Health-related behavior changes using IoHT for pregnant and postpartum women: From the Be-TWINKLE study

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Abstract

Prenatal care during pregnancy not only affects the woman's own health, but also has a significant impact on the unborn child, including the normal development of the fetus and safe delivery. The health status of the postpartum woman is also the foundation underlying emotional attachment to the baby and has a influence on child-raising going forward. However, there is a lack of healthcare services to maintain and promote the health of expectant and nursing mothers, and there is a need for services that are appropriately tailored to the actual living circumstances of most women, namely, services that can be used as needed, have a low burden, and are reliable. Therefore, this study developed a smartphone application (TEKUTECH) specialized to support the health of pregnant and nursing mothers and investigated whether there were any changes in attitudes and behaviors toward health maintenance and promotion among pregnant and nursing mothers. Sixty-five expectant and nursing mothers were given lifestyle advice to promote practices supportive of good health using a smartphone application for a period of 20 to 23 weeks (from mid-pregnancy to one month postpartum), and changes in their indoor and outdoor walking behavior, sun exposure, and nutritional intake were investigated. This paper introduces the functionality of the app, the overall design of the experiment using the app, the types of data collected, and the participants' impressions and ratings of the app.

Keywords

pregnant and postpartum women, Health-related behavior change support, Healthcare application

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1. Introduction

The aim of this study was to examine the effectiveness of a behavior change model using the Internet of Health Things (IoHT) for improving the health of pregnant and postpartum women. This project was conducted in collaboration with Keio University as the principal investigator, Juntendo University Nerima Hospital, KDDI Research Institute, Inc., the National Institute for Environmental Studies, and Sato Hospital. The project was named the “Be-TWINKLE study” (Behavior change by Trust Worthy information using INternet of health things from Keio sfc for Ladies Expecting babies).

1.1. Maternal health issues

Managing health during pregnancy is crucial, not just for the woman's own well-being but also for the proper development of the fetus and ensuring a safe childbirth, significantly influencing the child's future. In recent years, there has been an increase in the incidence of gestational diabetes, gestational hypertension, and the proportion of low-birth-weight infants (less than 2500g at birth), which are often linked to health management issues such as obesity, underweight, nutritional imbalances, and lack of exercise before and during pregnancy. To safeguard the health of pregnant women and their fetal development, it is vital to focus on nutritional management and encourage appropriate exercise before and during pregnancy. In addition, there is growing concern about the risk of rickets due to vitamin D deficiency in newborns and infants, prompting consideration of the benefits of sunlight exposure for pregnant women and their babies [1]. Preventive measures include ensuring adequate vitamin D intake during pregnancy and lactation, moderate sunlight exposure, and encouraging mothers to expose their infants to sunlight [1].

1.2. Self-care for pregnant and postpartum women

Over the past few years, there has been an increase in the number of smartphone apps being developed, and research using these apps has been aimed at improving the health of pregnant women and nursing mothers. For example, intervention studies have been conducted using the AI health advice app “CaloMama plus” to manage the health of thin or obese women during pregnancy [2]. Intervention studies have also shown a decrease in nutrient intake in obese women during pregnancy, with advice being given through an app to rectify this problem [3]. Support for the physical and mental health of pregnant and parturient women is becoming increasingly important, especially against the backdrop of an increase in low-birth-weight babies and depression among pregnant and parturient women. Therefore, this study developed an application specifically designed to transform and promote healthy behavior in pregnant women (walking, nutritional intake, and sun exposure) and examined its effectiveness.

In this study, we examined whether using IoHT and providing lifestyle advice to improve the health of pregnant and parturient mothers would influence changes in their health-related behaviors. The IMB model (Information-Motivation-Behavioral skills model) was adopted as a background psychological theory model (see Fig 1). The IMB model was developed in an attempt to explain HIV-related behavior change and continues to be used as a basic theory in various behavior change domains [4, 5]. Specifically, the IMB model attempts to explain behavior change based on three factors: “information,” “motivation,” and “behavioral skills." Regarding

the relationships among these factors, “information” and “motivation” are thought to not only have a direct impact on behavioral change but also bring about behavioral change through the mediation of behavioral skills [6]. In short, to improve health-related behaviors in pregnant women (walking, nutritional intake, sun exposure), we need to provide them with information, motivate them to maintain their health, and foster behavioral skills that enable them to adopt healthy behaviors. We consider this an effective approach.

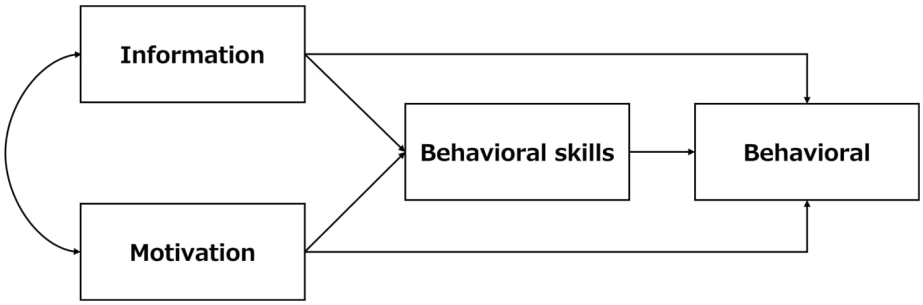

Figure 1: Information-Motivation-Behavioral skills model (Fisher and Fisher, 1992).

Therefore, with the aim of activating these factors and promoting health behavior change, the present study adopted methods commonly used as persuasion strategies [7] in healthcare research, such as self-monitoring, rewards, information provision, and information authoritativeness [8, 9].

Firstly, "self-monitoring" involves understanding and managing one's own actions, directing awareness toward her mental and physical states, observing the current state of her mind and body, and being attuned to perceiving them. The benefits include the ability to comprehend changes in her behavior, identify areas for improvement, and facilitate self-management and goal-setting [10].

Next, the effectiveness of "rewards" is a fundamental technique for controlling behavior and motivation through the traditional concept of "the carrot and the stick," which if frequently incorporated into many healthcare apps. In addition, the intervention strategy of "information provision" enhances behavioral skills through the presentation of relevant information, with an associated increase in her perceived self-efficacy.

Finally, "authority of information" is a psychological phenomenon where endowing information sources with "authority" results in the information being perceived as credible and valid, thereby positively influencing behavioral changes.

1.3. Purpose of this study

This study used the Internet of Health Things (IoHT)2 to investigate whether it is possible to promote health behaviors in healthy pregnant women. The goals include (1) developing a

[2] In this study, by using a smartphone-based healthcare solution, which is a type of IoHT, pregnant women were not only able to record their pregnancy progress and self-monitor but were also given advice information appropriate to the pregnancy period and information on health management. It is thought that knowledge, behavioral skills, and motivation will increase, leading to the promotion of healthy behavior among pregnant and nursing mothers.

specialized app for pregnant women and (2) conducting an intervention experiment using the app (to be used by participants between 20 weeks of pregnancy and one month postpartum). In particular, based on the hypothesis that authoritative information can positively influence change in health-related behavior in pregnant women, the information provided to participants is categorized into "health information with information sources explicitly stated as being from experts" and "health information without explicitly stating the source of the information," with the aim of finding out this results in a transformation of health-related behaviors.

However, due to space constraints on space in this paper, we limit (1) the discussion to introducing the development of the app and (2) summarizing the intervention experiment using it, as well as the feedback and opinions from participants after using the app. Any discussion of the transformative effects on health behaviors resulting from the intervention experiment is omitted.

Research ethics review: This study was conducted with the approval of the Juntendo University Medical (App Research Ethics Committee roval Number: E22-0265-N01).

Clinical trial registration: This study was registered as a clinical trial (UMIN Trial ID: UMIN000051235).

2. IoHT mobile application development

In this study, an iOS app named TEKUTECH (for pregnancy and postpartum health management application) was developed by KDDI Research, Inc. with the aim of promoting healthy behaviors in pregnant and postpartum women3. The TEKUTECH app was utilized in an intervention study targeting this population.

First, an explanation of the overall structure of the TEKUTECH app will be provided, followed by a description of the types of data that can be collected through the app.

2.1. Overall structure of the TEKUTECH application

This app is primarily composed of a home screen, weight and advice screen, mission screen, reward screen, and notification screen.

[3] This application is intended for research purposes only and is not intended to provide services for patients in the future.

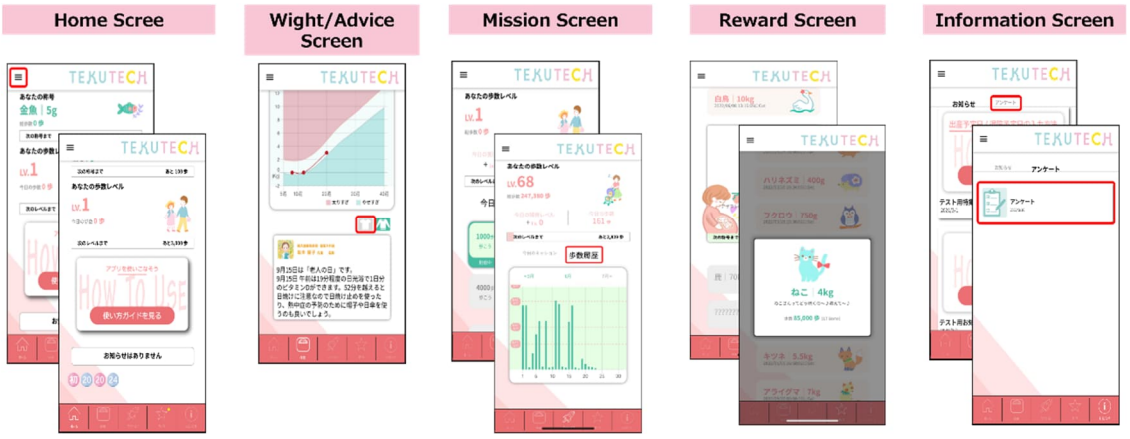

Figure 2: TEKUTECH app screens.

Home screen: On the "Home Screen," users can access a guide on how to use the app, the step levels, and the rewards earned from completing a mission. In addition, badges corresponding to completed surveys are displayed at the bottom of the screen. For example, when the survey for the 20th week is completed, a badge indicating the completion of that survey is displayed, allowing users to visually track their progress in the surveys. Furthermore, if there are notifications asking users to respond to a survey, pop-up banners appear on the home screen, and clicking on them guides users to the survey screen.

Weight and advice screen: On the "Weight and Advice Screen," the current gestational week and the remaining days until the expected delivery are displayed at the top of the screen.

Next, when the current weight is entered, the weight variation based on the initial weight in early pregnancy is displayed as a line graph on the "Pregnancy Weight Gain Curve" on the screen. This not only allows the user to observe wight changes but also enables comparison with the standard weight gain trend during pregnancy. Consequently, behavioral changes through self-monitoring, such as promoting self-management of weight during pregnancy and reassessing lifestyle habits, can be expected.

In addition, intervention advice information is displayed at the bottom of the screen, and there is a feature to aid in the choice of attire for the day (short sleeves/long sleeves). This allows for the presentation of intervention advice tailored to the user's attire.

Furthermore, these pieces of advice were tailored specifically for pregnant and postpartum women, encompassing messages aimed at promoting appropriate weight management, maintaining a healthy diet, and encouraging exposure to sunlight according to the gestational week. For example: "At 38 weeks pregnant: Protein, referred to as the 'main dish,' is an essential nutrient for building the body. (omission) Natto is an easily accessible 'main dish.' It is rich in high-quality protein, iron, and vitamin K, which are essential for bone formation. Vitamin K is also crucial during the newborn period. Considering breastfeeding, it is advisable to start consciously incorporating it into your diet from now on."

Mission screen: On the "Mission Screen," the number of steps taken on the current day is displayed, along with the corresponding step level. In addition, not only the step number for the current day but also the historical step records and achievement levels are presented in the

form of a bar graph. These features enable daily goal management and, through comparison with past performance, can lead to long-term self-management and motivation enhancement.

Reward screen: On the "reward Screen," specific titles are awarded based on the number of steps taken. Titles are represented by cute animal illustrations, accompanied by text expressed in a baby-like tone (e.g., "How does a cat meow?~♪. Tell me~♪"). This presentation creates a sense of the baby in the belly engaging in a conversation with the mother. Not only can users review past titles on the screen, but an upcoming title is also displayed. The goals for achieving the next title and the number of steps required to obtain it is also displayed. Such titles are acquired based on the number of steps taken, and this is expected to have a reward effect on participants. Additionally, information about subsequent titles is not shown on the screen until the next title is achieved. This absence of information contributes to the activation of participants' curiosity, fostering a psychological effect that encourages walking behavior. The most recently acquired title is also displayed similarly on the "Home Screen" and "Mission Screen," as mentioned above.

Information screen: The "Information Screen" is primarily composed of two sections, namely the "Announcement Screen" and the "Survey Screen," and screen transitions can be made by clicking buttons. First, the "Announcement Screen" contains details about how to use the app (e.g., "How to input weight" or "How to input the expected date of delivery/clinic visit date"). Next, on the "Survey Screen," entering a specified number will display the corresponding screen, allowing users to respond to the survey.

This app offers specialized features tailored for pregnant women, unlike typical health apps. These features include self-management of gestational weeks and due dates, monitoring weight fluctuations displayed on the "pregnancy weight gain curve," providing health advice tailored to pregnant and postpartum women based on gestational weeks, and acquiring illustrative images that give the sensation of interacting with the baby in the womb. It is believed that these features could contribute to improving the health issues faced by pregnant and postpartum women, such as nutritional imbalances, lack of physical activity, and vitamin D deficiency.

2.2. Types of data the App can collect

In this app, user behavioral data are collected within the permitted scope, including location information, Wi-Fi connection details, step count, and app operation history. When location information is recorded, the data are transmitted to the server. In the event of transmission failure, retransmission is attempted at the next recording interval. The details of the collected data are described below.

Location information: Location-related information includes the recording of GPS data and Wi-Fi access point information4. The recording occurs when the operating system detects the movement of the smartphone, and there is an approximate error of 100 m in the GPS data.

Step count: When recording location information, the step count from midnight to the current time is obtained using an API[5] and saved to a file.

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[4] In this study, the acquired location information is processed to prevent the identification of individuals and is used for effectiveness verification.

[5] To obtain walking data, This app uses the API called CMPedometer on iPhone to retrieve step counts.

App operation history: Every time a participant interacts with the app, their operation history is recorded.

3. Research method

3.1. Participants

This study recruited pregnant women who visited the Juntendo University Nerima Hospital, a collaborative research facility, between December 2022 and August 2023. A total of 69 individuals consented to participate in the study. However, 4 participants withdrew from the study based on the discontinuation criteria outlined below. Ultimately, the study focused on 65 pregnant women (mean age: 33.32 years, Standard deviation: 4.63). These participants met the eligibility criteria and were healthy pregnant women who did not meet any of the exclusion criteria.

Eligibility criteria: This study established the following criteria for eligibility: (1) Less than 20 weeks pregnant (15-19 weeks) at the time of obtaining consent; (2) A pre-pregnancy Body Mass Index (BMI) between 18.5kg/m2 and 24.9 kg/m2; (3) Singleton pregnancy; (4) Regular use of an iPhone; (5) Agreed to undergo all prenatal check-ups to 1 month postpartum at the research facility

Exclusion criteria: In this study, the following criteria were established for exclusion: (1) Individuals aged under 20 years; (2) Those with a multiple pregnancy; (3) Individuals not using an iPhone with iOS 14.1 or later; (4) Individuals diagnosed with diabetes before pregnancy or with evident diabetes during pregnancy; (5) Individuals with any other medical condition or complication requiring nutritional counseling; (6) Those with a pre-pregnancy BMI<18.5kg/m2 or BMI 25kg/m2; (7) Individuals unable to communicate in Japanese; (8) Cases where the attending physician deemed the individual inappropriate for inclusion in this study.

Discontinuation criteria: This study established the following criteria for discontinuation: (1) If a research participant expresses a desire to withdraw from participation or revokes consent; (2) If the entire study is discontinued; (3) In the opinion of the principal investigator and research collaborators, it is deemed appropriate to terminate the study.

3.2. Study period

The research period for this project extended from the research implementation approval date at each collaborating institution to September 30, 2025. Within this time frame, the registration and observation periods for the study participants were as follows:

- Registration Period: December 17, 2022, to October 31, 2023
- Observation Period: December 17, 2022, to September 30, 2024

The study participants received intervention through the TEKUTECH app from the day consent was obtained for participation in the research until postpartum. At the one-month postpartum check-up, an explanation regarding the conclusion of research participation was given, and the participant was thanked for engaging in the study, marking the conclusion of the study.

3.3. Study design

This study was conducted based on the research implementation plan and was divided into three periods: “pre-intervention,” “during intervention,” and “post-intervention” (see Fig 3).

3.3.1. Pre-intervention

During the pre-intervention period (up to weeks 16-19 of pregnancy), we recruited eligible pregnant women at Juntendo University Nerima Hospital to participate in the research. The recruitment procedure included confirming eligibility, explaining the study, obtaining consent, and installing an intervention app for data collection (e.g., step counts, questionnaires). We distributed the study information and consent documents through physicians, and participants watched a video summarizing the study. After obtaining consent, we confirmed app terms, explained features through a manual, and guided participants on how to install the app. We informed participants that the app would collect usage history, GPS location, step counts, and questionnaire responses and reassured them that their anonymity would be protected when location data were processed.

3.3.2. During intervention

During the intervention period (week 20 of pregnancy until childbirth), activities involved grouping participants, measuring various data on physiology, behavior, psychology, and health, and responding to participant inquiries. Eligibility criteria were confirmed before week 20, and participants were randomly assigned to two groups (with or without authoritative information) using the block substitution method. This method involved creating blocks of four items, generating six random patterns, and randomly assigning participants. The allocation was managed by KDDI Research Institute, ensuring blinded interactions at Juntendo University Nerima Hospital, which only received participant numbers without group assignment information.

The intervention, started at week 20 of pregnancy and continued for approximately 5 months until childbirth, while similar advice messages were given to both groups. However, the group with authoritative information received messages accompanied by an illustrative image of the information source, unlike the group that did not receive authoritative information, which underwent the intervention without knowledge of the source.

The intervention advice is based on the IMB model and consists of elements related to “information,” “motivation,” and “behavioral skills” for weight management, dietary habits, and sun exposure, respectively (see Fig 1). The information advice included guidance on appropriate weight (BMI) during pregnancy, foods containing vitamin D, and the effects of sunlight exposure. The motivation advice included messages to increase motivation for proper weight management, healthy dietary habits, and sun exposure. The behavioral skills advice included effective methods for achieving proper weight management, maintaining a healthy diet, and practicing sun exposure.

The intervention advice, totaling 99 separate pieces of advice, was created to be provided over a period of 22 weeks (from week 20 to week 41 of pregnancy). The breakdown includes 66 pieces of advice for weight management (3 weight categories: low/standard/high×22weeks), 22

for dietary habits, 9 for sun exposure (3 time periods: 0:00-12:29/12:30-17:29/17:30-23:59×3 weather conditions: sunny/cloudy/rainy). The advice for health management and dietary habits was developed by a health informatics expert from Keio University Graduate School (4th author in this paper), and the sun exposure advice was created by an orthopedic surgeon from Juntendo University Nerima Hospital Orthopedic Department (3rd author in this paper). All contents were overseen by Sato Hospital.

Sun exposure recommendations were adjusted based on seasons categorized into three types: May to September (months with strong UV rays), April and October (months with moderate UV rays), and November to March (months with weak UV rays). Taking into account factors such as clothing (short/long sleeves) and weather conditions (sunny/cloudy/rainy), the recommended sun exposure time contained in intervention messages was modified[6]. For example, on a sunny day in September with strong UV rays, if wearing short sleeves, the recommended sun exposure time is approximately 10 min, while wearing long sleeves on the same day would suggest a relatively longer sun exposure time of around 19 min.

3.3.3. Post-intervention

The post-intervention period comprised the month following childbirth, during which app-generated behavioral data and survey responses were continuously collected. However, the provision of intervention advice through the app was discontinued. Specifically, when Juntendo University Nerima Hospital provided participant childbirth information to the KDDI Research Institute, the system registered the childbirth information. As a result, participants received a message on the app saying, “Congratulations on the birth of your child,” and the advice provided during pregnancy was hidden.

[6] The sun exposure duration for long-sleeved attire was calculated by categorizing the recommended past ultraviolet exposure times derived from environmental research. This utilized minute-by-minute data from November 21, 2013, to December 31, 2019, in Tsukuba, Japan. The data were classified on the basis of various conditions such as month (12 months), time of day (morning, afternoon), and weather conditions (clear, cloudy, rainy). Median values were then computed. Subsequently, when corresponding to the conditions of month, weather, and time, the respective median values were presented as the recommended sun exposure duration. For short-sleeved attire, half of the corresponding median value was suggested as the sun exposure duration.

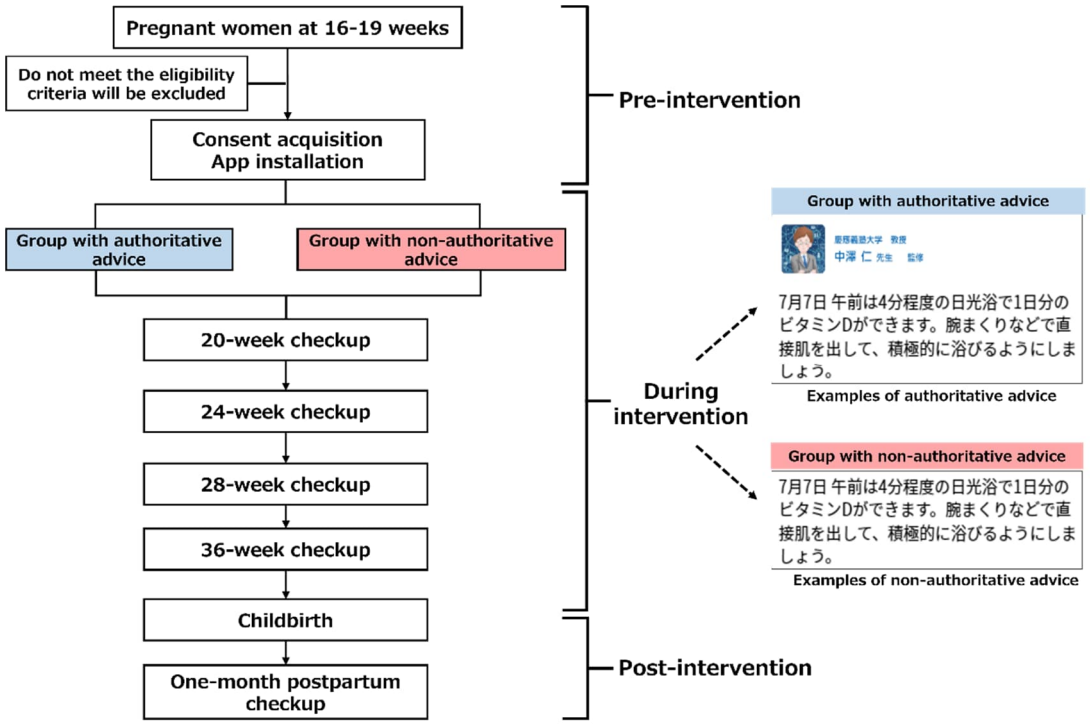

Figure 3: Study design[7]

3.4. Collected data

During the period from the date of obtaining research participant consent (at the 16th to 19th week prenatal check-up) to the one-month postpartum check-up, various data were collected. The data were categorized into those directly obtained at Juntendo University Nerima Hospital and those acquired through the app.

3.4.1. The data collected at the hospital

At Juntendo University Nerima Hospital, various data were collected, including physiological data (e.g., blood tests, bone density, weight, body composition, blood pressure measurements), dietary and nutrition information, paper-based surveys, and foundational pregnancy data (medical records).

(A) Physiological data

Blood test: During routine prenatal check-ups, blood samples were collected for hemoglobin analysis. And another 10 ml of blood was used for serum albumin, serum alkaline phosphatase, serum zinc, serum intact parathyroid hormone, serum 25-hydroxyvitamin D [s25(OH)D], serum

[7] Translation of advice in the figure:On the morning of July 7, approximately 4 min of sunbathing can produce a day's worth of vitamin D. Let us expose our skin directly, such as by rolling up sleeves, and actively soak up the sun.

calcium, and serum phosphorus. s25(OH)D was also analyzed using 3ml of blood collected from the umbilical cord at the time of delivery.

Bone density measurement: We measured bone strength of calcaneus by quantitative ultrasound (QUS) measurements of bone speed of sound (SOS). The measurement, lasting approximately 3 minutes, [A-1000EXP, GE Healthcare Japan].

Body composition measurement: During the waiting time at the prenatal check-up, we used a bioelectrical impedance analysis (BIA) method body composition analyzer (The Tanita Professional Body Composition Analyzer, MC190EM) to measure the body fat percentage, fat mass, and lean body mass for the whole body and specific regions. The measurement took approximately 30 seconds.

Weight and blood pressure: During the waiting period for the prenatal check-up, we measured weight and blood pressure using hospital scales and blood pressure monitors.

(B) Paper-based questionnaire survey

Dietary and nutritional data: During the waiting period for prenatal check-ups, participants were asked to respond to a paper-based, self-administered questionnaire, specifically, the Brief-type Self-Administered Diet History Questionnaire (BDHQ) [11]. During the 1-month postpartum checkup, to shorten the length of hospital stay, the participants took the questionnaire home, answered it, and returned it via a reply-paid envelope. The completion of the questionnaire required approximately 20 min.

Japanese version of the Edinburgh Postnatal Depression Scale (EPDS): The scores from the Edinburgh Postnatal Depression Scale (10 items) questionnaire [12] administered during the 1-month postpartum checkup were extracted from the electronic medical records.

Mother-to-Infant Bonding Scale (MIBS): Administered under the guidance of a midwife during prenatal checkups, the questionnaire includes 10 items such as “feeling affectionate towards the baby” and “feeling irritated by the baby.” Reactions were measured on a 4-point scale, with higher scores indicating stronger negative feelings toward the baby [13]. In particular, in cases of elevated negative emotions, the midwife provided psychological counseling.

(C) Basic pregnancy-related data

Obtained recorded data from medical records including delivery date, pre-delivery weight, delivery method, bleeding volume, newborn’s length and weight, gender, infant’s survival status, presence of gestational diabetes, and presence of gestational hypertension (with information on antihypertensive medication if applicable).

3.4.2. The data collected from the app

Next, we obtained behavioral data (e.g., step counts and app usage history) and survey response data (time spent outdoors, sun exposure, bone literacy, psychological factors, feedback on research participation etc.) through the app.

(D) Behavioral data

The app logs measure location data (GPS and Wi-Fi connect information), step counts, and usage history of the TEKUTECH app. Using this data enables the calculation of the following behavioral metrics.

Location data: Using GPS and Wi-Fi connected information from the device, the participant's location data were obtained, allowing determination between indoor and outdoor settings (at home and outside). With these data, it became possible to calculate outdoor duration and frequency. Moreover, when combined with step count records, it enabled the calculation of the number of steps taken indoors and outdoors. Additionally, by combining location data with outdoor time data, daily UV exposure can be calculated[8], contributing to the verification of the effects of sun exposure on the participants.

Step count records: These records can be used to examine variations in the walking behavior of pregnant and postpartum women and to assess the effectiveness of interventions.

App viewing frequency: Data from the TEKUTECH app's browsing history make it possible to calculate the frequency of viewing each screen, thereby providing a means to assess the effectiveness of interventions.

(E) App-based survey

UV exposure survey: A retrospective survey lasting approximately 1 min was conducted to ascertain the time participants usually spent outdoors and sunscreen cream usage. This data, combined with data on the presence or absence of outdoor activities and the duration of outdoor exposure calculated from app logs, will enable the verification of the intervention effects of a participant's sun exposure.

Bone literacy survey: A unique set of questions was created to measure knowledge and behaviors related to bones, and a response survey lasting approximately 1 min was conducted.

Self-Care Motivation Scale: The Self-Care Motivation Scale [14] was used to measure the motivation for self-care related to overall health. For example, items such as "I am willing to try to be healthy" and "To be healthy, it is important to be patient" were measured using a 6-point scale with 4 items. Higher scores indicate higher motivation.

Self-Management Skills Scale: The Self-Management Skills Scale [15] was used to measure self-management related to health. Items such as "When trying to do something, gather enough information" and "When executing something, make your own plan" were measured using a 4-point scale with 10 items. Higher scores indicate higher self-management skills.

Evaluation and feedback after study participation: In the final 1-month postpartum survey, additional items were included to assess participants' feelings during app usage. Specifically, the following items were measured using a 5-point scale: (1) Was the advice helpful? (2) Was the advice reliable? (3) Did the advice feel like it came from an expert? (4) Was the content of the advice easy to understand? (5) Would you want to use this app again in a future pregnancy?

Higher ratings indicate a more positive evaluation. The results are presented in Figure 5 in the order of usefulness, reliability, expertise, understandability, and future use. in addition, participants were asked if they took action on the basis of the advice (4-point scale). Finally,

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[8] The ultraviolet exposure level is an indicator that represents the extent to which an individual has been exposed to ultraviolet radiation.

participants were free to provide comments on what they liked and any difficulties encountered during their participation in the study.

3.5. Data acquisition

The timing of data acquisition for various types of data is shown in Figure 4.

Data Types	Items Implemented	Pre-intervention	During intervention					Post-intervention
		16-19 weeks	20-week	24-week	28-week	36-week	Childbirth	Postpartum 1 Month
Physiological Data	Vitamin D	-	-	●	-	●	●	-
	Intact PTH	-	-	●	-	●	-	-
	Alkaline Phosphoatase	-	●	-	●	●	-	●
	Zinc	-	-	●	-	●	-	-
	Bone Density Measurement	-	●	●	●	●	-	●
	Body Composition Measurement	-	●	●	●	●	-	●
Behavioral Data	App Log Tracking	●	●	●	●	●	●	●
Survey Data	Brief-type Self-Administered Diet History Questionnaire (BDHQ)	-	●	●	●	●	-	●
	UV Exposure Survey	-	●	●	●	●	-	●
	Bone Literacy Survey	●	●	-	●	● (34-week)	-	●
	Self-Care Motivation Scale	●	●	-	●	● (34-week)	-	●
	Self-Management Skills Scale	●	●	-	●	● (34-week)	-	●
	Edinburgh Postnatal Depression Scale (EPDS)	-	-	-	-	-	-	●
	Mother-to-Infant Bonding Scale (MIBS)	-	-	●	-	-	-	●

Figure 4: Measurement Timing for Various Data.

4. Results and discussion

In this study, we developed the TEKUTECH app specifically for pregnant women to promote healthy behaviors. The intervention targeted pregnant women from mid-pregnancy to 1 month postpartum, covering approximately 20-23 weeks. Due to space constraints, we omit the details of the intervention's effects on changing maternal health-related behavior. Instead, this paper focuses on the assessments and feedback from participants who used the app. Specifically, we compiled responses from 36 participants who completed the postpartum 1-month survey by October 31, 2023. As shown in Figure 5, the average ratings based on the app users' assessments exceeded the midpoint of 3 (neither agree nor disagree), indicating a relatively positive trend in participant evaluations.

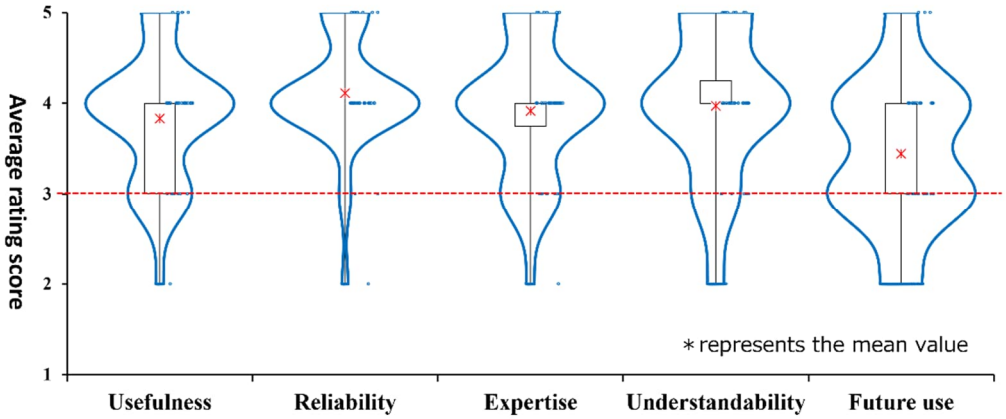

Figure 5: Participant evaluation after using the app.

Next, feedback after usage was categorized into positive aspects and challenges. First, regarding positive aspects, four main dimensions were identified:

- Acquisition of Knowledge and Information: Participants highlighted gaining necessary information and acquiring new knowledge (e.g., “I obtained the information I needed” and “I gained new knowledge.” 9 responses).
- Increased Health Awareness: Users reported heightened awareness of health management, such as consciously monitoring weight and step counts (e.g., “I became conscious of managing weight and steps” and “My awareness of health has increased.” 7 responses).
- Effectiveness of Weight Management: Respondents expressed satisfaction with the ease of weight management and the significant utility of daily weight tracking (e.g., “Weight management was easy” and “Daily weight management was very helpful.” 6 responses).
- Motivation for Healthy Living and Exercise: Participants indicated that the app served as a motivation for maintaining a healthy lifestyle, particularly in terms of walking (e.g., “It became a motivation for a healthy life” and “Managing steps and earning badges motivated me to walk.” 6 responses).

These results demonstrate the positive impact of the intervention design, focusing on self-monitoring, rewards, and suggestions, achieving psychological effects such as increased motivation, interest, and self-efficacy in promoting healthy behaviors.

However, some challenges were reported, which are categorized as follows:

- Issues with Step Count Records: Some participants mentioned occasional inaccuracies in step count records, making it difficult to rely on the app as a daily pedometer (e.g., "There were occasional discrepancies in step counts, making it unreliable on certain days." 2 responses).

- Difficulty with Continuous App Operation: Respondents expressed the difficulty of keeping the app running continuously, describing it as stressful to always have it active (e.g., "There was pressure to keep it open all the time." 2 responses).
- Other Challenges: Participants also highlighted burdens, inconveniences in data input, and requests for feedback on the study as additional challenges.

These comments provide insights into areas that may require improvement, such as addressing technical issues, reducing operational burdens, and enhancing user experience based on participant feedback.

In this study, we addressed the significant issue of maternal health management, which has not been adequately examined thus far, by developing a smartphone application aimed at promoting health. We confirmed its usefulness, reliability, and usability. Specifically, what kind of application did we develop, and what empirical research did we conduct using it? What were the participants' feelings about using the app? We focused on these questions in our discussion. However, descriptions of the effects and outcomes of the intervention, such as changes in attitudes and behaviors of pregnant and postpartum women and improvements in health status, were insufficient. We will provide detailed descriptions of these aspects in future papers.

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