Chapter

Application of a Pedometer for the Management of Impaired Glucose Tolerance in Pregnant Women

Mariko Ueno, Mitsue Muraoka and Koichiro Takagi

Abstract

The proper management of impaired glucose tolerance (IGT) in pregnant women is important for both obstetricians and diabetologists as this condition is of interest to both obstetrics and internal medicine. Although nutritional intervention along with insulin treatment is the mainstream approach of IGT treatment in pregnant women, exercise intervention is another important component of the IGT management. A pedometer is a useful tool for objective exercise evaluation. Nonetheless, its application in the management of IGT in pregnant women is limited. On the other hand, with the widespread use of smartphones equipped with pedometer function, exercise by walking is easily monitored and utilised in both healthy pregnant women and pregnant women with obesity and impaired glucose tolerance. In this chapter, we review the present perspective on the use of a pedometer in the management of IGT in pregnant women by introducing our recently published work.

Keywords: pregnancy, impaired glucose tolerance, gestational diabetes mellitus, exercise, pedometer

1. Introduction

Followed by recent substantial progress in the field of IT, smartphones equipped with a pedometer function have enabled us to measure the amount of steps we take daily and to estimate a daily caloric expenditure, which are useful tools of health self-monitoring. Pedometer or pedometer-equipped smartphones might theoretically help improving health of the people with conditions such as obesity, locomotive problems, and impaired glucose tolerance. Nonetheless, there are a few reports demonstrating the effectiveness of a pedometer in weight control and metabolic control in non-pregnant individuals as well as in pregnant women partly because the difficulties in the setting of quantitative outcome of the study or the special nature of the subjects those who are reluctant to exercise. The management of impaired glucose tolerance requires strict blood glucose control through a proper management of diet and exercise. However, the difficulty in quantification of the amount of exercise may let obstetricians and internists to prefer too strict nutritional control or easier use of insulin. We believe that exercise quantification, which is an important part of glycemic control, might be beneficial for the management of impaired glucose tolerance. In this chapter, we review a recent report on the role of a pedometer during effective management of impaired glucose tolerance during pregnancy.

IntechOpen

2. Maternal weight gain during pregnancy

Women gain approximately 12.5 kg of body weight during pregnancy [1]. This increase is due to the uterus and its contents, i.e., the foetus, the placenta, and the amniotic fluid, but also due to enlarged breasts with the extracellular fluid. This compartmentalisation makes the assessment of obesity and weight gain difficult during a short period of pregnancy, which lasts 9 months. Weight gain during pregnancy is associated with offspring obesity and cardiometabolic traits in early childhood in a trimester-specific fashion [2]. Greater rate of gestational weight gain in the first trimester of pregnancy was associated with increased risk of overweight and obesity from 2 years to 4 years of age, high waist circumference, high sum of skinfold thickness and higher diastolic blood pressure at 4 years of age. In contrast, Greater rate of gestational weight gain during the second and the third trimesters was associated with greater risk of large-for-gestational age neonates [2]. Our group has recently reported that in hyperemesis gravidarum, in which maternal undernutrition occurs in the first trimester of pregnancy, the pattern of foetal head growth differs from that of the normal pregnancy [3]. Moreover, the weight gain in slim and obese women should not be the same because of the differences in their nutritional demands during pregnancy. Association of gestational weight gain with adverse maternal and infant outcomes has been demonstrated by the LifeCycle Project-Maternal Obesity and Childhood Outcomes Study Group [4]. From this large scale meta-analysis of 25 cohort studies, they concluded that maternal prepregnancy BMI, and to a lesser extent gestational weight gain, are associated with risks of adverse maternal and infant adverse outcomes. Gestational weight gain ranges that were associated with lower risks for adverse outcomes were 14.0 Kg to less than 16.0 Kg for underweight women, 10.0 Kg to less than 18.0 Kg for normal weight women, 2.0 Kg to less than 16.0 Kg for overweight women, and 2.0 Kg or less than 6.0 Kg for grade I obese women [4]. The Institute of Medicine and National Research Council revised its guidelines for weight gain during pregnancy according to the prepregnant nutritional status estimated by the pre-pregnancy BMI [5]. In Japan, according to the Healthy Parents and Children 21 by the Health, Labour and Welfare of Japan Government, the weight gain guidelines are 10–12 Kg for women with a pre-pregnancy BMI less than 18.5 Kg/m^2, 7–12 Kg for women with a pre-pregnancy BMI of 18.5 to 25 Kg/m^2, and appropriate increase for those with prepregnant BMI over 25 Kg/m^2 [6]. However, adherence to the gestational weight gain recommendations seems to be limited for obese women in preventing increased birth weights [7]. In addition, behavioural interventions by the healthcare providers for the obese women are practically complicated due to several factors such as educational levels, ethnicity, and socio-economical levels. In particular, weight control is of huge importance during pregnancy complicated with diabetes and gestational diabetes, in which obesity is strongly associated with their pathophysiology.

3. Carbohydrate metabolism during pregnancy

The energy metabolism of women changes dramatically during pregnancy, as sufficient nutrition for the foetus must be provided. The foetus is nourished through the maternal-foetal interface called the placenta, by which essential nutrients, including the main foetal energy source—glucose and oxygen, are transported from the mother to the foetus. In line, foetal waste products such as carbon dioxide are transported from the foetus to the mother via the placenta. Various hormones are involved in the promotion of insulin resistance. Prolactin (PRL) and human placental lactogen (hPL) have been reported to suppress glucose uptake through the action of GLUT4 [8, 9]. Moreover, a study of the effect of oestradiol (E2) and progesterone (P4) on the action of insulin has shown that P4 suppresses insulin signalling and reduces glucose uptake through a step-wise process by reducing the amount of protein in the insulin receptor to suppress the transport of GLUT4 to cell membranes, downregulating the PI3-kinase-independent pathway [8, 9]. It has also been shown that insulin sensitivity is reduced through the suppression of tyrosine phosphorylation in insulin receptors via increased E2 blood levels that have been observed in the latter half of human pregnancy [8, 9].

4. Impaired glucose tolerance during pregnancy

As mentioned in the previous section, pregnancy itself is to some extent diabetogenic in its third trimester. Thus, women who are obese or relatively older when becoming pregnant may have a higher risk of developing glucose intolerance during pregnancy. This condition is known as gestational diabetes. Alternatively, a woman may have pregestational diabetes or undiagnosed diabetes until she becomes pregnant. In all of these cases, the foetus is over-nourished, which results in obesity in new-born babies with higher perinatal morbidity and mortality and a higher risk of developing diabetes in the near future in cases of gestational diabetes [9]. As mentioned previously, a special metabolic change of pregnancy let a pregnant women change into insulin-resistant condition. For this reason, the maximum insulin demand in the third trimester of pregnancy of prepregnant diabetic women with type I and type 2 diabetes mellitus are reported to be 1.5 times and 2 times higher than those of pre-pregnant demands, respectively [10]. The fundamental approach in the management of impaired glucose tolerance in pregnancy is to keep blood glucose levels as close to the non-pregnant levels as possible [11]. There are two important factors which need to be considered when achieving this goal, namely energy intake and energy expenditure. Measurements of blood glucose levels, glycosylated haemoglobin or albumin are routinely employed for the monitoring of diabetic control [12]. However, suitable energy expenditure, in other words, suitable exercise has not been studied in detail to date.

5. Exercise and carbohydrate metabolism during pregnancy

Regular exercise is recommended during pregnancy. In 2009, The American College of Obstetricians and Gynaecologists recommended that in the absence of contraindications such as pre-existing medical complications and pregnancy complications, pregnant women should be encouraged to engage in regular, moderate-intensity physical activity for 30 minutes or more daily [13]. Antenatal lifestyle interventions including exercise and diet for obese women also improved infant adiposity as well as maternal lifestyle behaviours at 6 months postpartum [14]. There are some evidence suggesting that pregnant women who engage in recreational physical activity have 50% lower risk of gestational diabetes and 40% risk reduction for preeclampsia [15].

Studies concerning the relationship between exercise and blood glucose levels have shown that, in healthy individuals, moderate amounts of exercise increase gluconeogenesis in the liver and other organs by decreasing insulin levels and elevating glucagon levels [8, 9]. Eighty percent of the glucose is used by skeletal muscles, making them the major user of carbohydrates in the body [9]. There are two pathways for the use of carbohydrates in the skeletal muscles. One is a pathway by which the GLUT4 that is present in muscle cells is transported to the surface of cell membranes (translocation) and glucose uptake then occurs when insulin binds with receptors on the surface of the muscle cell membranes [9]. The other pathway is one by which insulin-independent glucose uptake is made possible by translocation of GLUT4 by adenosine monophosphate-dependent protein kinase that is activated in conjunction with muscle contractions [9]. Although the GLUT4 on the cell surface disappears 2 to 3 hours after exercise, the turn-over of the translocation of GLUT4 is upregulated by the exercise in response to the same levels of blood insulin concentrations [9]. Furthermore, the gene transcription of GLUT4 is enhanced after 10 or more hours after exercise [9]. As a result, even though glucose from the blood is uptaken by skeletal muscles, blood glucose levels are almost unaltered. However, although patients with type 2 DM are able to increase the uptake of glucose into skeletal muscle through exercise, they experience a decrease in the blood glucose level through the suppression of gluconeogenesis in the liver due to hyperinsulinemia [9]. Further, post-exercise promotion of glycogen synthesis and insulin sensitivity causes a drop in blood glucose levels. Recently, participation of angiotensin-(1–7), a vasoactive peptide of the renin-angiotensin system is demonstrated in enhanced skeletal muscle insulin sensitivity after a bout of exercise [16]. It is known that patients treated with insulin and hypoglycaemic agents are particularly susceptible to hypoglycaemia from the day of exercise to the following day [8]. Similar to type 2 DM, carbohydrate metabolism switches into insulin resistance in the latter half of pregnancy. Therefore, one may speculate that the blood glucose levels might be influenced by exercise during pregnancy. However, Artal et al. measured the blood glucose levels, insulin concentrations, and glucagon concentrations in women in the third trimester of normal pregnancies before and after a 15-minute treadmill exercise. The results indicated that the post-exercise blood glucose level and insulin level did not change, but that the glucagon level was elevated [17]. In contrast, Soultanakis et al. showed that continuous prolonged exercise in pregnancy with about 55% VO_2 or higher could result in hypoglycaemia after 45–60 minutes of continuous exercise, suggesting the importance of appropriate exercise plans in the management of blood glucose levels in women with impaired glucose tolerance [18]. In line, Artal suggested that one moderate bout of exercise of 30–45 minutes/day and one bout of exercise after each meal to burn at least 200 kcal or more per day is effective in obtaining or maintaining euglycemia during pregnancy [17]. It is noteworthy that a regular programme of exercise before pregnancy appears to lower the risk of developing gestational diabetes mellitus (GDM) [19].

6. Application of a pedometer as an exercise-monitoring tool

A rationale for the application of a pedometer for exercise quantification has been tested in non-pregnant women using doubly-labelled water, a gold standard measurement of free-living energy expenditure with that of the accelerometer. The study demonstrated that the accelerometer is an alternative objective tool for the evaluation of exercise quantitatively in non-pregnant individuals [20]. Furthermore, Harrison et al. compared the accelerometer and pedometer as well as the subjective exercise assessment questionnaire, the International Physical Activity Questionnaire (IPAQ), showing that the pedometer was superior to the accelerometer and IPAQ in an objective assessment of exercise during pregnancy [21].

7. Application of a pedometer as a health care improving tool

7.1 Non-pregnant condition

The application of a pedometer for health improvement has been examined in the non-pregnancy context. Richardson et al. reported a meta-analysis of pedometer-based walking interventions and weight loss [22]. They searched 6 electronic databases and found nine studies which met their inclusion criteria. Those studies demonstrated that pedometer-based walking programs resulted in a modest amount of weight loss, on average 0.05 kg per week during the interventions. Mitsui et al. showed gender differences in the relationship between steps/day and BMI in Japanese adults [23]. Walker et al. showed that a 10,000 steps per day for 6 months resulted in a 3.0 cm loss in waist circumference, whereas there were no differences in body mass index among 142 subjects, including both genders [24]. The application of pedometer was examined for ovulation induction along with administration of clomiphene citrate in overweight women with polycystic ovary syndrome with greater number of spontaneous ovulation and pregnancy [25]. With respect to the effect of exercise monitored with a pedometer on carbohydrate metabolism, Huus et al. showed that physical activity assessed with a pedometer in healthy schoolchildren at the age of 8 and 12 longitudinally improved insulin sensitivity and decreased fasting C-peptide irrespective of the BMI [26]. This report is interesting because they investigated the association of exercise monitored with pedometer and insulin sensitivity qualitatively.

7.2 Pregnant condition

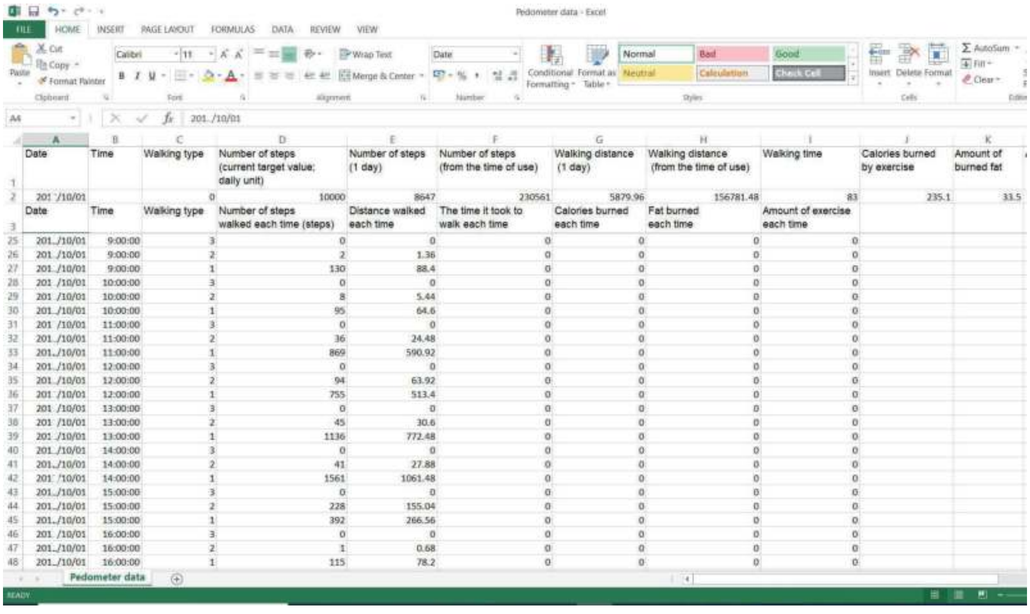
The clinical use of pedometers in obese pregnant women has been a controversial topic. Streuling et al. performed a meta-analysis on clinical trials which dealt with the application of a pedometer in the management of gestational weight gain [27]. Out of 1380 studies, they identified 12 trials that met their inclusion criteria. In seven trials, gestational weight gain was lower in the exercise group than in the control group, whereas five trials showed a lower GWG in the control groups. In Asia, Jiang et al. reported that pregnant women being physically active assessed by pedometer had less weight gain during pregnancy [28]. In this report, the activity levels were divided into 4 groups as sedentary (< 5000 daily steps), low active (5000–7000 daily steps), somewhat active (7500–10,000 daily steps) and active (≥10,000 daily steps). In accordance with Jiang's report, Cohen and Koski reported that both more than 5000 steps/day assessed by pedometer and daily energy intakes within 300 kcal of estimated energy requirements minimised postpartum weight retention of healthy pregnant women [29]. Although the application of a pedometer for the control of gestational weight gain seems controversial based on the abovementioned meta-analysis, one of the most important questions is related to the use of a pedometer by obese women, because they may be reluctant to exercise and that could be one of the reasons why they are obese. Even in a recent multi-institutional study conducted in Australia which used a randomised controlled trial in order to assess a pedometer-based intervention to increase activity and reduce excessive weight gain in pregnant women, the conclusion of the study showed negative results with the notion that the improvement of compliance with activity data recording and behavioural interventions delivered [30]. However, there are promising reports on the use of a pedometer for the management of overweight and obese pregnant women by active intervention with individualised nutritional support and individual exercise plans. For example, one study described an intervention at

16 to 20 weeks of gestation in overweight and obese women. The average number of steps after the intervention was over 10,000, along with the intake of 2000 kcal/day. This approach resulted in the prevention of excessive weight gain as well as excessive postpartum weight retention [31]. The study clearly demonstrated that both nutritional and exercise interventions are necessary in order to achieve reasonable outcomes in the management of glucose metabolism in obese pregnant women. In comparison of a smartphone pedometer with a reference pedometer, The Yamax Digiwalker, Tokyo, Japan, a smartphone pedometer is even superior at a low walking speed, suggesting a smartphone pedometer might be superior to pregnant women who are not expected to walk faster. [32]. So, there is no problem in using a smartphone pedometer instead of stand-alone pedometer.

8. Application of a pedometer for the management of impaired glucose tolerance in pregnant women

It is reasonable to assume that walking quantified by a pedometer is beneficial for the management of impaired glucose tolerance not only in non-pregnant subjects but also in pregnant subjects. Dahjio et al. reported a study on pedometer-monitored walking for the management of glucose in non-pregnant individuals. They examined a 12-week aerobic exercise training program monitored with a pedometer in type II diabetic Cameroonian women [33]. The subjects showed a significant reduction in body weight, waist circumference, and mean glycaemia after 12 weeks of the program. However, no study so far has reported the use of a pedometer in pregnant women with impaired glucose tolerance. Hence, we examined the feasibility of using a pedometer to quantify the exercise intensity and the relationship between the amount of exercise and carbohydrate metabolism in pregnant women with impaired

Figure 1.
Citizen digital pedometer TW700, connected to a laptop computer. The pedometer was connected to a laptop computer through a USB cable to upload steps.



	A	B	C	D	E	F	G	H	I	J	K
1	Date	Time	Walking type	Number of steps (current target value; daily unit)	Number of steps (1 day)	Number of steps (from the time of use)	Walking distance (1 day)	Walking distance (from the time of use)	Walking time	Calories burned by exercise	Amount of burned fat
2	201./10/01		0	10000	8647	230561	5879.96	156781.48	83	235.1	33.5
3	Date	Time	Walking type	Number of steps walked each time (steps)	Distance walked each time	The time it took to walk each time	Calories burned each time	Fat burned each time	Amount of exercise each time		
25	201./10/01	9:00:00	3	0	0	0	0	0	0		
26	201./10/01	9:00:00	2	2	1.36	0	0	0	0		
27	201./10/01	9:00:00	1	130	88.4	0	0	0	0		
28	201./10/01	10:00:00	3	0	0	0	0	0	0		
29	201./10/01	10:00:00	2	8	5.44	0	0	0	0		
30	201./10/01	10:00:00	1	95	64.6	0	0	0	0		
31	201./10/01	11:00:00	3	0	0	0	0	0	0		
32	201./10/01	11:00:00	2	36	24.48	0	0	0	0		
33	201./10/01	11:00:00	1	869	590.92	0	0	0	0		
34	201./10/01	12:00:00	3	0	0	0	0	0	0		
35	201./10/01	12:00:00	2	94	63.92	0	0	0	0		
36	201./10/01	12:00:00	1	755	513.4	0	0	0	0		
37	201./10/01	13:00:00	3	0	0	0	0	0	0		
38	201./10/01	13:00:00	2	45	30.6	0	0	0	0		
39	201./10/01	13:00:00	1	1136	772.48	0	0	0	0		
40	201./10/01	14:00:00	3	0	0	0	0	0	0		
41	201./10/01	14:00:00	2	41	27.88	0	0	0	0		
42	201./10/01	14:00:00	1	1561	1061.48	0	0	0	0		
43	201./10/01	15:00:00	3	0	0	0	0	0	0		
44	201./10/01	15:00:00	2	228	155.04	0	0	0	0		
45	201./10/01	15:00:00	1	392	266.56	0	0	0	0		
46	201./10/01	16:00:00	3	0	0	0	0	0	0		
47	201./10/01	16:00:00	2	1	0.68	0	0	0	0		
48	201./10/01	16:00:00	1	115	78.2	0	0	0	0		

Figure 2.
An example of the uploaded step data into a spreadsheet of Microsoft Excel.

		Correlation coefficient	P value
Relation between no. of steps and pre-prandial blood glucose level immediately following walking	No. of steps, morning & BL	−0.12	n.s.
	No. of steps, afternoon & BD	0.28	n.s.
	No. of steps, night & vds	0.25	n.s.
Relation between no. of steps and postprandial blood glucose level immediately following walking	No. of steps, morning & AB	0.06	n.s.
	No. of steps, afternoon & AL	0.02	n.s.
	No. of steps, night & AD	0.03	n.s.
Relation between total no. of steps per day and blood glucose level	Total no. of steps per day & vds	0.06	n.s.
	Total no. of steps per day & following day FBS	−0.02	n.s.
Relation between no. of steps per day and following day FBS	Insulin: yes	0.003	n.s.
	Insulin: no	−0.03	n.s.
Relation between no. of steps and change in blood glucose level before and after	No. of steps, morning & AB-BL	−0.12	n.s.
	No. of steps, afternoon & AL-BD	−0.24	n.s.
	No. of steps, night & AD-vds	−0.05	n.s.
	No. of steps, night & AD-following day FBS	−0.01	n.s.
	Total no. of steps per day & following day FBS-FBS	−0.08	n.s.

FBS: Pre-breakfast blood glucose, AB: After-breakfast blood glucose, BL: Pre-lunch blood glucose, AL: After-lunch blood glucose, BD: Pre-dinner blood glucose, AD: After-dinner blood glucose, vds: Bedtime blood glucose, n.s.: not significant.

Table 1.
Comparison of number of steps and blood glucose levels in 1-day based (from Ref. [34], with permission).

glucose tolerance employing a pedometer (Citizen Digital Pedometer TW 700 with high-sensitivity 3D acceleration sensor, CITIZEN SYSTEMS JAPAN CO., LTD, Japan) by which the recorded data of number of steps are stored chronologically for 30

		Correlation coefficient	P value
Relation of no. of steps per day and amount of change in HbA1c (comparison of 4-week based data)	**Entire pregnancy**	**−0.43**	**0.0263**
	Second trimester	**−0.64**	**0.0330**
	Third trimester	0.24	n.s.
Relation between avg. no. of steps and amount of change in GA (comparison of 4-week based data)	Entire pregnancy	−0.38	n.s. (0.082)
	Second trimester	−0.57	n.s. (0.109)
	Third trimester	0.24	n.s.
Relation between no. of steps per day and amount of change in maternal body weight (comparison of 2-week based data)	**Entire pregnancy**	**−0.49**	**0.0005**
	First trimester	−1(n = 2)	n.s.
	Second trimester	**−0.76**	**0.0003**
	Third trimester	−0.11	n.s.
Relation between no. of steps per day and average amount of insulin administered per day (comparison of 1-week based data)	**Entire pregnancy**	**−0.43**	**<0.0001**
	First trimester	0.69	n.s.
	Second trimester	**−0.42**	**0.0111**
	Third trimester	**−0.52**	**0.0005**
No. of steps per day for entire period and infant birthweight (SD score)		−0.22	n.s.

HbA1c: haemoglobin A1c, GA: Glycoalbumin, n.s.: not significant.

Table 2.
Comparison of average number of steps per day and all data items (from Ref. [34], with permission).

consecutive days [34]. The data stored in the pedometer are transferred through USB port of the computer and analysed chronologically (**Figures 1** and **2**). In a 24-hour time frame, there was no correlation between the number of steps walked and pre- or postprandial blood glucose level immediately after walking, nor between the average number of steps per day and the fasting blood glucose level on the next day (**Table 1**). However, the 4-week data showed that there was a negative correlation between the number of steps per day and the change in HbA1c levels (**Table 2**). Moreover, there was a negative correlation between the average number of steps per day and change in the maternal body weight (**Table 2**). A 1-week based data from the subjects administered with insulin indicated that there was a negative correlation between the average number of steps per day and the total amount of insulin administered per day. Our results indicated that pedometer-monitored walking improved insulin resistance without affecting blood glucose levels just after the bouts of walking. In addition, carrying the pedometer may have self-promoting effect for sustaining the exercise for the women with impaired glucose tolerance by noticing the improvement in the changes in the body weight and HbA1c levels in response to her steps walked. To conclude, our report was the first to show the usefulness of a pedometer for the management of IGT in pregnant women. We plan to continue studying this issue in future studies with higher numbers of participants along with nutritional counselling. Further studies are anticipated in order to design appropriate pedometer-monitored exercise plans not only for the management of IGT in pregnant women but also for that of the obese pregnant women. Nowadays, so many kinds of applications for pregnant women dealing with weight control, nutrition, foetal movement, maternal heart rates, it would be worthwhile to develop applications for incorporating pedometer data with body weight, maternal heart rate, ultrasound foetometric data and the parameters of the blood glucose control for the women with impaired glucose tolerance.

9. Conclusion

With the widespread use of smartphones equipped with pedometer function, walking exercises are easily monitored and utilised not only in normal but also in pregnant women with obesity and impaired glucose tolerance. Furthermore, data including footsteps, and pulse rates if smart watch will be used together with smartphone and information of the foetal growth, comprehensive management of the exercise and body weight control will be achieved. Further studies are expected to assess how many steps per day and how many bouts are optimal for the best blood sugar and body weight control during pregnancy.

Acknowledgements

We would like to thank Editage (www.editage.jp) for English language editing.

Conflict of interest

No conflict of interest exists.

Author details

Mariko Ueno[1], Mitsue Muraoka[2] and Koichiro Takagi[3]*

1 Department of Obstetrics and Gynecology, Tokyo Women's Medical University Medical Center East, Tokyo, Japan

2 Department of Obstetrics and Gynecology, Shiseikai Daini Hospital, Tokyo, Japan

3 Saigusa Maternity Clinic, Tokyo, Japan

*Address all correspondence to: kotak0821@gmail.com

References

[1] Hytten FE. Weight gain in pregnancy—30 year of research. S Afr Med J. 1981; 4(60):15-19.

[2] Karachaliou M, Georgiou V, Roumeliotaki T, Chalkiadaki G, Daraki V, Koinaki S, Dermitzaki E, Sarri K, Vassilaki M, Kogevinas M, Oken E, Chatzi L. Association of trimester-specific gestational weight gain with fetal growth, offspring obesity, and cardiometabolic traits in early childhood. Am J Obstet Gynecol 2015; 212:502.e1-14.

[3] Muraoka M, Takagi K, Ueno M, Morita Y, Nagano H. Fetal head growth during early to mid-gestation associated with weight gain in mothers with hyperemesis gravidarum: a retrospective Cohort study. Nutrients 2020;12, 1664;DOI:10.3390/nu12061664.

[4] LifeCycle Project-Maternal Obesity and Childhood Outcomes Study Group. Association of gestational weight gain with adverse maternal and infant outcomes. JAMA 2019;7:1702-1715.

[5] Institute of Medicine. Weight gain during pregnancy: reexamining the guidelines. Washington, DC: National Academies Press; 2009.

[6] Ministry of Health, Labour and Welfare (Guideline): Healthy Parents and Children 21: Diet and Lifestyle Guidance for Pregnant Women Investigation Committed, 2006 (in Japanese).

[7] Gesche J, Nilas L. Pregnancy outcome according to pre-pregnancy body mass index and gestational weight gain. Int J Obstet Gynecol Obstet 2015; 129:240-243.

[8] Yamori Y, Mochizuki M, Tojo N. Insulin and glucagon during pregnancy. Adv Obstet Gynecol. 1979;31:513-552.

[9] Kawanaka K. Exercise and skeletal muscle GLUT4. Trends in Academics. 2006;10:42-46 (in Japanese).

[10] Sanaka M. Diabetes and pregnant women. J Tokyo Women's Med Univ 2006; 76:389-393.

[11] ACOG Practice Bulletin No.190. Gestational diabetes mellitus. Obstet Gynecol. 2018;131(2):e49-e64.

[12] Diabetes Canada Clinical Practice Guidelines Epert Committee. 2018 Clinical Practice Guidelines Diabetes and Pregnancy. Can J Diabetes 2018;42:5255-5282.

[13] American College of Obstetricians and Gynecologists: Exercise during pregnancy and the postpartum period. Committee Opinion 2002, No. 267.

[14] Patel N, Godfrey KM, Pasupathy D, Levin J, Glynn AC Hayes L, B riley AL, Bell R, Lawlor DA, Oteng-Ntim E, Nelson SM, Robson SC, Sattar N, Singh C, Wardle J, White S, Seed PT, CStat, Poston L. Infant adiposity following a randomised controlled trial of a behavioural intervention in obese pregnancy. Int J Obes (Lond). 2017;41:1018-1026.

[15] Dempsey JC, Butler CL, Williams MA. No need for a pregnant women for a pregnant pause:Physical activity may reduce the occurrence of gestational diabetes mellitus and preeclampsia. Exerc Sport Sci Rev. 2005;33:141-149.

[16] Echeverria-Rodrigeuz O, Gallardo-Ortiz IA, Valle-Mondragon LD, Villalobous-Molina R. Angiotensin-(1-7) participates in enhanced skeletal muscle insulin sensitivity after bout of exercise.J Endocr Soc 2020;4:doi:1210/jendso/bvaa007.

[17] Artal R, Platt LD, Sperling M, Kammula RK, Jilel J, Nakamura R. Exercise in pregnancy. I. Maternal cardiovascular and metabolic responses in normal pregnancy. Am J Obstet Gynecol 1981;140:123-127.

[18] Soultanakis HN, Artal R, Wiswell RA. Prolonged exercise in pregnancy: glucose homeostasis, ventilatory and cardiovascular responses. Semin Perinatol. 1996;20(4):315-327. DOI: 10.1016/s0146-0005(96)80024-3

[19] Chapter 33: Role of exercise in reducing the risks of gestational diabetes mellitus in obese women. Raul Artal p.265-268. Lois G, Gian Carlo Di Renzo, Alberto De Leiva, Oded Langer. Textbook of Diabetes and Pregnancy (Maternal-fetal Medicine), Third edition. 2016.

[20] Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. Obesity (Silver Spring). 2007;15(10):2371-2379. DOI: 10.1038/oby.2007.281

[21] Harrison CL, Thompson RG, Teede HJ, Lombard CB. Measuring physical activity during pregnancy. Int J Behav Nutr Phys Act. 2011;8:19. DOI: 10.1186/1479-5868-8-19

[22] Richardson CR, Newton TL, Abraham JJ, Sen A, Jimbo M, Swartz AM. A meta-analysis of pedometer-based walking interventions and weight loss. Ann Fam Med. 2008;6(1):69-77. DOI: 10.1370/afm.761

[23] Mitsui T, Shimaoka K, Tsuzuku S, Kajioka T, Sakakibara H. Pedometer-determined physical activity and indicators of health in Japanese adults. J Physiol Anthropol. 2008;27(4):179-184. DOI: 10.2114/jpa2.27.179

[24] Walker JR, Soroush A, Ainsworth BE, Belyea M, Swan PD, Yngve A. U.S. Cohort Differences in Body Composition Outcomes of a 6-Month Pedometer-Based Physical Activity Intervention: The ASUKI Step Study. Asian J Sports Med. 2014;5(4):e25748. DOI: 10.5812/asjsm.25748

[25] Nagelberg J, Burks H, Mucowski S, Shoupe D. The effect of home exercise on ovulation induction using clomiphene citrate in overweight underserved women with polycystic ovarian syndrome. Contraception and Reproductive Medicine 2016; 1:14 DOI 10.1186/s40834-016-0025-2.

[26] Huus K, Åkerman L, Raustorp A, Ludvigsson J. Physical Activity, Blood Glucose and C-Peptide in Healthy School-Children, a Longitudinal Study. PLoS One. 2016;11(6):e0156401. DOI: 10.1371/journal.pone.0156401

[27] Streuling I, Beyerlein A, Rosenfeld E, Hofmann H, Schulz T, von Kries R. Physical activity and gestational weight gain: a meta-analysis of intervention trials. BJOG. 2011;118(3):278-284. DOI: 10.1111/j.1471-0528.2010.02801.x

[28] Jiang H, Qian X, Li M, Lynn H, Fan Y, Jiang H, He F, He G. Can physical activity reduce excessive gestational weight gain? Findings from a Chinese urban pregnant women cohort study. International Journal of Behavioral Nutrition and Physical Activity.2012;9:12 http://www.ijbnpa.org/content/9/1/12.

[29] Cohen T, Koski KG. Limiting excess weight gain in healthy pregnant women: Importance of energy intakes, physical activity, and adherence to gestational weight gain guidelines. J of Pregnancy 2013;http://dx.doi.org/10.1155/2013/78032.

[30] Darvall JN, Wang A, Nazeem MN, et al. A Pedometer-Guided Physical

Activity Intervention for Obese Pregnant Women (the Fit MUM Study): Randomized Feasibility Study. JMIR Mhealth Uhealth. 2020;8(5):e15112. DOI: 10.2196/15112

[31] Mottola MF, Giroux I, Gratton R, et al. Nutrition and exercise prevent excess weight gain in overweight pregnant women. Med Sci Sports Exerc. 2010;42(2):265-272. DOI: 10.1249/MSS.0b013e3181b5419a

[32] Presset B, Laurenczy B, Malatesta D, Barral J. Accuracy of a smartphone pedometer application according to different speeds and mobile phone locations in a laboratory context. Journal of Exercise Science & Fitness. 2018; 16:43-48.

[33] Dahjio Y, Noubiap JJ, Azabji-Kenfack M, et al. Impact of a 12-week aerobic exercise training program on anthropometric and metabolic parameters of a group of type 2 diabetes Cameroonian women aged ≥50 years. Ann Transl Med. 2016;4(19):364. DOI: 10.21037/atm.2016.09.26

[34] Ueno M, Takagi K, Tachibana Y, et al. Quantitative analysis of exercise among pregnant women with impaired glucose tolerance using pedometer data: An observational study. J Obstet Gynaecol Res. 2020;46(3):396-404. DOI: 10.1111/jog.14164.