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Daily walking is effective for the management of pregnant women with gestational diabetes mellitus

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Abstract

Aim: This study evaluated the usefulness of daily walking for gestational diabetes mellitus (GDM) management by analyzing the relationship between daily walking and glucose tolerance in pregnant women with GDM who were in the second trimester.

Methods: This longitudinal study was conducted at TOYOTA Memorial Hospital in Toyota, Japan, from January 2015 to June 2016. Pregnant women with GDM wore accelerometers on the waist for 7–12 weeks.

Results: Seventy-three women with GDM were included in the present study; data collected from 24 women were analyzed. The estimated number of steps walked daily showed a significant positive correlation (r = 0.798, P = 0.000) with energy expenditure related to physical activity. There was a significant negative correlation (r = −0.603, P = 0.014) between the post- to pre-research casual glucose level (CGL) ratio and the number of steps walked daily. No significant correlation (r = −0.004, P = 0.986) was detected between the ratio of hemoglobin A_{1c} and the number of steps taken. When the study was completed, the 11 participants who walked ≥6000 steps/day showed significantly lower CGL (95 + 10 mg/dL [mean + SD]) than the 13 participants in the <6000 steps/day group (111 + 18 mg/dL) (P = 0.013).

Conclusion: Simple walking for light intensity physical activity is effective for controlling the CGL in pregnant women with GDM. We recommend that pregnant women with GDM should walk a minimum of 6000 steps/day.

Key words: casual glucose level, daily walking, gestational diabetes mellitus, physical activity.

Introduction

Gestational diabetes mellitus (GDM) is a major perinatal complication.[1] On the basis of the universal definitions and diagnostic criteria for GDM proposed by the hyperglycemia and adverse pregnancy outcome study in 2008,[2] the prevalence of GDM was reported to be about 8% in Japan,[3] indicating that GDM occurs commonly in pregnant women.

It is known that GDM is associated with other disorders, such as high fetal body weight for gestational age and congenital malformations.[4,5] Fetal macrosomia causes shoulder dystocia and increases the possibility of a cesarean delivery. Moreover, hypertensive disorders in pregnancy shows relatively higher complication rates when occurring with concurrent GDM.[6] Glucose intolerance during the perinatal period affects women even after delivery. Previous studies have reported that women who experienced GDM developed type 2 diabetes at a seven times higher rate than women without GDM.[7,8] Because diabetes is a major cause of death worldwide,[9] primary prevention of GDM is essential. Although the recognition of GDM as clinical diabetes seems to be important for early

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detection and treatment, there is still no consensus on appropriate measures for glucose control during pregnancy to prevent the development of type 2 diabetes.

Diet, exercise and drug therapies are used to treat glucose intolerance in patients with type 2 diabetes. Diet and exercise therapy should be attempted first, with drug therapy added if diet and exercise alone cannot correct glucose tolerance sufficiently. A recent study has shown that physical activity (PA) is more effective than diet for improving insulin resistance in patients with type 2 diabetes.[10] Appropriate PA can effectively improve glucose tolerance in the general population.[11] The American College of Obstetricians and Gynecologists (ACOG) recommends at least 30 min of moderate-intensity PA on most, if not all, days of the week.[12]

Regarding pregnant women, studies have consistently found that increasing the pace of walking is significantly and inversely associated with the risk of GDM.[12] The pregnant abdomen in the second trimester causes changes in physical function. The body's center of gravity is inclined forward, and the feet become difficult to see. Therefore, pregnant women lean backward while walking for safety.[13] Moderate-intensity PA for non-pregnant women is equivalent to high-intensity PA for pregnant women. Daily walking is popular during pregnancy because of its lower intensity and higher accessibility.[14,15]

Daily walking does not require special equipment and may be the most suitable light-intensity PA for pregnant women. However, there is insufficient scientific evidence on the effects of daily walking during the gestation period. Therefore, this study aimed to evaluate the usefulness of daily walking for GDM management by analyzing the relationship between walking and glucose tolerance in pregnant women with GDM who were in the second trimester.

Methods

Subjects

This longitudinal study was conducted at TOYOTA Memorial Hospital in Toyota, Japan, from January 2015 to June 2016. Pregnant women who visited the hospital and who were diagnosed with GDM in the second trimester were included. Pregnant women who were less than 20 years old, who could not complete a questionnaire, who had type 1 or type 2 diabetes, who were using steroids, who required hospitalization, who had a pregnancy complicated by fetal disorder, or who performed habitual moderate and vigorous PA were excluded.

This hospital had 776 first trimester outpatients for perinatal care at the obstetrical department for the recruiting period of 18 months. Among the 716 women (92.3%) who underwent biochemical testing, 245 women (34.2%) had a casual glucose level (CGL) greater than 100 mg/dL in the first trimester (less than 16 weeks of gestation) or a level greater than 140 mg/dL in a 50-g glucose challenge test at the second trimester (24–28 weeks of gestation). The 75-g oral glucose tolerance test (OGTT) was performed in 184 women (75.1%) to diagnose GDM according to the following standard criteria: blood glucose ≥92 mg/dL at fasting, ≥180 mg/dL at 60 min after loading or ≥153 mg/dL at 120 min after loading. A total of 63 patients were found to have GDM. The calculated occurrence rate for GDM was 8.8%. An additional 10 cases that had already been diagnosed with GDM with 75-g OGTT were referred to the hospital by nearby private clinics. Among 73 pregnant women with GDM, 32 (43.8%) agreed to participate in the study. Two women voluntarily withdrew, one relocated and three received medication, including insulin, during the research; the remaining 26 women completed the study. However, final data were analyzed for only 24 pregnant women with GDM because sufficient daily walking data were not obtained from two women (Fig. 1).

Research protocol

Women with GDM were recruited in the second trimester while awaiting routine examination in an outpatient hospital room; questionnaires provided to them assessed dietary intake. Background information, including maternal age, gestational week, pre-pregnancy body mass index (BMI), pregnancy history, fetus number, pregnancy complications and laboratory biochemical data were obtained from patient medical charts. Body weight was measured except the women who were followed as antenatal care at other clinics.

The total amount of daily walking was estimated from the number of steps taken and the amount of exercise performed daily, as measured with an accelerometer (Lifecorder EX; Suzuken Co Ltd).[16] Participants attached the accelerometer to the waistbands of their skirts or pants, as instructed at the time of recruitment by investigators. The accelerometers assessed daily walking for a total of 7–12 weeks because periodic pregnancy examinations were performed every

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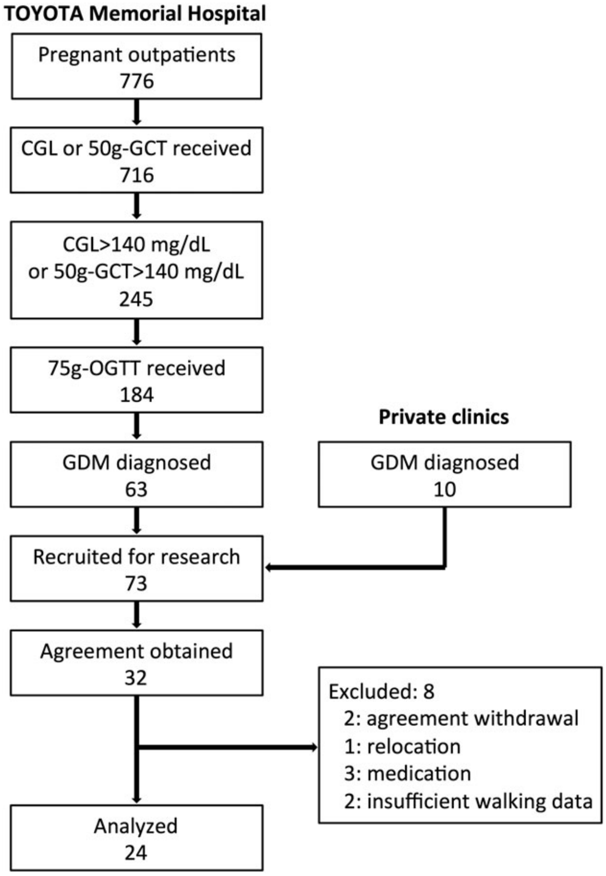

Figure 1 The recruitment and entry process for women with gestational diabetes mellitus (GDM) for the present study.

4 weeks on the basis of the number of steps taken and the amount of exercise performed every day from the second trimester to the third trimester. The accelerometers were removed during sleeping and bathing. In the third trimester, the participants removed the accelerometers permanently and completed questionnaires that assessed dietary intake.

Each participant was given detailed information on the study protocol, and all provided written informed consent. This study procedure was reviewed and approved by the Ethics Committees of Kyoto University School of Medicine (No. E2279) and TOYOTA Memorial Hospital. It was registered in the University Hospital Medical Information Network (UMIN) Center (ID: R000017881).

Measurements

Daily walking was assessed using the accelerometer, which measured steps, PA-related intensity and PA-related energy expenditure (PAEE). PA-related intensity was judged from the strength and frequency of impact as transmitted to an acceleration sensor. PAEE was calculated every 4 s, using PA-related intensity and body weight. The accelerometer frequency was 32 Hz, and its time base range was 0.06–1.94 g. As accelerometers only have two axes, their detection range is limited. No reports have indicated adverse events related to accelerometer use in pregnant women.

CGL, hemoglobin (Hb) and hemoglobin A_{1c} (HbA_{1c}) were measured at the initiation and completion of the research to estimate pre- and post-research carbohydrate metabolism.

Dietary intake during the most recent month was assessed with a brief self-administered diet history questionnaire (BDHQ), and the amount of daily intake for 50 foods and selected nutrients[17,18] was calculated from the BDHQ.

Statistical analyses

The Mann–Whitney *U*-test and Spearman's correlation coefficient were performed using BellCurve for Excel Version 2.03 (Social Survey Research Information Co. Ltd). Two-tailed *P*-values less than 0.05 were considered statistically significant.

Clinical trial registration

UMIN (https://upload.umin.ac.jp/cgi-bin/icdr/ctr_reg_list.cgi)

UMIN ID:UMIN000015663. Official scientific title of the study: Verification of the effect of exercise on pregnant women with glucose intolerance.

Results

Participant characteristics

The mean values (range) for age (years), pre-pregnant BMI (kg/m^2), gestational weeks at the initiation and completion of the study, and the duration of walking measurements (weeks) for the 24 GDM women were 35.9 (29–42), 24.1 (16.7–36.8), 21.9 (14–27), 30.5 (25–35) and 8.6 (7–12), respectively (Table 1). Also body weight at the initiation and completion of the study and overall body weight gain of the women were 64.7 (41.4–99.2), 68.7 (47.8–110) and 8.2 (−0.2–14.4), respectively. One woman had a pre-pregnancy BMI <18 kg/m^2, and two had a BMI >30 kg/m^2. Twelve women were primiparas. Two of the multiparas had GDM in prior pregnancies. The mean values of Hb

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Table 1 Participant characteristics and parameters

No.	Age (years)	P/M	History of GDM	Pre-pregnant BMI (kg/m^2)	No. of steps walked/day	PAEE	At initiation of research: Gestational weeks	At initiation of research: BW (kg)	At initiation of research: CGL (mg/dL)	At initiation of research: HbA1c (%)	At initiation of research: Hb (g/dL)	At completion of research: Gestational weeks	At completion of research: BW (kg)	At completion of research: CGL (mg/dL)	At completion of research: HbA1c (%)	At completion of research: Hb (g/dL)	Research duration (weeks)	BW gain during study period (kg)	Overall BW gain (kg)	Ratio of CGL change (initiation/completion)	Dietary intake (kcal/day)	Child birth: Gestational weeks at delivery	Child birth: Delivery mode	Child birth: Birth weight (g)
1	30	P		36.8	2947	112	24	99.2	97	5.6	11.5	32	110.0	111	6.0	10.9	8	11	15	1.14	1319	40	NVD	3746
2	29	M	+	19.9	3804	69	23	51.2	69	5.2	11.5	31	ND	115	5.3	ND	8	ND	ND	1.67	1938	38	NVD	3012
3	37	M	−	24.1	3836	100	19	69.0	74	5.5	12.9	28	71.0	99	5.3	11.0	9	2	5.6	1.34	1814	40	VD (forceps)	3562
4	42	M	−	25.6	4013	122	27	77.0	87	5.4	10.2	35	80.0	97	5.3	9.0	8	3	12	1.11	2761	40	NVD	3460
5	31	M	−	18.3	4059	125	25	56.0	81	5.6	10.3	33	60.0	117	5.7	9.1	8	4	14.4	1.44	1677	40	NVD	4124
6	35	M	−	22.5	4092	99	19	ND	92	5.4	ND	27	ND	95	5.3	ND	8	ND	ND	1.03	1605	41	NVD	3416
7	30	P		26.7	4167	111	25	66.0	87	4.4	13.8	33	73.0	124	4.4	ND	8	7	8	1.43	1712	38	CS (elective)	2950
8	35	P		21.0	4602	105	27	63.2	127	5.3	11.2	35	65.0	104	5.3	11.5	8	1.8	7	0.82	1503	40	NVD	3144
9	42	P		24.6	4602	108	22	65.0	113	5.1	13.2	30	66.4	95	5.2	12.8	8	1.4	−0.2	0.84	1210	35	NVD	1764
10	40	M	−	25.3	4796	132	25	79.0	90	5.1	11.9	33	80.0	128	5.3	11.0	8	1	ND	1.42	1358	40	NVD	3066
11	35	P		21.0	4813	100	19	56.0	77	4.8	11.1	31	64.5	86	5.2	ND	12	8.5	15	1.12	1355	40	CS (emergency)	2990
12	39	P		23.8	4855	116	14	65.0	103	6.0	12.0	26	63.0	122	5.3	12.0	12	−2	7.2	1.18	1515	41	NVD	2946
13	38	P		29.6	5391	125	26	77.5	173	5.2	13.0	34	77.8	154	5.3	12.5	8	0.3	6.8	0.89	1204	34	CS (emergency)	1554
14	42	M	−	18.7	6159	119	24	53.4	102	5.3	11.2	31	54.0	94	5.9	11.2	7	0.6	6.8	0.92	1810	38	NVD	3074
15	35	M	−	20.8	6567	168	24	63.0	154	5.1	10.9	35	63.0	83	5.2	11.1	11	0	11.8	0.54	1868	38	NVD	2966
16	37	P		24.1	7004	185	14	62.8	123	5.8	10.9	25	69.0	99	6.0	8.7	11	6	13	0.80	2235	41	NVD	3658
17	35	M	−	25.8	7094	184	28	67.2	108	5.4	12.9	35	66.5	106	5.7	ND	7	−0.7	6	0.98	2403	39	NVD	3102
18	41	P		25.1	7305	169	27	59.2	97	5.8	12.5	35	73.2	119	5.9	11.6	8	14	3.2	1.23	1682	37	CS (elective)	2218
19	32	P		26.1	7896	152	16	60.0	156	5.4	11.6	25	62.0	88	4.9	11.4	9	2	8.6	0.56	1125	41	NVD	3432
20	29	M	−	30.9	8270	266	24	80.5	149	5.4	13.2	32	78.6	96	5.6	12.9	8	−1.9	0.6	0.64	1601	38	NVD	2988
21	31	M	+	25.2	8632	196	17	66.4	98	5.4	13.1	25	67.8	96	5.3	13.1	8	1.4	8.8	0.98	1667	40	VD (vacuum)	3646
22	35	P		16.7	8977	147	19	41.4	102	4.7	10.1	28	47.8	87	4.7	10.9	9	6.4	ND	0.85	2063	38	VD (vacuum)	2752
23	42	M	−	25.3	9037	238	18	61.0	83	5.4	12.0	25	65.8	82	5.4	ND	7	4.8	5	0.99	2057	38	CS (elective)	3030
24	40	P		20.5	9205	169	19	50.0	128	5.3	14.0	27	53.0	93	5.3	12.5	8	3	9.8	0.73	1552	41	NVD	3200
Mean	35.9			24.1	5921.8	142.4	21.9	64.7	107.1	5.3	12.0	30.5	68.7	103.8	5.4	11.3	8.6	3.3	8.2	1.0	1709.8	39.0		3075
SD	4.4			4.3	1937.9	46.0	4.2	11.9	27.5	0.3	1.1	3.6	12.3	16.8	0.4	1.3	1.4	4.0	4.2	0.3	386.6	1.8		570

BMI, body mass index; BW, body weight; CGL, casual glucose level; CS, cesarean section; GDM, gestational diabetes mellitus; Hb, hemoglobin; HbA1c, hemoglobin A1c; M, multipara; ND, not determined; NVD, normal vaginal delivery; P, primipara; PAEE, physical activity-related energy expenditure; VD, vaginal delivery.

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(g/dL) at the initiation and completion of the study were 12.0 (10.1–14.0) and 11.3 (8.7–13.1). The research was initiated at 21.9 (14–28) gestational weeks and completed at 30 (25–35) weeks. The research duration was 8.6 (7–12) weeks.

The CGL values on the first and last day of walking measurements were 107 (69–156) and 104 (82–154), respectively. Thirteen women showed a CGL decrease during the research period.

Gestational complications and deliveries

Two women (nos. 13 and 19) showed hypertension in pregnancy and one (no. 9) indicated preeclampsia after the research had completed (Table 1). Mean gestational weeks at delivery was 39.0; two women (nos. 9 and 13) had preterm childbirths. Delivery treatment of forceps (no. 3) or vacuum extraction (nos. 21 and 22) was applied in three cases, and five women received elective (nos. 7, 18 and 23) or emergency (nos. 11 and 13) cesarean section. Following delivery, disseminated intravascular coagulation occurred in patient no. 3 and was treated. Mean birth weight was 3075 g; macrosomia (more than 4000 g) was observed in infant no. 5, and three infants (nos. 9, 13 and 18) demonstrated low birth weight (less than 2500 g).

Number of steps walked and PAEE

The number of mean steps taken daily by the 24 participants was 5922 steps, ranging from 2947 to 9205. A significant positive correlation (r = 0.798, P = 0.000) was observed between the number of steps walked and the PAEE, which indicated that daily walking as PA does consume sufficient energy, even in pregnant women.

The relationship between walking and glucose tolerance

The ratios of CGL and HbA_{1c} changes (completed/initiated) ranged from 0.54 to 1.67 and 0.83 to 1.10, respectively. As shown in Fig. 2a, there was a significant (r = −0.603, P = 0.013) negative correlation between the number of steps walked daily and the CGL ratios. In contrast, the number of steps walked daily showed no clear correlation (r = −0.071, P = 0.755) with the ratios of HbA_{1c} (Fig. 2b). On the other hand, no clear correlation was observed between the CGL ratios and body weight gain during the study period (r = 0.338, P = 0.124).

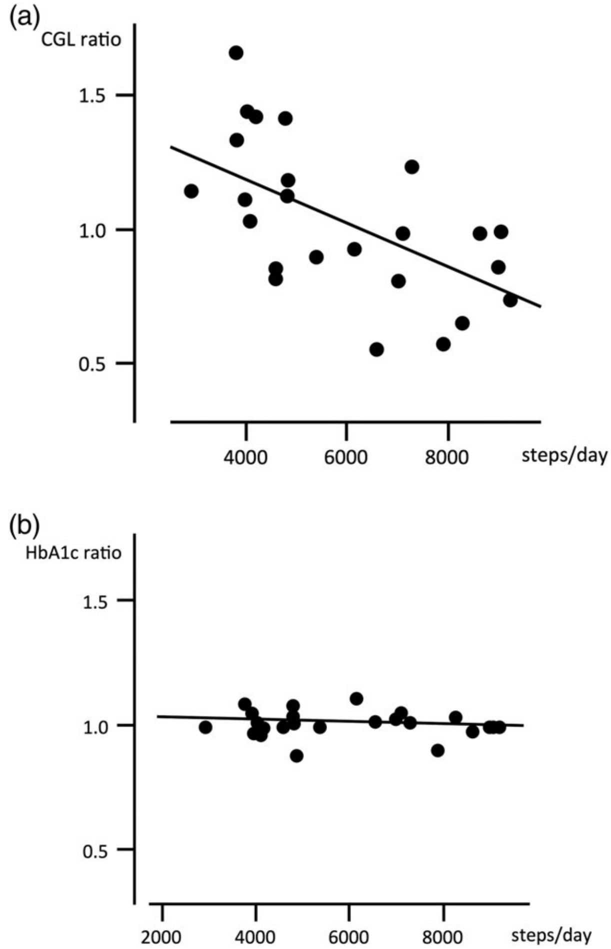

Figure 2 The correlation between the number of steps walked daily and the ratio of post- to pre-research casual glucose level (CGL) (a) and hemoglobin A_{1c} (HbA_{1c}) (b). The number of steps walked correlated significantly with CGL ratio (r = −0.603, P = 0.013) but not with the HbA_{1c} ratio (r = −0.071, P = 0.755).

PA and dietary intake

The dietary intakes evaluated by BDHQ ranged between 1125 and 2761 kcal/day (Table 1). No statistically significant correlation was observed between the number of steps walked and the dietary energy intake or the each intake of carbohydrate, protein and fat (data not shown).

Discussion

Since women who experience GDM often subsequently develop type 2 diabetes, it is very important to prevent GDM or to modify lifestyle habits such as

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diet and exercise after GDM develops. Our present study demonstrates that simple walking as light intensity PA is effective for controlling CGL independent of dietary intake in pregnant women with GDM. Our results suggest that pregnant women with GDM can benefit from walking, which can be measured as the number of steps per day.

CGL measurement is more convenient and less burdensome for pregnant women than fasting blood sugar measurement and/or a 75-g OGTT. It is known that high-intensity exercise can easily decrease CGL.[19] Barakat *et al*.[20] demonstrated that an exercise program for healthy pregnant women consisting of three sessions of aerobics and swimming per week resulted in a decrease in CGL in the intervention group. However, such an exercise program is not likely to be feasible. Prospective epidemiological studies have shown that PA is associated with a reduction in the risk of developing type 2 diabetes.[21,22] Low PA leads to glucose intolerance, and pregnant women with GDM may not exercise adequately. Thus, pregnant women with GDM require a lifestyle change, such as PA after delivery, to prevent type 2 diabetes. Despite the difficulty of obtaining adequate exercise in many pregnant women with GDM, it can be important for them to develop habits to improve non-exercise activity thermogenesis.[23] The finding of a significant negative correlation between the changes of CGL and the number of steps walked daily should be of interest in that it suggests that walking would be very beneficial for pregnant women with GDM.

In another report, improvement in HbA_{1c} level was found to be directly proportional to exercise intensity, but there was no significant HbA_{1c} improvement on the basis of the amount of exercise.[24] This finding suggests that CGL improved in proportion to exercise intensity, rather than the amount of exercise. In our research, the exercise intensity of the walking was low, which may be why no significant negative correlation between HbA_{1c} level and the number of steps walked daily was observed.

One question that remains is: What is the minimum number of steps that is suitable for GDM management in pregnant women? Although our present results suggest that the higher the number of steps walked, the better the results may be in terms of glucose tolerance improvement, it was clear from our findings that middle-aged women can prevent metabolic syndrome by walking 6000 steps or more per day.[25] Our previous study also demonstrated that walking ≥6000 steps per day could improve CGL in healthy pregnant women in the second trimester.[26] Thus, the participants in this study were divided into two groups according to the cutoff of 6000 walking steps, and CGL recorded at the point at which the research was completed were analyzed. The CGL in the group of ≥6000 steps walked (n = 11) was 95 ±10 mg/dL (mean ±SD), which was significantly lower than that (111 ±18) in the <6000 steps walked group (n = 13) (P = 0.013). No significant differences in CGL were detected when the patients were instead separated according to the cutoffs of walking 5000 (P = 0.264) or 7000 (P = 0.062) steps, respectively.

There are several limitations of this study. First, it is known that there are ethnic variations in glucose tolerance, but only Asians participated in the study. As they show the least insulin secretion on the basis of genetic factors among all ethnic groups,[27–29] it is possible for Asians to develop glucose intolerance without concomitant obesity. Thus, it is necessary for pregnant Asian women to be cognizant not only of their diet, but also of PA. Second, as the study was conducted in one hospital, our results may not be generalizable. Because the hospital is located in Toyota city, where the population of car users is highest in Japan, people may generally walk less than people in other regions. Third, although GDM occurs in all populations, the participant number was small in the present study. This may have resulted in insufficient walking data collected. Wearing of the accelerometer constantly for more than 8 weeks might also bother pregnant women during the second and third trimesters. For critical analyses, we restricted the participants to those who could complete the research protocol. Fourth, participants could not be blinded to the data from the accelerometers. Proper use was individually instructed, but number of steps walked may have been underestimated by incorrect use. Fifth, the influence of meals could not be ruled out, because CGL, rather than fasting blood sugar level, was evaluated.

In conclusion, we can recommend walking as a light-intensity PA for pregnant women for the management of GDM. However, it is necessary to follow-up sequentially with women with GDM after delivery for the long-term evaluation of the effects of this exercise regimen. Further studies should be performed to confirm that not only CGL, but also insulin resistance, is improved by walking in pregnant women with GDM.

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Disclosure

None declared.

Author contributions

A. H. participated in designing the research plan, coordinated the data analyses and contributing to the writing of the manuscript. Y. K. and Y. B. collected the data. N. S. coordinated the field work, designed the research plan and considered the composition of the paper. H. O. and J. S. collaborated and performed the study.

References

1. American Diabetes Association. Diagnosis and classification of diabetes mellitus. *Diabetes Care* 2009; **32** (Suppl 1): S62–S67.
2. HAPO Study Cooperative Research Group, Metzger BE, Lowe LP, Dyer AR *et al*. Hyperglycemia and adverse pregnancy outcomes. *N Engl J Med* 2008; **358**: 1991–2002.
3. Morikawa M, Yamada T, Yamada T *et al*. Change in the number of patients after the adoption of IADPSG criteria for hyperglycemia during pregnancy in Japanese women. *Diabetes Res Clin Pract* 2010; **90**: 339–342.
4. Steel JM, Johnstone FD, Hepburn DA, Smith AF. Can prepregnancy care of diabetic women reduce the risk of abnormal babies? *BMJ* 1990; **301**: 1070–1074.
5. Fuhrmann K, Reiher H, Semmler K, Fischer F, Fischer M, Glöckner E. Prevention of congenital malformations in infants of insulin-dependent diabetic mothers. *Diabetes Care* 1983; **6**: 219–223.
6. Landon MB, Spong CY, Thom E *et al*. A multicenter, randomized trial of treatment for mild gestational diabetes. *N Engl J Med* 2009; **361**: 1339–1348.
7. Bellamy L, Casas JP, Hingorani AD, Williams D. Type 2 diabetes mellitus after gestational diabetes: A systematic review and meta-analysis. *Lancet* 2009; **373**: 1773–1779.
8. O'Sullivan JB. Diabetes mellitus after GDM. *Diabetes* 1991; **40** (Suppl 2): 131–135.
9. WHO. Global health risks: Mortality and burden of disease attributable to selected major risks. 2009. [Cited 1 Jun 2018.] Available from URL: http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf
10. Tamura Y, Tanaka Y, Sato F *et al*. Effects of diet and exercise on muscle and liver intracellular lipid contents and insulin sensitivity in type 2 diabetic patients. *J Clin Endocrinol Metab* 2005; **90**: 3191–3196.
11. Nelson JD, Poussier P, Marliss EB, Albisser AM, Zinman B. Metabolic response of normal man and insulin-infused diabetics to postprandial exercise. *Am J Physiol* 1982; **242**: E309–E316.
12. American College of Obstetricians and Gynecologists (ACOG). Physical activity and exercise during pregnancy and the postpartum period. Committee opinion 650. *Obstet Gynecol* 2015; **126**: e135–e142.
13. Sunaga Y, Kanemura N, Anan M, Takahashi M, Shinkoda K. Estimation of inertial parameters of the lower trunk in pregnant Japanese women: A longitudinal comparative study and application to motion analysis. *Appl Ergon* 2016; **55**: 173–182.
14. Mottola MF, Campbell MK. Activity patterns during pregnancy. *Can J Appl Physiol* 2003; **28**: 642–653.
15. Pereira MA, Rifas-Shiman SL, Kleinman KP, Rich-Edwards JW, Peterson KE, Gillman MW. Predictors of change in physical activity during and after pregnancy: Project viva. *Am J Prev Med* 2007; **32**: 312–319.
16. Kumahara H, Schutz Y, Ayabe M *et al*. The use of uniaxial accelerometry for the assessment of physical-activity-related energy expenditure: A validation study against whole-body indirect calorimetry. *Brit J Nutr* 2004; **91**: 235–243.
17. Kobayashi S, Murakami K, Sasaki S *et al*. Comparison of relative validity of food group intakes estimated by comprehensive and brief-type self-administered diet history questionnaires against 16 d dietary records in Japanese adults. *Public Health Nutr* 2011; **14**: 1200–1211.
18. Kobayashi S, Honda S, Murakami K *et al*. Both comprehensive and brief self-administered diet history questionnaires satisfactorily rank nutrient intakes in Japanese adults. *J Epidemiol* 2012; **22**: 151–159.
19. Hayashi A, Suganuma N. Physical activity for gestational diabetes mellitus. *Clinics Mother Child Health* 2016; **13**: 238, https://doi.org/10.4172/2090-7214.1000238.
20. Barakat R, Cordero Y, Coteron J, Luaces M, Montejo R. Exercise during pregnancy improves maternal glucose screen at 24–28 weeks: A randomised controlled trial. *Br J Sports Med* 2012; **46**: 656–661.
21. Helmrich SP, Ragland DR, Leung RW, Paffenbarger RS Jr. Physical activity and reduced occurrence of non-insulin-dependent diabetes mellitus. *N Engl J Med* 1991; **325**: 147–152.
22. Manson JE, Stampfer MJ, Colditz GA *et al*. Physical activity and incidence of non-insulin-dependent diabetes mellitus in women. *Lancet* 1991; **338**: 774–778.
23. Levine JA, Lanningham-Foster LM, McCrady SK *et al*. Inter-individual variation in posture allocation: Possible role in human obesity. *Science* 2005; **28**: 584–586.
24. Tamura Y, Tanaka Y, Sato F *et al*. Effects of diet and exercise on muscle and liver intracellular lipid contents and insulin

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sensitivity type 2 diabetic patients. *J Clin Endocrinol Metab* 2005; **90**: 3191–3196.
25. Colpani V, Oppermann K, Spritzer PM. Association between habitual physical activity and lower cardiovascular risk in premenopausal, perimenopausal, and postmenopausal women: A population-based study. *Menopause* 2013; **20**: 525–531.
26. Hayashi A, Matsuzaki M, Kusaka M, Shiraishi M, Haruna M. Daily walking decreases casual glucose level among pregnant women in the second trimester. *Drug Discov Ther* 2016; **10**: 218–222.
27. Unoki H, Takahashi A, Kawaguchi T *et al*. SNPs in KCNQ1 are associated with susceptibility to type 2 diabetes in east Asian and European populations. *Nature Genet* 2008; **40**: 1098–1102.
28. Okamoto K, Iwasaki N, Nishimura C *et al*. Identification of KCNJ15 as a susceptibility gene in Asian patients with type 2 diabetes mellitus. *Am J Hum Genet* 2010; **86**: 54–64.
29. Yamauchi T, Hara K, Maeda S *et al*. A genome-wide association study in the Japanese population identifies susceptibility loci for type 2 diabetes at UBE2E2 and C2CD4A-C2CD4B. *Nature Genet* 2010; **42**: 864–868.

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