Effectiveness of mHealth interventions with and without medical nutrition therapy in improving dietary intake, physical activity, and gestational weight gain: A theory of planned behaviour – informed study among pregnant women in Malaysia

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ABSTRACT

Background and Objectives: Appropriate gestational weight gain (GWG) is vital for maternal and fetal health, with both inadequate and excessive GWG posing risks. This study evaluated the effectiveness of mHealth intervention, alone or with personalised medical nutrition therapy (MNT) using Theory of Planned Behaviour-based (TPB), in improving GWG, dietary intake, and physical activity among pregnant women in Malaysia. **Methods and Study Design:** This 6-month cluster randomized controlled trial involved 290 pregnant women assigned to control (standard care), mHealth alone, or mHealth combined with personalised MNT incorporating TPB dietitian consultation. Follow-up assessments were conducted twice for women recruited at ≤16 weeks' and once for those ≥17 weeks. Retention rates ranged from 70-85 % across groups. **Results:** Participants averaged 31 years old, with 91% having tertiary education; a high proportion presented with high pre-pregnancy body mass index and gestational diabetes. At the end of the intervention, the mHealth + MNT group had higher energy intake and improved nutrient adequacy. They also had significantly lower odds of both inadequate (OR = 0.33, 95%CI: 0.14–0.80, $p = 0.013$) and excessive (OR = 0.28, 95%CI: 0.10–0.74, $p = 0.011$) GWG. Physical activity increased by 80 minutes/day in the mHealth group but declined in control and mHealth+MNT groups. This indicates mHealth alone enhances physical activity, while the addition of MNT improves GWG management through professional support. **Conclusions:** mHealth alone significantly improved physical activity but had limited impact on diet and GWG outcomes. The integration of MNT representing personalized, human-delivered care significantly enhanced nutritional outcomes and increased the likelihood of achieving adequate GWG, highlighting the need for professional support alongside digital tools.

Key Words: gestational weight gain, mobile health (mHealth), medical nutrition therapy, dietary intake, physical activity

INTRODUCTION

Gestational weight gain (GWG) is a critical determinant for maternal and infant health, with both excessive and inadequate GWG are associated with increased risks of complications and long-term obesity.[1, 2] Recent reviews show most pregnant women do not achieve the recommended GWG, with only 22.4% meet guidelines while 20.3% have inadequate and 57.3% excessive weight gain.[3] Regional variations are also evident, with the prevalence of inadequate GWG reported at 21 % in the U.S., 18 % in Europe, and 31% in Asia.[4]

Conversely, excessive GWG affects approximately 50% of women in both the United States and Europe, and 37% of women in Asia.[4] These findings underscore the global challenge of achieving optimal GWG and highlight the need for context-specific strategies to support healthy weight gain during pregnancy.

In Malaysia, while 30% of pregnant women achieved adequate GWG, 47 % experienced inadequate GWG and 23% had excessive GWG.[5] GWG patterns also vary by pre-pregnancy BMI, with most underweight (89.8%) and normal-weight (95.5%) women achieving inadequate to adequate GWG, whereas 44% of overweight and 52% of obese women had adequate or excessive GWG.[6] These findings reflect the global challenge of appropriate GWG and the need for culturally tailored interventions, as lifestyle factors including suboptimal dietary intake and low physical activity contribute to inappropriate weight gain.[1, 7] In addition, psychosocial barriers like low motivation and limited knowledge further hinder healthy behaviours.[8] Since these factors are modifiable, targeted behavioural interventions are essential.

Mobile health (mHealth) tools have emerged as scalable solutions to support health behaviour change during pregnancy.[9] mHealth combined with dietitian-led MNT and guided by the Theory of Planned Behaviour (TPB) can improve dietary habits by addressing key behavioural drivers like attitudes, norms, and perceived control.[10, 11] However, such evidence remains limited in Malaysia. Therefore, this study aimed to evaluate the effects of an mHealth intervention, with or without dietary counselling, on dietary intake, physical activity, and GWG among pregnant women.

The TPB posits that attitudes, subjective norms, and perceived control influence behavioural intentions and subsequent actions. These constructs have been used to guide the development of health behaviour interventions. In the context of mHealth and MNT, TPB-informed interventions have the potential to enhance behaviour change. In this study, TPB served as the conceptual framework to inform the design of the mHealth and MNT intervention and the including development of relevant its behaviour change strategies. However, evidence regarding the use of TPB-informed approaches in mHealth interventions for gestational weight gain remains limited.[12] Although mHealth interventions in maternal health have been studied, research in Malaysia remains limited. Furthermore, few studies have compared the effectiveness of mHealth alone versus mHealth combined with MNT on GWG, dietary intake and physical activity. This study addresses these gaps and aims to inform the development of future digital health strategies to improve pregnancy outcomes.

MATERIALS AND METHODS

Study population and recruitment

A cluster, community-based randomized controlled trial was conducted among pregnant women attending government health clinics, which were located regionally within the Klang Valley (Putrajaya and Selangor). The study was conducted in three government health clinics in Putrajaya and Selangor: Presint 9 Health Clinic, Presint 18 Health Clinic, and Seri Kembangan Health Clinic. Details of the clinic selection and randomisation procedures have been described previously in the published study protocol.[13] Briefly, eligible health clinics located within a 25-km radius of the Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, were considered for inclusion. The three selected clinics were randomly allocated to one of the three study arms: the mHealth-only intervention, the mHealth plus dietitian-supported intervention, or the control group, with one clinic assigned to each study arm. The clinics served as the unit of randomisation to minimise contamination between participants receiving different intervention models within the same clinic.

Accordingly, participants were allocated to the study arm corresponding to the clinic from which they were recruited. Potential eligible participants were identified from clinic attendance lists and medical records based on the predefined eligibility criteria. These individuals were subsequently approached, provided with information about the study, and formally screened for eligibility. Those who were eligible and agreed to participate provided written informed consent prior to enrolment. Recruitment continued at each participating clinic until the required sample size for the respective study arm was achieved.

This cluster randomised controlled trial evaluated a TPB-based mHealth intervention with or without dietitian-led nutrition therapy on diet, physical activity, and gestational weight gain in 290 pregnant women. Pregnant women attending routine antenatal care at selected government health clinics in intervention and control states were recruited. Potential participants were identified based on predefined inclusion and exclusion criteria and invited to provide written informed consent. Consenting participants downloaded the Ibu Sihat mobile application via a QR code with specific login code at no cost.

Eligibility criteria included Malaysian women aged 18–40 years, in the first or second trimester of a singleton pregnancy, any ethnicity and BMI category, with or without non-communicable diseases (e.g., diabetes mellitus with or without low-dose insulin, or hypertension), and access to a smartphone with internet connectivity. Sample size was calculated using Lemeshow's formula 14 with 95% confidence and 80% power, based on a pilot study reporting intervention group means of 11.19 (SD 22.04) at baseline and 22.66 (SD

29.39) post-intervention.[15] With 20% added for dropout, 294 participants were targeted (98 per group).

Ethical approval

Ethical approval was granted by Universiti Putra Malaysia Institutional Review Board (IRB) (JKEUPM-2022-072) and the Ministry of Health Malaysia (NMRR ID-22-00622-EPU [IIR]). Permissions were obtained from Selangor (JKNS/KA/Q-712/04-01 Jld 19[14]) and Kuala Lumpur/Putrajaya health offices (Bil. [41] dlm. JKWPKL/203/4 Bhg.13). Informed consent was obtained from all participants.

Study groups

Participants were allocated to one of three groups based on the health clinics they attended:

1. mHealth-only intervention: Standard antenatal care plus access to the Ibu Sihat app.
2. mHealth + MNT intervention: Standard antenatal care, Ibu Sihat app, and dietitian-delivered individualized counselling.
3. Control: Standard antenatal care only.

Intervention: Ibu Sihat Mobile Application

The Ibu Sihat ("Healthy Mom") mobile application was designed to support healthy lifestyle behaviours during pregnancy through structured education, self-monitoring, and personalized guidance. The app featured three components as shown in Appendix 1. It included modules on maternal nutrition, GWG monitoring, dietary tracking, physical activity, and psychosocial health, with embedded behaviour change strategies such as goal setting, self-monitoring, educational messages, and personalized feedback.

Content was tailored to participants' gestational stage and physical activity level (less active, moderately active, or active), ensuring relevance throughout pregnancy. Participants could access the app at any time and from any location, enabling continuous engagement. App engagement was assessed based on usage data, with participants recording an average session duration of 11 mins 22 sec as shown in Appendix 3. Through the app, participants were able to monitor GWG, track dietary intake, and access evidence-based guidance on healthy pregnancy and postpartum practices, management of common pregnancy discomforts, and strategies for achieving optimal weight and lifestyle behaviours.

The app design and the overall intervention were informed by the TPB, which posits that behavioural change is influenced by intentions shaped by attitudes, subjective norms, and perceived behavioural control. By enhancing attitudes toward healthy behaviours, strengthening perceived behavioural control through self-monitoring, and reinforcing adherence to recommended practices, the program aimed to promote healthy behaviours related to GWG, diet, physical activity, and blood glucose monitoring throughout pregnancy.

The intervention was informed by the TPB, which served as the conceptual framework for developing behaviour change strategies. TPB guided the intervention design rather than being formally tested, as its constructs were not directly measured in this study. Specifically, TPB principles informed the development of intervention components of Ibu Sihat mobile application, including goal setting, self-monitoring, educational content, and MNT counselling strategies aimed at supporting healthy lifestyle behaviours during pregnancy. The Ibu Sihat mobile application is a comprehensive digital intervention designed to promote healthy dietary behaviours, physical activity, and gestational weight management among pregnant women through integrated monitoring, education, and self-management tools.

Monitoring components

As shown in Appendix 2, the application incorporates multiple self-monitoring features to support behavioural tracking and adherence. A gestational weight gain monitoring module enables users to record weekly weight and visualize progression through graphical displays, allowing comparison with recommended weight gain ranges and early identification of deviations.

Dietary monitoring is facilitated through a personalized food intake tracking system. Users are provided with recommended daily energy intake and corresponding food group servings, and their actual intake is compared against these recommendations. The application also presents comparisons between reported dietary energy intake and individual energy requirements, along with summaries of servings consumed by food group. These features allow users to assess dietary adequacy and make informed adjustments.

In addition, the application includes physical activity recommendation based on participants' conditions. A gestational week tracking feature is also integrated, enabling users to follow their pregnancy progression and receive stage-specific information. A questionnaire module collects socio-demographic and pregnancy-related data to support personalized monitoring and feedback.

Educational components

The educational component provides evidence-based information to support informed decision-making. Nutritional education includes guidance on dietary intake during pregnancy, energy requirements, meal planning, and nutritional needs, as well as strategies to manage common pregnancy-related discomforts. Personalized diet recommendations further support healthy eating behaviours.

Physical activity education includes recommendations on safe exercises during pregnancy, such as strength and aerobic activities, along with guidance to reduce sedentary behaviour and practical suggestions including walking for health. Additional resources include a BMI calculation guide and recommend gestational weight gain ranges based on BMI categories. The application also highlights the risks associated with inadequate or excessive weight gain and provides explanations of physiological changes during pregnancy to enhance understanding of normal maternal adaptations.

Psychosocial health is addressed through information on emotional and psychological changes during pregnancy, as well as guidance on managing psychosocial well-being and recognizing potential warning signs. Overall, the Ibu Sihat mobile application delivers a multi-component intervention integrating monitoring and educational strategies across nutrition, physical activity, weight management, and psychosocial health to support optimal maternal outcomes.

Additional intervention: Medical Nutrition Therapy (MNT)

Participants in the mHealth + MNT group received individualized dietary counselling from trained dietitians during scheduled follow-up visits. Sessions included goal setting and recommendations based on nutritional status, GWG, and dietary intake. Supportive guidance and reminders reinforced recommended practices, strengthening subjective norms according to TPB principles.

Follow-up schedule

Participants were recruited during either the first or second trimester of pregnancy and followed up every three months. Those enrolled in the ≤16 weeks completed baseline, 3 months, and 6 months, whereas those enrolled in the 17-27 weeks completed only the baseline and 3-month assessments to ensure that all follow up assessments were conducted during pregnancy. Outcome measures were evaluated at the scheduled follow-up visits according to participants' trimester at enrolment.

Measurements

Data were collected using a pre-tested, bilingual (English and Malay) self-administered questionnaire, which comprised the following domains:

1. Sociodemographic and anthropometric data

Information on age, ethnicity, education, occupation, and household income was collected via structured questionnaires. Pre-pregnancy BMI was derived from self-reported weight and height; final pregnancy weight was extracted from clinic records.

2. Dietary intake and physical activity

Dietary intake of participants was assessed using three non-consecutive 24-hour recalls (2 weekdays and 1 weekend), conducted during baseline, mid- and late pregnancy by dietitian. Nutrient analysis was performed using Nutritionist Pro™, referencing the Malaysian Food Composition Database (4th Edition).[16] On the other hand, physical activity of the participants was measured using the validated Pregnancy Physical Activity Questionnaire (PPAQ), capturing frequency and duration across key domains. Physical activity data were categorized into household/caregiving, occupational, sports/exercise, transportation, and sedentary domains. Weekly energy expenditure (MET-h/week) was calculated by multiplying the reported duration of each activity by its intensity value. Intensity levels were classified as sedentary (<1.5 METs), light (1.5-3.0 METs), moderate (3.0-6.0 METs), and vigorous (≥6.0 METs). Total activity was expressed as the sum of MET-h/week across all intensities. Domain-specific contributions (household/ caregiving, occupational, transportation, and sports/exercise) were also computed.

Participants were classified into a binary variable: “sedentary/slightly active” versus “moderate/vigorous” activity. This classification was based on validated PPAQ cut-offs for pregnant populations,[17] ensuring that the categories reflect meaningful differences in physical activity levels during pregnancy. These measures were used to compare activity levels within and between groups across the three gestational stages.

3. Gestational Weight Gain (GWG)

Gestational weight gain was calculated as the difference between pre-pregnancy and final pregnancy weight, and subsequently classified according to the Institute of Medicine (IOM) 2009 BMI-based guidelines.[16]

Full methodological details are available in the registered study protocol (NCT05377151).[13]

Statistical analysis

Data were analysed using IBM SPSS Statistics (version 29.0), with statistical significance was set at p <0.05. Data distribution was assessed using skewness and kurtosis values. Descriptive statistics included means ± SD for numerical and frequencies (%) for categorical variables. Baseline differences between groups were assessed using one-way ANOVA for continuous variables and chi-square tests for categorical variables. Multinomial logistic regression assessed the intervention's effect on GWG and generalized estimating equations (GEE) were used to analyse dietary intake and physical activity, accounting for within-participant correlations due to repeated measurements over time. The GEE models included intervention group, time, and group-by-time interaction terms. Analyses were performed at the individual participant level using an available case approach, whereby participants with available outcome data at each assessment time point were included in the corresponding analyses.

As each of the three clinics was assigned exclusively to a single intervention arm, clinic and intervention effects were completely confounded and could not be separately estimated. Consequently, clinic-level clustering could not be accounted for in the statistical analyses. This limitation should be considered when interpreting the findings, as potential differences between clinics could not be distinguished from the effects of the intervention.

RESULTS

Of the 337 individuals screened in person, 290 were randomized according to the cluster randomization procedure, as shown in the CONSORT flow diagram (Figure 1). Of those, 176 (79.6%) completed two follow-up visits, while 52 (75.4%) completed one follow-up assessments were conducted at 12 weeks intervals. There was no statistically significant difference in attrition between the groups for either the one follow-up (p = 0.393) or two follow up assessments (p = 0.302). The smaller and unequal sample sizes at the 6-month follow-up were due to both the planned follow-up schedule and participant attrition. Therefore, the 6-month findings should be interpreted with caution.

Table 1 shows the baseline characteristics of pregnant women. As compared to the control group, the mHealth + MNT group was significantly older (F = 5.070, p = 0.007) and had a higher proportion of participants with intermediate household incomes (RM 4851–10,970) (χ^2 = 18.197, p = 0.001). Gestational diabetes was common, affecting almost one in five pregnant women. About 60%, 40%, and 45% of control, mHealth, and mHealth + MNT groups had normal pre-pregnancy BMI, with no significant differences across the groups (χ^2 = 10.224, p = 0.116). No significant differences were observed across the groups in highest educational level, ethnicity, current weight or height (p >0.05 for all). At baseline, there were significant differences between the groups in terms of energy, carbohydrate, protein, and fat intake, as shown in Table 2 and significant difference in total mean physical activity (Table 3). Given the potential influence of these variables on GWG, they were included as covariates in the multinomial logistic regression model.

Dietary intake of respondents is depicted in Table 2. At baseline, most participants across all groups fell short of RNI for energy. The control group had significantly higher mean energy (1677 ± 400 kcal) and carbohydrate intake (202.8 ± 56.3g) than other groups. Protein intake was higher in the control (61.9 ± 14.0g) and mHealth + MNT groups (61.9 ± 23.4g), than in the mHealth-only group (53.2 ± 19.6g) (F = 6.574, p = 0.002). Fat intake was also higher in the control group (68.5 ± 19.5g) (F = 22.625, p <0.001). Due to strong correlations with energy intake (carbohydrate: r = 0.902, fat: r = 0.891) and high variance inflation factors (carbohydrate: 9.864; fat: 8.206), these variables were excluded from subsequent analysis to minimise multicollinearity.

Table 3 presents the mean energy intake and the proportion of participants achieving the recommended nutrient intake (RNI) across the three study groups over time. At baseline, most participants did not meet the energy RNI, ranging from 86.7% in the control group to 93.8% and 93.7% in the mHealth and mHealth + MNT groups, respectively. Mean energy intake differed significantly between groups at Month-3 (p = 0.016) and Month-6 (p = 0.011), with the mHealth + MNT group recording the highest mean energy intake at both follow-up assessments. Consistent with this finding, by Month-6, 41.2% of participants in the mHealth + MNT group achieved the energy RNI, whereas none of the participants in the control or mHealth groups met the recommendation. Because there were no participants achieving the energy RNI in the control and mHealth groups at Month-6, the generalized estimating equation (GEE) interaction analysis for RNI achievement could not be estimated due to zero events in these groups.

Mean duration of physical activity was lowest in the mHealth + MNT group. This was coupled with the lowest proportion of mothers engaging in moderate-to-vigorous physical activity, suggesting a more sedentary baseline profile compared to the other physical activity level groups (Table 3). At the end of intervention, the PAL was significantly increased in the mHealth group, with 35.7% of participants engaging in moderate-to-vigorous levels. In contrast, the mean duration of physical activity decreased in the mHealth + MNT group, with none of the participants achieving moderate-to-vigorous activity. Adjusted analysis showed that the odds of engaging in moderate-to-vigorous physical activity at the end of intervention were significantly higher in the mHealth group compared to the control group participants in the mHealth group had significantly lower odds of being sedentary/slightly active at the end of the intervention than those in the control group (AOR = 0.31; 95% CI: 0.11–0.87; *p* = 0.038), indicating a greater likelihood of engaging in moderate-to-vigorous physical activity.

Table 4 presents weight gain and GWG outcomes as stratified by group. Mean weight gain was lowest in the control group and highest in the mHealth group. The highest proportion of women achieving adequate gestational weight gain (GWG) was observed in the mHealth + MNT group, followed by the mHealth group and the control group. Furthermore, multivariate analysis revealed that women in the mHealth + MNT group had significantly lower odds of both inadequate GWG (AOR = 0.33; 95% CI: 0.14–0.80, *p* = 0.013) and excessive GWG (AOR = 0.28; 95% CI: 0.10–0.74, *p* = 0.011) relative to the control group. In contrast, no significant differences were observed in the mHealth group for either inadequate (AOR = 0.58; 95% CI: 0.23–1.49, *p* = 0.258) or excessive GWG (AOR = 1.58; 95% CI: 0.61–4.06, *p* = 0.344) as compared to the control group (Table 5).

DISCUSSION

This study demonstrated that combining mHealth with professional support, including medical nutrition therapy, improved gestational weight gain and may have contributed to reducing the proportions of both inadequate and excessive gestational weight gain. However, many women still did not achieve the recommended weight gain, energy intake, or activity levels, highlighting the ongoing challenges of promoting healthy lifestyle behaviours during pregnancy.

The respondents in this study were in their early adulthood which was comparable with earlier local studies.[18, 19] The mean pre-pregnancy BMI in this cohort was higher than the Asian (21.24 kg/m²) and global mean values (23.08 kg/m²),[20] but comparable with previous local study. 6 This should be interpreted alongside the high prevalence of gestational diabetes mellitus (GDM) (16.6%), which exceeds rates reported among pregnant women in Singapore[21] and Japan.[22] This finding underscores the maternal health burden in Malaysia and is consistent with the well-established association between obesity and GDM risk,[23] while also indicating an increased risk of other complications, including hypertension[24] and preeclampsia.[25]

The current baseline energy intake (1511 kcal/day) was notably lower than a recent systematic review.[26] Higher intakes in the Americas (2228 kcal/day) and Eastern Mediterranean (2227 kcal/day) suggest suboptimal energy intake in the current study[26] and adequate energy intake during pregnancy is crucial to support fetal growth and maternal health.[27] At baseline, many pregnant women in this study did not meet recommended energy intake, similar to findings in Japan[28] and Iran.[26] Lower intake may reflect under-reporting or lack of awareness. Excessive GWG suggests some women compensate with extra calories, underscoring the need for careful assessment during pregnancy. By Month-6, most participants (86.5%) still did not meet the Recommended Nutrient Intake (RNI). Notably, 41.2% in the mHealth + MNT group met the RNI, while none did in the other groups.

Although a higher proportion of participants in the mHealth + MNT group achieved the RNI, mean energy intake did not differ significantly between groups at the end of pregnancy which consistent with Australian studies showing no significant diet improvement from smartphone app interventions.[29] However, an Irish study found that an intervention with dietitian support and the PEARS app significantly reduced daily energy intake compared to controls.[30] Therefore, larger studies with longer follow-up and more intensive dietitian support are warranted to confirm these findings. Although dietary intake was assessed using repeated 3-day (2 weekdays and 1 weekend day) 24-hour dietary recalls at each study time point, the present analyses focused primarily on energy and macronutrient intake. Future studies should also evaluate dietary quality, food group consumption, and micronutrient intake to provide a more comprehensive assessment of dietary changes during pregnancy.

At baseline, fewer than one-fifth of respondents engaged in moderate or vigorous activity. The mean total physical activity intensity in this cohort was 49% higher than that reported in China,[31] 37% and 17% higher than two local studies[5, 32] and 9% higher than European population.[33] However, activity levels were 6% lower compared to pregnant mothers in Indonesia.[34] Few pregnant women engaged in vigorous activity, likely due to safety concerns.[35] Overall physical activity declined during pregnancy, with higher sedentary levels than pregnant women in China[31] and Indonesia.[34] Regular physical activity during pregnancy offers many benefits, including lowering the risk of gestational diabetes,[36] hypertension[37, 38] and depression[39] while supporting healthy fetal growth. Thus, monitoring physical activity helps manage gestational weight gain and prevent complications.[38]

Despite mHealth intervention, there was no significant improvement in moderate or vigorous activity levels of the pregnant mothers. Over 85% of pregnant mothers in this study are working, limiting their activity due to busy schedules.[40] Pregnancy-related discomforts such as fatigue and lack of energy,40 nausea, pain and physical awkwardness due to weight gain[41] combined with the increased body mass and fetal growth[42] can significantly hinder physical activity. Nevertheless, women in the mHealth groups were less sedentary at Months-

3 and -6 than those in the control group after adjustment. Interestingly, physical activity improved more in the mHealth-only group than in the mHealth + MNT group, possibly because dietary counselling received greater emphasis during MNT or because behavioural barriers to physical activity remained difficult to overcome despite professional support. This aligns with an Irish study showing increased activity after mHealth intervention.[30] A Swedish study, however, found no significant difference in moderate-to-vigorous activity between groups at follow-up.[42]

The mean total GWG of respondents was aligned with Asian population but was lower than the global average of GWG.20 Only one-third of respondents met the recommended adequate GWG, consistent with findings from Indonesia[43] and previous local study.[44] Inappropriate GWG is common in Asian pregnant women, with only about 40% in Singapore[45] and 25% in Thailand[46] meeting recommended GWG, which is crucial for maternal and infant health.

The present findings suggest that combining mHealth with MNT provides greater benefits for GWG management than mHealth alone. The mHealth + MNT group showed the highest rate of adequate GWG, indicating that the combination of digital tools and professional nutrition support may improve adherence and outcomes. These findings align with earlier studies.[12, 47, 48] Additionally, a previous study reported that intervention group had a significantly lower rate of exceeding the prescribed GWG compared to the control group.[49] Together, these findings reinforce the value of multidisciplinary, digitally supported interventions for promoting healthy GWG during pregnancy.

However, our findings contrast with studies from Taiwan[50] and the US[51] which reported no significant improvements in GWG. These discrepancies may reflect differences in intervention intensity, intervention components, participant characteristics, or healthcare delivery models. These variations may result from differences in intervention intensity and components, suggesting that a combined approach of technology and human support could be more effective. Moreover, it is important to highlight that the former studies were led by either nurses[50] or lifestyle coach,[51] while the present study was led by a dietitian. As dietitians are specifically trained in medical nutrition therapy, their expertise in providing individualized nutritional assessment and counselling may have contributed to the more favourable GWG outcomes observed in this study.

The beneficial effect of the combined intervention may be attributed to the complementary roles of digital self-monitoring and individualized medical nutrition therapy. Dietitian support likely reinforced behaviour change through personalised counselling, goal setting, and regular feedback, complementing the self-monitoring functions of the mobile application. These findings are consistent with previous studies demonstrating that integrated mHealth and professional support improve gestational weight gain outcomes. Nevertheless, although nearly half of the women in the mHealth + MNT group achieved the recommended energy intake and appropriate gestational weight gain, most participants still did not meet the recommended physical activity levels. This highlights the complexity of behaviour change during pregnancy and suggests that future interventions should incorporate more intensive and tailored behavioural strategies to simultaneously improve dietary intake, physical activity, and gestational weight gain.

Limitations

A key limitation of the mHealth application in this study was the absence of daily alerts or reminders within the application, which may have affected user engagement and adherence to the recommended behaviours. Although average session duration was available as an indicator of engagement, more detailed adherence metrics, such as logging frequency and active days, were not captured. The absence of behavioural prompts may have limited participants' routine use of self-monitoring features, including dietary logging and physical activity tracking, thereby potentially reducing overall intervention engagement. Additionally, most of the data collected were self-reported, which introduces the possibility of recall and reporting bias. Although the application included structured input formats and guided prompts to enhance consistency and accuracy, self-reporting inherently relies on participant memory and honesty, which may affect the precision of the captured data. Furthermore, although the intervention was informed by the TPB, its core constructs were not directly measured. Future studies should assess these constructs as potential mediators to better understand the behavioural mechanisms underlying intervention effects.

The 6-month follow-up included smaller and unequal sample sizes because only participants recruited at ≤16 weeks of gestation were eligible for this assessment, as specified in the study design. Consequently, the precision and stability of the month-6 estimates may have been reduced, and these findings should be interpreted with caution. The GEE analysis for RNI achievement at month-6 could not be performed because some outcome categories contained zero observations, resulting in model instability. In addition, the analyses were conducted using a complete-case approach without imputation for missing data. Although the differing sample sizes across follow-up assessments were primarily due to the study design, complete-case analyses may still be susceptible to bias if participants with missing outcome data differed systematically from those with complete follow-up.

Furthermore, the generalisability of the findings may also be limited by the sociodemographic characteristics of the study population, which predominantly comprised participants with tertiary education, were of Malay ethnicity, and employed in the government sector. Therefore, the findings should be interpreted cautiously when applying them to pregnant women from different educational, ethnic, or socioeconomic backgrounds.

Lastly, differences in gestational age at enrolment resulted in varying durations of intervention exposure and numbers of follow-up assessments, leading to different sample sizes across time points. Although this was inherent to the study design, complete-case analyses may still be susceptible to bias if participants with missing follow-up data differed systematically from those with those with complete data. These limitations highlight areas for improvement in the design of future mHealth interventions to enhance both data reliability and user engagement.

Conclusions

This study highlights the potential of a hybrid intervention combining mobile health tools with dietitian-led medical nutrition therapy to improve maternal diet and gestational weight gain. Findings suggest digital interventions paired with professional support are more effective at driving meaningful behavioural change than stand-alone mHealth alone. Incorporating the Theory of Planned Behaviour underscores the importance of addressing psychosocial factors to improve nutrition interventions during pregnancy. This supports the growing evidence for multidimensional, theory-driven strategies in maternal health promotion. Given the scalability of mHealth, integrating such tools into routine maternal care may offer a practical and effective way to improve outcomes. Future programs should combine culturally tailored digital tools with personalized support to improve maternal and child health.

SUPPLEMENTARY MATERIALS

All supplementary tables and figures are available upon request from the editorial office, and are also accessible on the journal's webpage (apjcn.qdu.edu.cn).

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The authors declare no conflict of interest.

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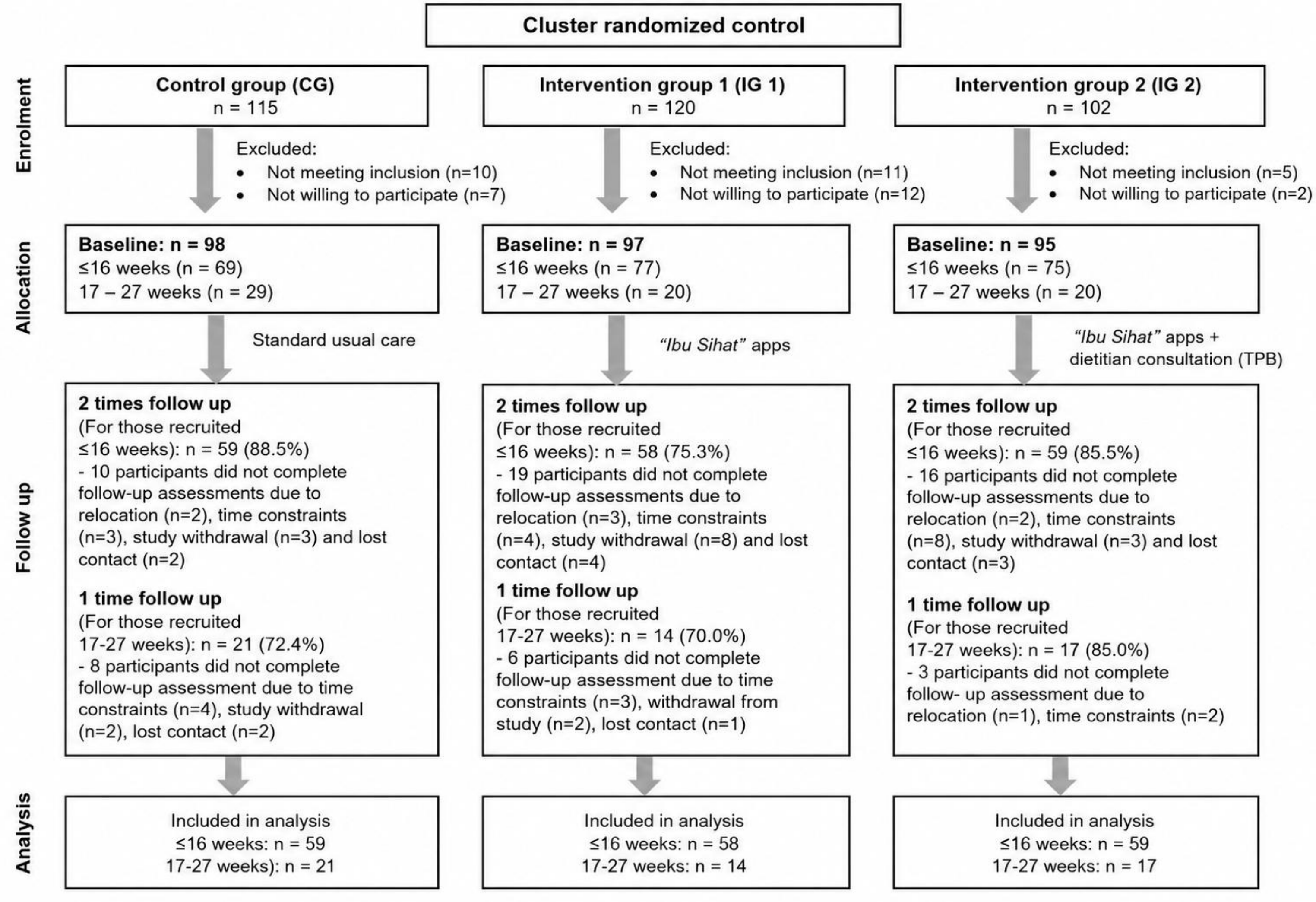


Figure 1. CONSORT diagram

Table 1. Sociodemographic characteristics and anthropometric data of participants at baseline (n=290)

Variable	Total (n=290) n (%)	Control (n=98) n (%)	mHealth alone (n=97) n (%)	mHealth + MNT (n=95) n (%)	$\chi^{2\ddagger}$/ $F^{\S}$	p value
Age (years)	31 ± 4	30 ± 4	31 ± 4	32 ± 4	5.070§	0.007*
Gestational age	221 (76.2)	69 (70.4)	77 (79.4)	75 (78.9)	2.750‡	0.253
≤16 weeks	69 (23.8)	29 (29.6)	20 (20.6)	20 (21.1)	6.678‡	0.154
17-27 weeks						
Highest educational level						
Primary education	2 (0.7)	1 (1.0)	1 (1.0)	-		
Secondary education	23 (7.9)	8 (8.2)	12 (12.4)	3 (3.2)		
Pre-university (High school) and above	265 (91.4)	89 (90.8)	84 (86.6)	92 (96.8)		
Ethnicity					1.963‡	0.375
Malay	278 (95.9)	92 (93.9)	93 (95.9)	93 (97.9)		
Non-Malay	12 (4.1)	6 (6.1)	4 (4.1)	2 (2.1)		
Working sector					18.708‡	<0.001*
Government	157 (54.1)	24 (24.5)	64 (66.0)	69 (72.6)		
Private company	85 (29.3)	43 (43.9)	26 (26.8)	16 (16.8)		
Self-employed	9 (3.1)	6 (6.1)	1 (1.0)	2 (2.1)		
Not working	39 (13.5)	25 (25.5)	6 (6.2)	8 (8.4)		
Total monthly household income					18.197‡	0.001*
≤ RM 4850	132 (45.5)	50 (51.0)	55 (56.7)	27 (28.4)		
RM 4851- RM 10970	145 (50.0)	45 (45.9)	37 (38.1)	63 (66.3)		
≥ 10971	13 (4.5)	3 (3.1)	5 (5.2)	5 (5.3)		
Presence of Diseases†					1.989‡	0.139
Diabetes Mellitus	2 (0.7)	1 (1.0)	1 (1.0)	-		
Gestational Diabetes Mellitus (GDM)	48 (16.6)	14 (14.3)	18 (18.6)	16 (16.8)		
Hyperlipidaemia	5 (1.7)	2 (2.0)	3 (3.1)	-		
Hypertension	2 (0.7)	1 (1.0)	-	1 (1.1)		
Others	26 (9.0)	15 (15.4)	4 (4.1)	7 (7.4)		
None	207 (71.4)	65 (66.3)	71 (73.2)	71 (74.7)		
Pre-pregnancy weight (kg)	60.0 ± 13.6	58.6 ± 12.3	62.0 ± 14.9	59.5 ± 13.4	1.70§	0.185
Current weight (kg)	62.5 ± 13.4	61.0 ± 12.4	64.9 ± 14.2	61.6 ± 13.2	2.410§	0.092
Height (m)	1.57 ± 0.06	1.57 ± 0.06	1.57 ± 0.06	1.56 ± 0.05	1.450§	0.236
Pre-pregnancy BMI (kg/m^2)	24.2 ± 5.7	23.6 ± 4.4	24.9 ± 6.0	24.0 ± 6.4	1.326§	0.267
Pre-pregnancy body weight status					10.224‡	0.116
Underweight	32 (11.0)	9 (9.2)	9 (9.3)	14 (14.7)		
Normal	140 (48.3)	58 (59.2)	39 (40.2)	43 (45.3)		
Overweight	72 (24.8)	20 (20.4)	30 (30.9)	22 (23.2)		
Obese	46 (15.9)	11 (11.2)	19 (19.6)	16 (16.8)		

RM: Malaysian Ringgit (MYR) (1 MYR was equivalent to 0.21 USD at the time of data collection)
Data were reported as Mean ± SD or n (%)

† multiple response; ‡ Chi square test; § ANOVA test
*p <0.05

Table 2. Baseline comparison of energy and macronutrient intake among the three groups (n=290)

Macronutrient (Mean ± SD)	Total (n=290)	Control (n=98)	mHealth alone (n=97)	mHealth + MNT (n=95)	F[a]	p value
Energy (kcal)	1511 ± 456	1677 ± 400	1390 ± 469	1463 ± 451	11.163	<0.001*
Carbohydrate (g)	190.4 ± 58.0	202.8 ± 56.3	175.5 ± 57.0	192.9 ± 58.0	5.695	0.004*
Protein (g)	59.0 ± 19.7	61.9 ± 14.0	53.2 ± 19.6	61.9 ± 23.4	6.574	0.002*
Fat (g)	57.2 ± 22.1	68.5 ± 19.5	51.9 ± 22.8	50.8 ± 19.2	22.625	<0.001*

† ANOVA test
*p <0.05

Table 3. Energy intake and physical activity levels across control and intervention groups over time, including achievement of Recommended Nutrient Intake (RNI)

	Control group	mHealth group	mHealth + MNT group	Between-group comparison		
				$\chi^{2\dagger}$ / F‡	p value	
Energy_intake						
Baseline (kcal/ day), Mean ± SD	1677 ± 400	1390 ± 469	1463 ± 451	10.856‡	<0.001*	Control at baseline
Not achieved RNI	85 (86.7)	91 (93.8)	89 (93.7)	3.435†	0.179	
Achieved RNI	13 (13.3)	6 (6.2)	6 (6.3)			
Month-3 (kcal/ day), Mean ± SD	1576 ± 344	1552 ± 332	1720 ± 448	4.180‡	0.016	mHealth group at month -3
Not achieved RNI	78 (97.5)	71 (98.6)	63 (82.9)	15.867†	<0.001*	mHealth + MNT group at month -3
Achieved RNI	2 (2.5)	1 (1.4)	13 (17.1)			
Month-6(kcal/ day), Mean ± SD	1498 ± 325	1351 ± 329	1895 ± 440	4.987‡	0.011	mHealth group at month-6
Not achieved RNI	21 (100)	14 (100)	10 (58.8)	8.276†	0.016	mHealth + MNT group at month-6
Achieved RNI	-	-	7 (41.2)			
Physical activity						
Baseline (minutes/ day) Mean ± SD	241.9 ± 138.5	250.7 ± 195.1	210.9 ± 119.5	4.643‡	0.010*	Control at baseline
Physical activity level (n, %)				2.202†	0.333	
Sedentary/ Slightly active	81 (82.7)	77 (79.4)	83 (87.4)			
Moderately active/ Vigorously active	17 (17.3)	20 (20.6)	12 (12.6)			
Month-3 (minutes/ day) Mean ± SD	189.5 ± 129.6	242.6 ± 201.7	216.2 ± 152.2	2.755‡	0.066	mHealth group at month-3 mHealth + MNT group at month-3
Physical activity level (n, %)				9.570†	0.008*	
Sedentary/ Slightly active	77 (93.9)	55 (76.4)	65 (85.5)			
Moderately active/ Vigorously active	5 (6.1)	17 (23.6)	11 (14.5)			
Month-6 (minutes/ day) Mean ± SD	184.3 ± 143.1	329.9 ± 247.9	159.1 ± 86.6	5.850‡	0.005*	mHealth alone at month-6 mHealth + MNT group at month-6
Physical activity level (n, %)				8.875†	0.012*	
Sedentary/ Slightly active	19 (90.5)	9 (64.3)	17 (100.0)			
Moderately active/ Vigorously active	2 (9.5)	5 (35.7)	-			

AOR: Adjusted Odds Ratio
†Chi square
‡ANOVA test
§Generalized Estimating Equation (GEE), Correlation matrix (unstructured), covariance matrix: robust estimator, sedentary/slightly active (reference outcome), Covariates: Age, mean haemoglobin value (baseline), mean sedentary activity value (baseline), mean energy intake (baseline), mean protein intake (baseline), working sector and total monthly household income
¶Time x group: there was no respondents in achieving RNI recommendation for both control and mHealth groups, therefore this variable was not able be analysed
††mHealth +MNT at month-6 intervention - there was no respondents in moderately active/ vigorously active level, therefore this variable was not able be analysed
**p* <0.05

Table 3. Energy intake and physical activity levels across control and intervention groups over time, including achievement of Recommended Nutrient Intake (RNI) (cont.)

	GEE	
	Time x Group AOR (95% CI)	p value
Energy_intake		
Baseline (kcal/ day), Mean ± SD	Ref§	
Not achieved RNI		
Achieved RNI		
Month-3 (kcal/ day), Mean ± SD	-¶	-¶
Not achieved RNI		
Achieved RNI		
Month-6(kcal/ day), Mean ± SD	-¶	-¶
Not achieved RNI		
Achieved RNI		
Physical activity		
Baseline (minutes/ day)	Ref§	
Mean ± SD		
Physical activity level (n, %)		
Sedentary/ Slightly active		
Moderately active/ Vigorously active		
Month-3 (minutes/ day)	0.32 (0.11-0.94)	0.026*
Mean ± SD	0.26 (0.03-2.26)	0.223
Physical activity level (n, %)		
Sedentary/ Slightly active		
Moderately active/ Vigorously active		
Month-6 (minutes/ day)	0.31 (0.11-0.87)	0.038*
Mean ± SD	- ††	- ††
Physical activity level (n, %)		
Sedentary/ Slightly active		
Moderately active/ Vigorously active		

AOR: Adjusted Odds Ratio
†Chi square
‡ANOVA test
§Generalized Estimating Equation (GEE), Correlation matrix (unstructured), covariance matrix: robust estimator, sedentary/slightly active (reference outcome), Covariates: Age, mean haemoglobin value (baseline), mean sedentary activity value (baseline), mean energy intake (baseline), mean protein intake (baseline), working sector and total monthly household income
¶Time x group: there was no respondents in achieving RNI recommendation for both control and mHealth groups, therefore this variable was not able be analysed
††mHealth +MNT at month-6 intervention - there was no respondents in moderately active/ vigorously active level, therefore this variable was not able be analysed
*p <0.05

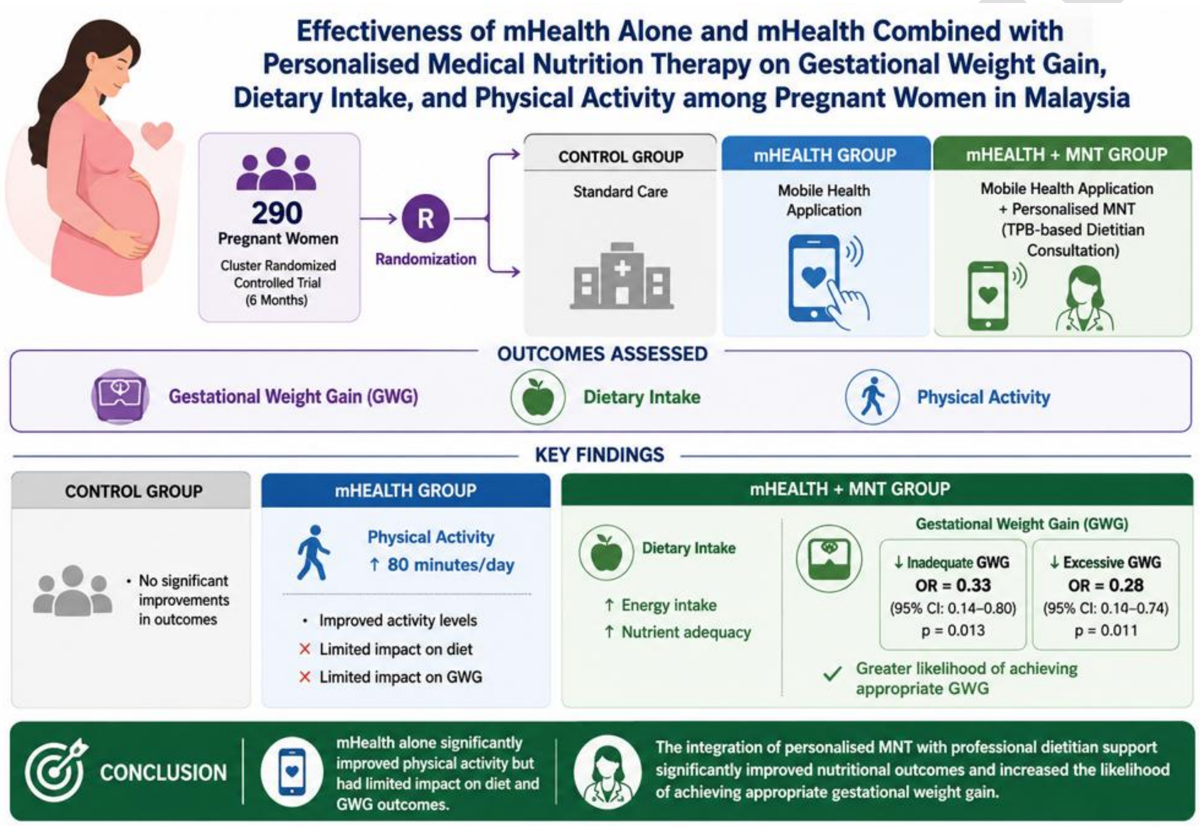
Table 4. Total weight gain and distribution of respondents according to achievement of GWG recommendation

	Total	Control group	mHealth alone	mHealth + MNT group
Total weight gain, Mean ± SD (kg)	11.76 ± 6.1	10.9 ± 6.1	13.4 ± 7.5	11.2 ± 4.5
Overall, n (%)				
Inadequate GWG	85 (34.8)	39 (45.9)	19 (25.7)	27 (31.8)
Adequate GWG	88 (36.1)	27 (31.8)	20 (27.0)	41 (48.2)
Excessive GWG	71 (29.1)	19 (22.4)	35 (47.3)	17 (20.0)

Table 5. Adjusted odds of inadequate and excessive gestational weight gain (GWG) by study groups

Group	Inadequate GWG		Excessive GWG	
	AOR (95% CI)	p value	AOR (95% CI)	p value
Control group	Ref		Ref	
mHealth group	0.58 (0.23-1.49)	0.258	1.58 (0.61-4.06)	0.344
mHealth + MNT group	0.33 (0.14-0.80)	0.013*	0.28 (0.10-0.74)	0.011*

AOR: Adjusted Odds Ratio, CI: Confidence Interval, Covariates: Age, mean haemoglobin value (baseline), mean sedentary activity value (baseline), mean energy intake (baseline), mean protein intake (baseline), working sector and total monthly household income
Reference category: Adequate GWG
* *p* <0.05



Graphical abstract.