternal FINDRISC score]. Finally, maternal and paternal BMI were equally effective in predicting childhood overweight and obesity.

Conclusions: Parental higher BMI, higher waist circumference and greater FINDRISC score were the main significant predictors of childhood obesity, of which the most important was parental BMI. Since childhood overweight and obesity is an alarming public health problem worldwide, to which parents may have a pivotal role, it is recommended that health promotion strategies and intervention programs should be family directed.

Key words: childhood obesity; risk factors; Feel4Diabetes; Type 2 Diabetes Mellitus

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ADA	American Diabetes Association
BMI	Body Mass Index
FINDRISC	Finnish Diabetes Risk Score
IDF	International Diabetes Federation
NAFLD	Non-alcoholic fatty liver disease
SES	Socioeconomic status
T2D	Type 2 Diabetes Mellitus
VFG	Vegetables, fruits and berries
WHO	Word Health Organization

1. Introduction

1.1. Introduction to childhood obesity and its definition

One of the greatest public health challenges nowadays is childhood obesity, whose prevalence seems to be increasing dramatically in recent years, reaching epidemic proportions (1). The total number of obese children worldwide is 158 million and is expected to reach 254 million in the next decade (2).

Presently, WHO defines obesity as a situation of abnormal or excessive fat accumulation at a degree which endangers the health of the individual (1). According to the latest clinical practice guidelines on pediatric obesity (3), a child over two years of age or an adolescent is diagnosed as overweight if the BMI is ≥ 85th percentile but <95th percentile, as obese if the BMI is ≥ 95th percentile and as extremely obese if the BMI is ≥120 % of the 95th for age and sex on the WHO charts or ≥ 35kg/m^2. A child younger than 2 years of age is diagnosed as obese if the sex-specific weight for recumbent length is ≥ 97,7th percentile on the WHO charts.

1.2. Epidemiology of childhood obesity

An increase in the prevalence of overweight and obesity among children and adolescents has been widely reported over the last decades. Regarding the prevalence of overweight and obesity in children and adolescents worldwide, according to a recent report of the World Obesity Federation, the number of children aged between 5- and 19-year old living with obesity was estimated to be 206 million in 2025 and 254 million in 2030 (2). Currently, almost one-third of children and adolescents in the United States of America, can be classified either as obese or overweight (4). Meanwhile in Europe, according to the WHO European Childhood Obesity Surveillance Initiative (5), prevalence of overweight is 13% to 43% for girls and 18% to 52% for boys, while of obesity 4 to 20% and 6 to 28% for girls and boys, respectively. In Greece specifically, the prevalence of obesity is 16% for girls and 22% for boys aged 7 years old and 20% for girls and 28% for boys aged 9 years old. These data suggest that more boys than girls are overweight or obese, in most age groups and especially in older ages.

Furthermore, it seems that countries of Southern Europe have a higher rate of overweight and obesity. In fact, unequal distribution across different socioeconomic groups has been widely suggested, with obesity being more prevalent in low-income populations (6-8).

1.3. Complications of childhood obesity

Both the short- and long-term physical and psycho-social health impacts of childhood obesity are well documented (4). Specifically, there is a greater risk of the most predominant chronic diseases, namely insulin resistance, T2DM, hypertension, dyslipidemia, and systemic inflammation (4, 9-11). Obese children suffer more often from respiratory problems such as obstructive sleep apnea and asthma (12-14). In addition, they are at a greater risk of gastrointestinal problems mainly NAFLD and cholecystitis (14-16). An increased incidence of various musculoskeletal problems such as lower extremity joint pain and fractures has also been reported in obese children (17-20).

Childhood obesity has also well-documented severe adverse psychological consequences. A systematic review of the psychological effects of childhood obesity (21) has led to the conclusion that obese children are in greater risk than their healthy-weight peers for stigmatization, bullying, social isolation, inattention issues and emotional symptoms. This fact is supported by a recent meta-analysis (22) which found strong evidence correlating childhood obesity with depression, especially in girls.

Moreover, obesity in childhood and adolescence is a strong predictor for obesity in adulthood and is associated with significant morbidity and mortality, by increasing the risk of insulin resistance, type II diabetes and cardiovascular diseases in adulthood (23-25). In fact, the earlier the onset of overweight and obesity the greater the burden, since it has been shown that adults who were obese children impact society financially 8 times more than adults who had healthy body weight during childhood (26). These economic consequences can be categorized as direct, such as medical expenses for the treatment of obesity and obesity-related diseases and as indirect such as absenteeism from school or employment (27). The direct costs mentioned above range as high as $209,7 billion in the United States and account for more than 20% of all annual health care costs, while the indirect cost outcomes reach $66 billion per year (28).

1.4. Etiology of childhood obesity

It is important to keep in mind that obesity is a multifactorial entity that involves an interplay of a variety of factors (29). The child's characteristics such as their gender, age, and genetic predisposition for obesity, interact with behavioral factors such as their diet, physical activity, and sedentary lifestyle. All these in turn, interrelate with processes in the family and school environment which themselves are influenced by characteristics of the community and society at large, thus placing the child at a certain risk of obesity (30).

1.5. Child-related risk factors for childhood obesity

1.5.1. Genetic factors

As mentioned before, childhood obesity is the consequence of interactions among a complex set of factors, one of which is genetic predisposition (4). Twin studies have estimated heritability to account between 30% and 70% of the total BMI variation (31). Several single gene defects and syndromes have been identified, the most common of which are Prader-Willi syndrome and mutations in the melanocortin-4 receptor. However, these account for less than 1% of childhood obesity as polygenetic obesity is the most frequently observed (32). Genome wide association studies have revealed various genetic loci associated with BMI or adiposity (33). Several genes have been related to appetite, satiety, lipoprotein metabolism and so forth, meanwhile their optimum expression can be altered by different lifestyles (34). Thus, showing that the risk of obesity is not only related to specific genotypes, but to gene-gene interactions and gene-environment interactions (34,35).

1.5.2. Perinatal and early-childhood risk factors

A recent meta-analysis (36) of data from 162,129 mothers and their children from 37 pregnancy and birth cohort studies showed that higher maternal pre-pregnancy BMI and excess gestational weight gain are associated with an increased risk of childhood overweight and obesity, with the

strongest effects in late childhood. Birth by caesarian section has also been implicated in the aetiology of childhood obesity (37) with the association extending till late adulthood (38).

Furthermore, studies suggest that high birth weight is associated with an increased risk of childhood overweight and obesity and may serve as a mediator between prenatal influences and later disease risk (39-42). Apart from birth weight, increased weight gain in the first few months of life has also been investigated, with two recent meta-analyses (43,44) revealing that accelerated weight gain is associated with an increased risk of childhood overweight and obesity, especially in low-birthweight and preterm babies. In fact, it would appear, that premature birth is an independent risk factor for childhood obesity (44).

In addition, it is widely known that a longer duration of breastfeeding may be protective against childhood overweight and obesity (41,45,46). This effect however appears to differ between risk groups (47) and is not consistent between studies (48).

1.5.3. Behavioral factors

It is well known that high energy intake relative to energy expenditure results in a positive energy balance that leads to obesity. Insufficient physical activity and poor nutrition are widely acknowledged as the primary mechanisms underlying the rise in excess body weight (49).

A recent meta-analysis (50) of 199 studies with 1.634.049 participants showed that physical activity and eating breakfast are the first and second most powerful protective factors against overweight and obesity in children and adolescents. On the contrary, inadequate sleep, watching too much TV and drinking sugar-sweetened beverages are associated with increased risk of childhood obesity.

1.6. Sociodemographic risk factors

A shift in attention to sociodemographic determinants of obesity has occurred since Sobal and Stunkard's review of the literature, in 1989 (51). Their review (52) included 144 studies with data on cross-sectional associations between SES and obesity in both adults and children. As far as childhood obesity was concerned, the relationship was not straightforward. In developed countries SES was

inversely associated with obesity in 32-40% of the studies, not associated in 35-41% and positively associated in 25-26% of studies. In contrast, in studies from developing countries, most associations were positive, with no inverse associations reported. More recently, a systematic review (53) of 45 cross-sectional studies between 1990-2000, showed that associations between SES and adiposity in children are predominately inverse and positive associations have all but disappeared.

Numerous noteworthy SES factors have been found to be related to children's weight status, including gender and ethnicity (53,54). Lower parental education levels have been associated with an unhealthy lifestyle and obesity in children (53, 55). Indices of family income (56) and parental occupation (57) have also been inversely associated with childhood overweigh and obesity. Meanwhile, neighborhood differentials with respect to childhood overweight have been identified. The most prominent correlation being between the school environment of low-income neighborhoods and childhood adiposity, due to the low frequency of physical education classes, the financial restraints for outdoor play and gymnasium equipment, the great availability of soft drinks and vending machines and the low quality of lunch provided (58).

1.7. Parental-related childhood obesity risk factors

1.7.1. Association of parental lifestyle and practices with childhood obesity

Behavioral child-risk factors are shaped by parenting styles and family characteristics such as parents' nutritional knowledge, dietary intake, and child feeding practices (30,59). There is good evidence that low levels of health literacy are associated with excess body weight, particularly in children (60). In fact, mothers' nutritional knowledge has been positively associated with children's fruit and vegetable intake and negatively associated with children's total energy and fat intake (61,62).

As mentioned before, children's dietary and physical activity patterns evolve within the context of family. Not surprisingly, consistent similarities have been noted in child and parent patterns of dietary intake (63). Specifically, in a review (64) of 69 studies, the influence of a "model" proved to

be one of the most powerful factors in shaping eating behavior as 64 studies showed a statistically significant effect of "modelling" on dietary intake regardless of methodology, type of food and characteristics of participants. Reasonably, children from families that eat together regularly are less likely to be overweight or obese (65-68), as they tend to eat a healthier diet especially when comparing them to children eating in front of the television, who are, thus, "mindlessly eating" and having a higher energy intake (69-72).

Furthermore, various parenting styles, feeding styles and feeding practices have been associated with child BMI (73). A recent meta-analysis (74) of 37 studies examined the wide variety of parental behaviors that either promote or prevent certain food consumption behaviors on children dietary habits. Some behaviors, such as parents' own food consumption behavior, and availing certain types of food, have been shown to be strong correlates of child food consumption behavior. On the other hand, some behaviors such as active and restrictive guidance, are effective only in certain contexts; active being more effective in encouraging fruits and vegetables consumption, while restrictive guidance is more effective in discouraging unhealthy eating. Meanwhile, a systematic review (75) of eight prospective studies examining the effects of parenting styles on offspring BMI, supports the idea that authoritative parenting may be protective against later overweight and obesity, although findings were mixed.

Finally, family functioning has been the subject of extensive research on its relationship with the occurrence of childhood obesity (76). Poor family functioning, commonly expressed as poor communication, poor behavior control, high levels of family conflict and low family hierarchy values, has been associated with increased risk of obesity and overweight in children and adolescents (77). Additionally, unfavorable family conditions, such as parental divorce have shown a positive correlation with the overweight of children (78,79).

1.7.2. Parental risk factors for T2D that associate with childhood obesity.

It is well known that obesity is the most important factor associated with insulin resistance and T2D (80). In an obese individual, excess adipose tissue, especially when distributed centrally, affects metabolism by secreting hormones and other substances including proinflammatory cytokines and non-esterified fatty acids, that are involved in the development of insulin resistance (81). As a result,

research shows that when examining the risk factors for T2D, most associations found are proxies or common risk factors for obesity (82). It is therefore of great interest to examine how different risk factors for T2D can be associated with obesity, especially in the parent-child dyad.

Both cross-sectional (83-88) and longitudinal (89,90) research provides convincing evidence of a positive relationship between child and **parental BMI**. This correlation seems to be linear (91,92) and can be encountered in many different countries (93,94), as well as in Greece (57,91,95-98) Of great interest is a recent meta-analysis of 27 studies which indicates a significant association between parental and child obesity (94). Meanwhile, both **maternal and paternal waist circumference** have been associated with offspring overweight, with the strongest associations being observed in parent-child dyads of the same gender (87,99).

To date three meta-analyses (100-102) have examined the evidence regarding intrauterine exposure to diabetes and whether it can "program" long-term overweight and obesity in the offspring. This growing body of evidence suggests that maternal diabetes is associated with higher offspring BMI z-score (100,101) and higher fat mass, body fat percentage and skinfold thickness in infancy (102). These effects tend to be more apparent in T1D and gestational diabetes, whereas the evidence for T2D is scarce (101,102) and in certain studies the effects of T2D were attenuated after adjustment for maternal pre-pregnancy BMI (100). As far as both maternal and paternal glycemia are concerned, a more recent study using data from 11.050 children from the "Exploring the Iceberg of Celiacs in Sweden/ETICS" study" suggests a higher risk of being overweight for children with parental diabetes, either maternal or paternal, compared with children without parental diabetes, irrespective of the type of diabetes (103).

Older **parental age** at childbearing has been associated with higher offspring BMI in a study of Swedish national data from 3,653,938 children (104). However, findings are mixed as older paternal age has been associated (105), not associated (106,107) or inversely associated (91) with children's BMI level. Meanwhile, older maternal age at birth has been associated with increased body fat accumulation and higher BMI (106, 108-109) or not associated at all (105) with the offspring's weight status.

As mentioned before, parents can have a strong impact on their children's health as lifestyle and behavioral traits which promote obesity easily transmit from parents to children (56). Low **parental**

levels of physical activity, widely acknowledged as a common obesogenic factor, have been studied as a possible influence on children's physical activity and as a predictor of children's weight status. Evidence from two recent reviews of cross-sectional as well as longitudinal studies, suggest that parental physical activity directly correlates with children's physical activity levels (110,111). However, findings suggest that parental support for physical activity might have a stronger positive association with children' physical activity behavior (112,113). Meanwhile, parental physical activity levels seem to be associated with offspring weight, however the evidence is scarce and controversial (87,90,114,115).

There is scant evidence on the influence of **parental hypertension** on cardiometabolic risk factors and especially overweight and obesity among their offspring. Studies suggest that children with parental history of hypertension are more obese (116). Adolescents with parental hypertension have a significantly higher weight than those without parental hypertension and are also at greater risk of having abdominal obesity (117). Similarly, a recent study of Japanese children demonstrated that children with maternal but not paternal history of hypertension are much more likely to be overweight (118).

Furthermore, **parental fruit and vegetable intake** has been shown to be an important predictor of fruit and vegetable consumption among children (119-124). Parents influence their children's VFB intake through role modelling, home food availability, feeding approaches, parental encouragement, knowledge, and other practices (74, 122,123). This influence appears to be similar in normal-weight and treatment-seeking overweight children. However, it seems that overweight children and their mothers eat FBV less frequently than normal-weight children and their mothers (124). In fact, evidence for the association between low fruit, berries and vegetable consumption and being overweight in childhood is consistent (125-127).

Finally, the **Finnish Diabetes Risk Score (FINDRISC),** the most widely used diabetes risk score in Europe, enables the identification of people at increased risk of developing T2D over the following 10 years (128). This 8-item questionnaire has been widely validated in Greece (129) and many other countries (130-139) and recommended by international health organizations such as the ADA (140) and the IDF (141). However, it is yet to be examined in the setting of predicting childhood obesity.

1.8. Research gap

As stated above, the prevalence of childhood obesity is escalating and has already reached epidemic proportions. Consequently, obesity-related complications are being diagnosed with increasing frequency in children and in certain cases can persist in adulthood and lead to life-threatening disease. As a result, prevention of obesity is of utmost importance; still, it represents a significant challenge, whose vital component is the identification of childhood obesity risk factors.

Parental characteristics and practices seem to play a pivotal role in shaping the offspring's weight status, mostly due to genetics, shared lifestyle practices and shared environmental components. In fact, of special interest are parental risk factors of T2D, such as age, daily fruit and vegetable consumption, daily physical activity, history of hypertension or glycemia, BMI and waist circumference. Obtaining information on these parental characteristics is of great advantage due to their lower cost, greater acceptability, and ability to provide a reflection of shared genetic, lifestyle and environmental factors. Yet, there is disparity in the associations noted between the above parental risk factors and childhood obesity, mostly due to the small sample sizes and the cross-sectional design of the studies conducted. Thus, there is need of further research, to develop awareness of these risk factors and therefore to promote screening, early detection of obesity and treatment in high-risk children.

1.9. Research question

In the interest of preventing childhood obesity as well as developing appropriate prevention programs, risk factors of child overweight and obesity need to be better understood. Since many risk factors for T2D and obesity are common, the aim of the present study is to examine the association between parental risk factors for T2D with childhood obesity in a large sample, from 6 European countries.

2. Methodology

2.1. Study Design

The Feel4Diabetes-study was a large school- and community- based intervention with a cluster-randomised design, aimed to prevent diabetes mellitus type 2 in families across Europe by promoting a healthy lifestyle and managing obesity and obesity-related metabolic risk-factors. Families (primary-school children, their parents, and grand-parents) were recruited from two low/middle –income countries (Bulgaria, Hungary), two low socio-economic areas in high – income countries (Belgium, Finland) and two countries under austerity measures (Greece, Spain).

The study consisted of two major components, the "all families" component, which was delivered at schools, home and the local municipalities and the "high-risk families" component, which was delivered out of the school setting, in families at increased risk of diabetes mellitus type 2. The study was conducted between 2015 and 2019 and reached 30.309 families. In the present study, data from the "all families" component were used in the analyses.

2.2. Ethics and consent

The Feel4Diabetes-study adhered to the Declaration of Helsinki and the conventions of the Council of Europe concerning human rights and biomedicine. Ethical clearance was obtained in all participating countries, prior to the initiation of the intervention, from the relevant ethical committees and local authorities. More specifically, in Greece ethical clearance was obtained from the Bioethics Committee of Harokopio University and the Greek Ministry of Education. All parents and caregivers gave signed consent before enrolling in the study.

2.3. Study Sample

The sample of the study consisted of families from "vulnerable" social groups from six European countries. In Bulgaria and Hungary, the two low/middle income countries, all areas within the selected provinces were considered "vulnerable" and eligible to participate in the study. In Belgium, Finland, Greece and Spain, the municipalities, school districts or other equivalent units were grouped

in tertiles according to socio-economic indices and “vulnerable” areas were randomly selected only from the lowest tertile.

Children attending the first three grades of primary school and their parents and grandparents were recruited into the study. In total 11.511 families were included in the final sample (“all families” group), of whom 2.230 families were at increased risk for T2D (“high risk” group). High risk families were identified by using the FINDRISC.

2.4. Measurements

2.4.1. Anthropometric measurements

During the study, anthropometric indices of the children and the adult family members were taken. All measurements were conducted by trained research assistants, using standardized protocols and calibrated equipment.

Height: Height was measured twice in every session by the same research assistant, using a portable stadiometer (SECA 213, SECA 214, SECA 217 and SECA 225). A third measurement was taken if the measurements varied by 1cm. Volunteers were asked to remove their shoes, heavy clothing and hair accessories that could lead to false measurements. Then they were asked to stand in a natural position firmly on the stadiometer with their head positioned correctly so that the Frankfort horizontal plane is parallel to the ground.

Weight: Weight was measured twice in every session, by a trained examiner. A third measurement was conducted if the first two differed for more than 100gr. Measurements were conducted by using an accredited digital weight scale (either SECA 813 or SECA 877). Participants were asked to remove shoes, any heavy objects such as belts or keys, and heavy clothing. They were asked to stand in the center of the scale with their weight evenly distributed on both legs. The indication was recorded and rounded to the nearest tenth of a kilogram. The volunteers were categorized according to their BMI, which was calculated as the ratio of weight to the squared height (BMI=kg/m^2) (142).

2.4.2. Finish Diabetes Risk Score (FINDRISC) questionnaires

In total, 20.442 families were screened with the FINDRISC-questionnaire, which consisted of eight questions including the age, body mass index, waist circumference, daily activity levels, daily consumption of fruit and vegetables, history of use of anti-hypertensive medication, history of hyperglycemia and family history of T2DM. For a family to be classified as “high-risk”, at least one parent had to fulfill the country-specific cut-off point. (143)

2.5. Statistical Analysis

For the statistical analysis of the Feel4Diabetes data, SPSS 21.0 (SPSS: Statistical package for social sciences, SPSS Inc., Chicago, IL, USA) was used and the statistical significance level was set at $p \leq 0.05$. The categorical variables are presented as relative frequencies. To assess the possible associations between maternal or parental age, BMI, waist circumference, daily physical activity levels, daily vegetable and fruit consumption, history of high blood glucose, family history of diabetes, regular use of antihypertensive drugs and FINDRISC score with the child BMI, logistic regression was performed to extract crude odds ratios (Crude OR, 95% Cl). Moreover, multiple logistic regression was performed after adjusting for all variables, region and parental education to extract adjusted odds ratios, in order to identify all factors independently associated with childhood overweight and obesity (Adjusted OR, 95% Cl).

Receiver operating characteristic (ROC) analysis was used to assess the accuracy of maternal and paternal BMI and FINDRISC in detecting childhood overweight and obesity. The area under the ROC curves (AUC-ROCs) were plotted, while sensitivity (Se) and specificity (Sp) were calculated for each risk factor. The optimal cut-offs were determined by the point with the shortest distance to (0,1) in the ROC curve that maximizes the Se and Sp of the test. The distance for each observed cut-off was calculated as the square root of [(1-Se)2 + (1-Sp)2] (144). All reported p values were derived from two-sided tests and compared with a significance level of 5%. For the ROC analysis of the Feel4Diabetes data, MedCalc statistical software version 19.6.4 was used.

3. Results

3.1. Descriptive characteristics

The study sample consisted of 20,151 adults, of which 10967 were mothers and 9184 were fathers. In total, 10,967 children were included in the study, of which 1780 were overweight and 682 were obese. Participants' characteristics are shown in table 1.

Table 1a. Descriptive characteristics of the study sample - general

Characteristics of the study sample	N (%)
Region of family residence	
High income countries (Belgium, Finland)	2963 (27)
High income countries under austerity measures (Spain, Greece)	3623 (33)
Low/middle income countries (Bulgaria, Hungary)	4381 (39.9)
Children weight status	
Overweight	1780 (18.7)
Obesity	682 (7.2)
Maternal education	
≤9 years	789 (7.6)
10-14 years	3652 (34.9)
>14 years	6009 (57.5)
Paternal education	
≤9 years	816 (9.1)
10-14 years	3969 (44.1)
>14 years	4223 (46.9)

Table 1b: Descriptive characteristics -maternal and paternal risk factors

Risk factors	Maternal:N(%)	Paternal: N(%)
Age		
Under 45 years	9908 (90.3)	7146 (77.8)
Higher than 45 years	1059 (9.7)	2038 (22.2)
BMI		
Lower than 25 kg/m^2	7366 (67.2)	2918 (31.8)
25-30 kg/m^2	2410 (22)	4368 (47.6)
Higher than 30 kg/m^2	1191 (10.9)	1898 (20.7)
Waist circumference		
Less than 80cm (♀) / Less than 94cm (♂)	4474 (40.8)	3174 (34.6)
80-88cm (♀)/ 94-102cm (♂)	3708 (33.8)	3612 (39.3)
More than 88cm(♀)/More than102cm (♂)	2785 (25.4)	2398 (26.1)
Physical activity for at least 30 minutes daily		
Yes	8598 (78.4)	7231 (78.7)
No	2369 (21.6)	1953 (21.3)
Frequency of VFB consumption		
Every day	8034 (73.3)	6103 (66,5)
Not every day	2933 (26.7)	3081 (33,5)
Under regular antihypertensive medication		
No	10238 (93.4)	7881 (85.8)
Yes	729 (6.6)	1303 (14.2)
History of high blood glucose		
No	9473 (86.4)	8593 (93.6)
Yes	1494 (13.6)	591 (6.4)
Family members diagnosed with diabetes		
No	6442 (58.7)	5907 (64.3)
Grandparent, aunt, uncle or first cousin	2337 (21.3)	1404 (15.3)
Parent, brother, sister or own child	2188 (20)	1873 (20.4)
FINDRISC categories		
0-11	9690 (88.4)	7966 (86.7)
12-14	793 (7.2)	799 (8.7)
15-26	484 (4.4)	419 (4.6)

Table 1c: Descriptive characteristics -parental risk factors

Risk factors	Parental: N (%)
Age	
Both parents “Under 45 years”	6676 (76.2)
At least one parent “Higher than 45 years”	2084 (23.8)
BMI	
Both parents “Lower than 25 kg/m2”	2062 (23.5)
At least one parent “25-30 kg/m2”	4279 (48.8)
At least one parent “Higher than 30 kg/m2”	2419 (27.6)
Waist circumference	
Both parents “Less than 80 cm or 94 cm”	1703 (19.4)
At least one parent “80-88 cm or 94-102 cm”	3495 (39.9)
At least one parent “More than 88 cm or 102 cm”	3562 (40.7)
Physical activity for at least 30 minutes daily	
Both parents “Yes”	5927 (67.7)
At least one parent “No”	2833 (32.3)
Frequency of VFB consumption	
Both parents “Every day”	5293 (60.4)
At least one parent “Not every day”	3467 (39.6)
Under regular antihypertensive treatment	
Both parents “No”	7098 (81)
At least one parent “Yes”	1662 (19)
History of high blood glucose	
Both parents “No”	7106 (81.1)
At least one parent “Yes”	1654 (18.9)
Family members diagnosed with diabetes	
Both parents “No”	3628 (41.4)
At least one parent “Grandparent, aunt, uncle or first	2154 (24.6)
At least one parent “Parent, brother, sister or own child”	2978 (34)
FINDRISC categories	
Both parents 0-11	6807 (77.7)
At least one parent 12-14	1194 (13.6)
At least one parent 15-26	759 (8.7)

3.2. Associations between maternal and parental risk factors for type 2 diabetes and overweight and obesity in children.

Associations between maternal and parental (both maternal and paternal) risk factors for T2D with children's overweight and obesity are shown in tables 2 and 3.

Higher maternal BMI and waist circumference were strongly associated with a higher offspring BMI and these effects remained significant when taking into consideration all other variables, region, and maternal education. Daily consumption of VFB and regular use of antihypertensive medication by the mothers were associated with the children's BMI. However, when adjusting for all other variables, region and maternal education, these associations did not remain significant. In addition, no associations were found between maternal age, daily physical activity, history of high blood glucose (e.g. in a health examination, during an illness, during pregnancy) or family history of diabetes with offspring overweight and obesity. Moreover, a maternal FINDRISC score over 12 was significantly associated with offspring overweight and BMI even when adjusting by region and maternal education.

The presence of at least one overweight or obese parent in a household was positively associated with offspring overweight or obesity. More precisely, when at least one parent is obese the offspring is three times more likely to be overweight or obese, when adjusting for all other variables, region, and parental education. Similarly, increased parental waist circumference was associated with an increased risk of overweight and obesity in childhood. Parental physical activity for at least 30 minutes daily was not related to children's overweight and obesity, although when adjusting for all variables, region, and parental education, a small negative association was observed. In addition, daily VFB consumption, regular use of antihypertensive medication and history of high blood glucose by at least one parent were associated with childhood overweight and obesity. However, these effects did not remain significant when adjusting for all other factors, region, and parental education levels. Finally, the presence of at least one parent with a FINDRISC score of 15 and higher, was associated with 87% increased risk of childhood overweight and obesity.

Table 2. Associations between maternal risk factors for type 2 diabetes and overweight/obesity in children.

	Children's overweight and obesity			
Maternal risk factors	**Crude OR N=10,952**	**(95% CI)**	**Adjusted OR N=8.353**	**(95% CI)**
Age			*	
Under 45 years	1.000	Ref	1.000	Ref
Higher than 45 years	1.149	0.996-1.325	1.007	0.843-1.202
BMI				
Lower than 25 kg/m^2	1.000	Ref	1.000	Ref
25-30 kg/m^2	**2.038**	**1.839-2.258**	**1.792**	**1.555-2.064**
Higher than 30 kg/m^2	**3.127**	**2.751-3.556**	**2.640**	**2.176-3.203**
Waist circumference				
Less than 80 cm	1.000	Ref	1.000	Ref
80-88 cm	**1.584**	**1.425-1.761**	**1.403**	**1.230-1.601**
More than 88 cm	**2.402**	**2.154-2.679**	**1.464**	**1.233-1.739**
Physical activity for at least 30 minutes daily				
Yes	1.000	Ref	1.000	Ref
No	1.100	0.991-1.220	0.892	0.783-1.016
Frequency of VFB consumption				
Every day	1.000	Ref	1.000	Ref
Not every day	**1.364**	**1.241-1.500**	0.993	0.879-1.122
Under regular antihypertensive medication				
No	1.000	Ref	1.000	Ref
Yes	**1.354**	**1.149-1.594**	0.889	0.721-1.098
History of high blood glucose				
No	1.000	Ref	1.000	Ref
Yes	1.108	0.979-1.254	0.918	0.787-1.069
Family members diagnosed with diabetes				
No	1.000	Ref	1.000	Ref
Grandparent, aunt, uncle or first cousin	1.050	0.942-1.171	0.962	0.842-1.099
Parent, brother, sister or own child	1.102	0.986-1.231	0.958	0.835-1.099
FINDRISC categories			**	
0-11	1.000	Ref	1.000	Ref
12-14	**1,698**	**1.456-1.980**	**1.544**	**1.284-1.857**
15-26	**1,690**	**1.393-2.051**	**1.599**	**1.272-2.009**

Ref: Referent category

Statistically significant odds ratios are indicated in bold font.

* Adjusted for all variables, region and parental education.

** Adjusted for region and parental education.

Table 3. Associations between parental risk factors for type 2 diabetes and overweight/obesity in children.

	Children's overweight and obesity			
Parental risk factors	**Crude OR N=8749**	**(95% CI)**	**Adjusted OR N=8171**	**(95% CI)**
Age			*	
Both parents "Under 45 years"	1.000	Ref	1.000	Ref
At least one parent "Higher than 45 years"	1.072	0.957-1.200	0.886	0.781-1.006
BMI				
Both parents "Lower than 25 kg/m^{2}"	1.000	Ref	1.000	Ref
At least one parent "25-30 kg/m^{2}"	**2.283**	**1.961-2.658**	**1.864**	**1.574-2.207**
At least one parent "Higher than 30kg/m^{2}"	**4.510**	**3.852-5.280**	**3.214**	**2.646-3.905**
Waist circumference				
Both parents "Less than 80 cm or 94 cm"	1.000	Ref	1.000	Ref
At least one parent "80-88 cm or 94-102	**1.693**	**1.444-1.984**	**1.335**	**1.121-1.590**
At least one parent "More than 88 cm or 102 cm"	**2.882**	**2.471-3.361**	**1.592**	**1.318-1.924**
Physical activity for at least 30 minutes daily				
Both parents "Yes"	1.000	Ref	1.000	Ref
At least one parent "No"	1.001	0.902-1.111	**0.826**	**0.733-0.930**
Frequency of VFB consumption				
Both parents "Every day"	1.000	Ref	1.000	Ref
At least one parent "Not every day"	**1.310**	**1.187-1.446**	1.029	0.921-1.150
Under regular antihypertensive medication				
Both parents "No"	1.000	Ref	1.000	Ref
At least one parent "Yes"	**1.419**	**1.260-1.598**	1.087	0.948-1.247
History of high blood glucose				
Both parents "No"	1.000	Ref	1.000	Ref
At least one parent "Yes"	**1.249**	**1.107-1.410**	1.105	0.967-1.264
Family members diagnosed with diabetes				
Both parents "No"	1.000	Ref	1.000	Ref
At least one parent "Grandparent, aunt, uncle or first cousin"	0.924	0.815-1.048	0.928	0.808-1.066
At least one parent "Parent, brother, sister or own child"	1.050	0.939-1.175	0.964	0.853-1.091
FINDRISC categories			**	
Both parents 0-11	1.000	Ref	1.000	Ref
At least one parent 12-14	**1.586**	**1.385-1.816**	**1.482**	**1.283-1.711**
At least one parent 15-26	**1.914**	**1.631-2.246**	**1.868**	**1.577-2.212**

Ref: Referent category

Statistically significant odds ratios are indicated in bold font.

* Adjusted for all variables, region and parental education.

** Adjusted for region and parental education.

3.3. Maternal and paternal BMI and FINDRISC score in detecting childhood overweight and obesity.

The following figures represent the ROC curves for childhood overweight and obesity for maternal BMI and maternal FINDRISC score (Fig.1), paternal BMI and paternal FINDRISC score (Fig.2) and all the above-mentioned factors together (Fig.3). The AUC-ROC for detecting childhood overweight and obesity was 0.638 (95% Cl: 0.628-0.647) for maternal BMI vs 0,586 (95% Cl: 0.577-0.596) for maternal FINDRISC score and 0.632 (95% Cl: 0.622-0.642) for paternal BMI vs 0.594 (95% Cl: 0.584-0.604) for paternal FINDRISC score.

When examining the prognostic performance between maternal BMI and maternal FINDRISC score, BMI succeeded at a greater degree at identifying childhood overweight and obesity and this was statistically significant (p <0.0001). The same applies for paternal BMI and paternal FINDRISC score (p <0.0001). When examining all the above AUC-ROC curves, maternal BMI was significantly better than paternal FINDRISC score (p <0.0001) and paternal BMI was significantly better than maternal FINDRISC score (p <0.0001), at identifying childhood overweight and obesity. It is worth mentioning that no statistically significant differences in the AUC-ROCs were found between maternal and paternal BMI for childhood obesity (p= 0.3931). The same applies for maternal and paternal FINDRISC scores (p= 0.2707).

Figure 1. Receiver operating characteristic (ROC) curve for childhood overweight and obesity by maternal BMI and maternal FINDRISC

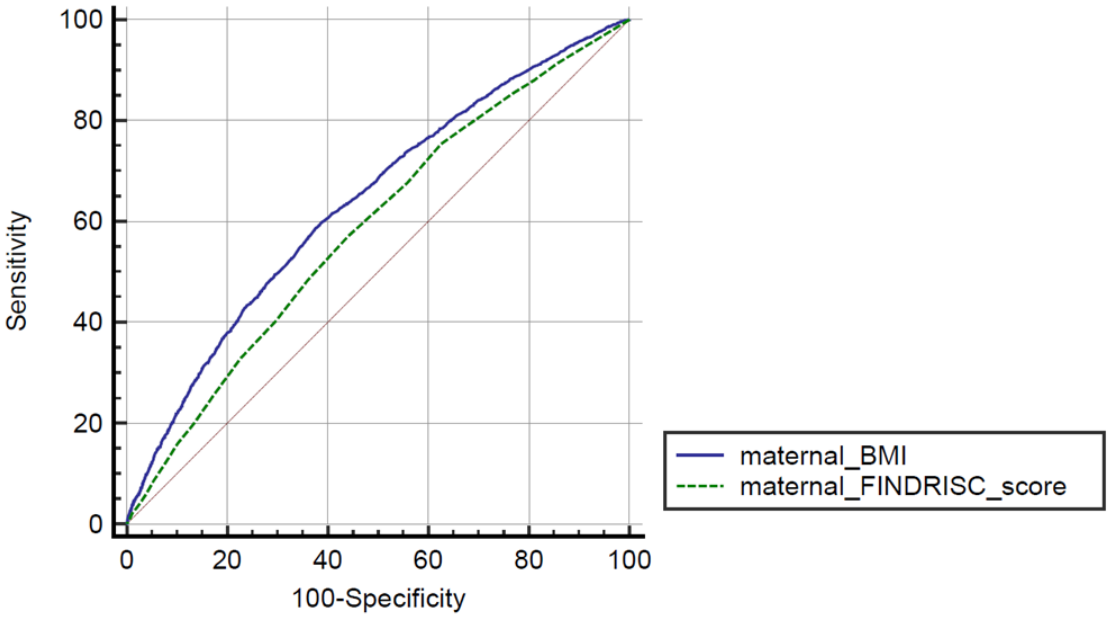


Figure 2. Receiver operating characteristic (ROC) curve for childhood overweight and obesity by paternal BMI and paternal FINDRISC

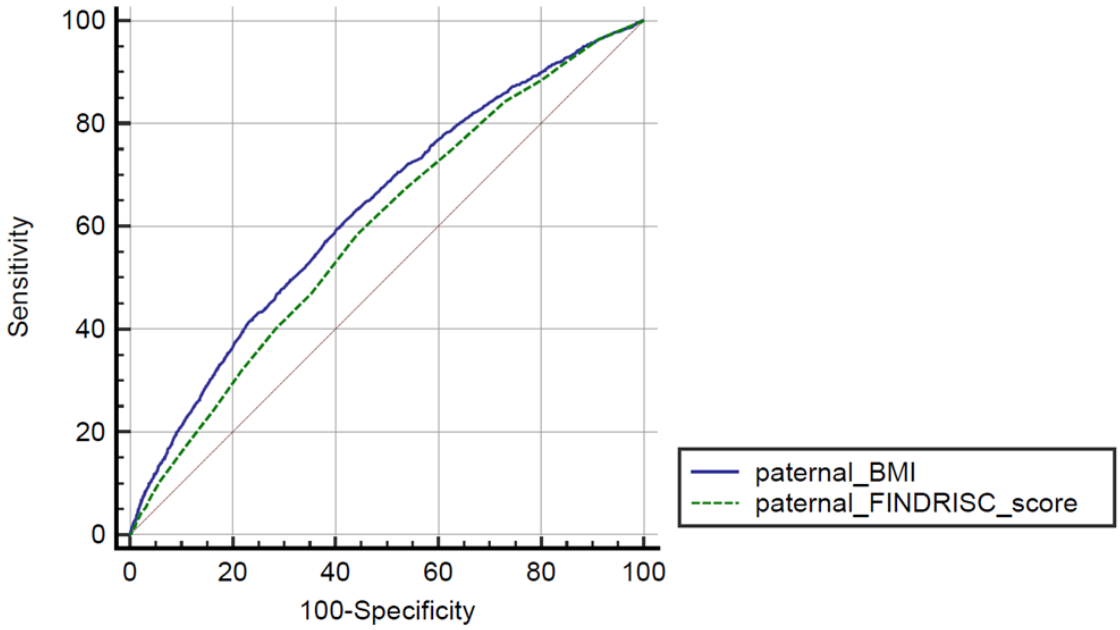
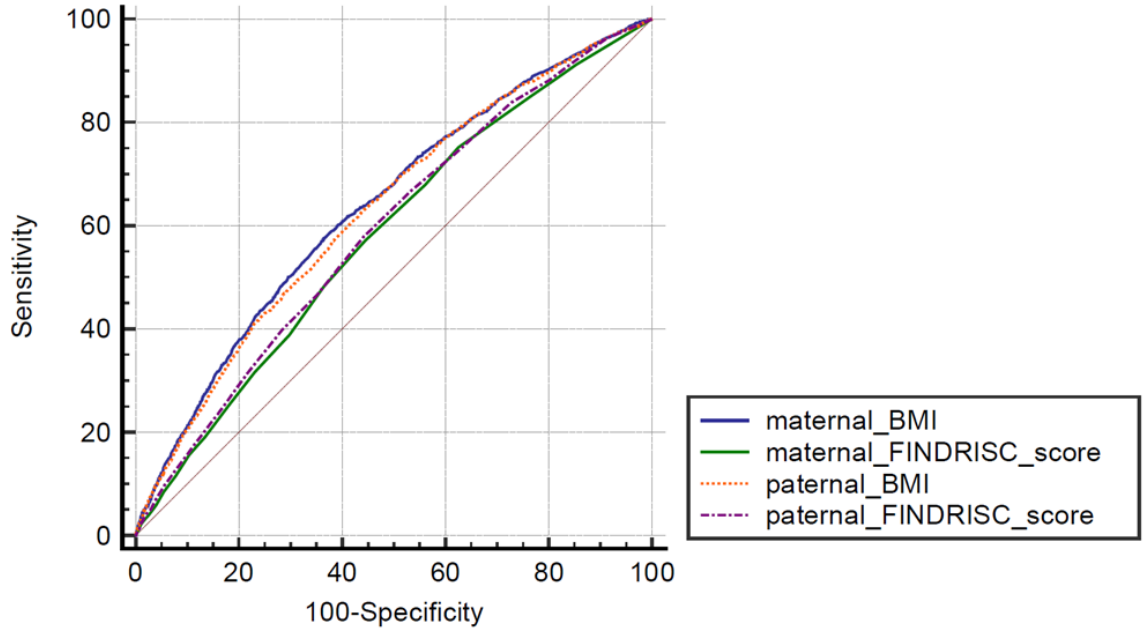


Figure 3. Receiver operating characteristic (ROC) curve for childhood overweight and obesity by maternal BMI and FINDRISC and paternal BMI FINDRISC.



4. Discussion

The study aimed to examine the association between maternal and parental (both maternal and paternal) risk factors for T2D and child overweight and obesity. The results underlined four principal findings. First, child overweight and obesity was significantly associated with maternal and parental weight status and waist circumference. Second, child overweight and obesity was associated with a maternal and paternal moderate to very high risk of developing diabetes, according to the FINDRISC score. Third, maternal and paternal BMI were the most significant predictors of childhood overweight and obesity. Fourth, maternal and paternal BMI were equally effective in predicting childhood overweight and obesity.

In more detail, the present study indicated that when at least one parent was obese the child was three times more likely to be overweight or obese, when adjusting for all other variables, region, and parental education. Similarly, parental abdominal obesity was associated with an increased risk of overweight and obesity in childhood. Weight status is a complex situation combining genetic, behavioral, and environmental factors, indicating family susceptibility of becoming obese. There are multiple possible explanations for the parent-child association in overweight and obesity. Firstly, common genetic predisposition puts parents and their offspring at similar levels of susceptibility for overweight and obesity (145). Secondly, obesogenic lifestyles can be passed down from parents to children (146). Thirdly, due to the shared living environment parents and children are exposed to the same obesogenic factors (147). Finally, another possible explanation is the fact that overweight mothers misperceive their children's excess weight problems compared to normal weight mothers (148). This mistaken maternal perception of offspring weight status is usually by underestimating the weight of overweight or obese children (149,150).

Moreover, a maternal FINDRISC score over 12 was significantly associated with offspring overweight and BMI even when adjusting by region and maternal education. Meanwhile, the presence of at least one parent with a FINDRISC score of 15 and higher, was associated with 87% increased risk of childhood overweight and obesity.

However, when examining parental history of high blood glucose, no association was found after adjusting for all other variables, region and parental education. The aforementioned result is

in contrast with other studies which suggest a higher prevalence of overweight and obesity in children of parents with diabetes, especially type 1 or gestational (100-103).

Parental age and children body weight status have also been studied previously with mixed results (41,151). In the present study, delayed parenthood was not associated with childhood obesity. However, due to an increasing trend in late parental reproductive age, further inquiry is needed.

Furthermore, daily VFB consumption by at least one parent was associated with childhood overweight and obesity, this effect however did not remain significant when adjusting for all other factors, region, and parental education levels. This weak association challenges the widely held belief that parents' VFB intake influences the children's VFB intake and thus their weight status (119-124).

Regular use of antihypertensive medication by at least one parent was associated with children overweight and obesity. Nevertheless, when adjusting for all other factors, this effect did not remain significant. This could be due to the fact that parental hypertension is correlated with parental overweight and obesity, which act as confounding factors (152).

Maternal daily physical activity was not associated with child weight status. However, when at least one parent was not physically active for at least 30 minutes daily, there was a small but greater chance that the offspring would be of normal weight status. The results from this study do not support the notion that active parents will yield active children by merely being active themselves. It seems that the parent-child behavior relationship is immensely complex. In fact, only when active parents model physical activity around their child, the child tends to be more active itself; while being active in the absence of the child may not provide the same opportunity for such modeling to occur (153). Meanwhile, parental support for children's physical activity might also have a stronger positive association with children's physical activity behavior (107,108).

Finally, of great interest are the results of the AUC-ROC analysis and most importantly, the fact that the FINDRISC score, is less effective than BMI in predicting childhood overweight and obesity. This is a novel finding, highlighting the fact that the FINDRISC score can be used as a predictive tool for childhood overweight and obesity, but still when compared with parental BMI it is less effective. Secondly, maternal and paternal BMI were able to predict at the same extent childhood overweight and obesity. To interpret this finding, the literature was examined, showing

no consistent differences between the strength of maternal and paternal BMI influences on offspring BMI. (154-158)

To the best of our knowledge, this is the first study that examines childhood obesity in the viewpoint of various parental risk factors for T2D in 6 different countries of Europe. This study has certain strengths and weaknesses. The large study sample, the standardized protocols and procedures followed across all centers and the objectively collected data (i.e. anthropometric indices) ensure more objective and reliable assessment and improve the generalizability of the findings. Conversely, most of the collected data is self-reported thus prone to recall and social desirability bias. In addition, due to the cross-sectional design of the present analysis, no temporal relationship and hence causal inferences can be established. Despite the limitations mentioned above, the reported findings deserve further attention for the development of effective strategies to fight childhood obesity.

5. Conclusion

After assessing various parental risk factors, maternal/parental overweight and obesity, especially central obesity and maternal/parental greater FINDRISC score remained the main significant predictors of childhood overweight and obesity. Of the aforementioned predictors, the most significant was BMI, with maternal and paternal BMI equally predicting a greater childhood BMI. Childhood overweight and obesity is an alarming public health problem worldwide, to which parents may have a pivotal role. It is therefore recommended that health promotion strategies and intervention programs should be family directed, to increase awareness on behavioral and lifestyle risk factors.

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