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Effects of dynamic stretching in a seated or supine position on blood glucose levels among young adult women wearing a maternity simulation jacket

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Abstract

During pregnancy, physiological insulin resistance increases due to endocrine factors secreted by the placenta. Gestational diabetes mellitus is an example of a common complication arising from this phenomenon, for which exercise therapy is used as standard treatment. While the acute effects of static stretching on blood glucose levels are known, the effects of dynamic stretching in a seated or supine position are unclear. This study investigated the effects of dynamic stretching in a seated or supine position on blood glucose levels in young adult women with post-load hyperglycemia wearing a maternity simulation jacket. We included 11 healthy women in the luteal phase of their menstrual cycles with blood glucose levels >140 mg/dL 30 min after glucose loading. Four exercise conditions were established: bed-stretching (BSt) involving dynamic stretching in a seated, supine, or lateral position, standing-stretching (SSt) involving dynamic stretching in a standing position, walking (W) involving treadmill walking at a comfortable speed, and control (C) involving sitting at rest. After fasting for 10–14 h, blood glucose levels were measured using self-monitoring blood glucose at baseline and every 15 min for 120 min thereafter. In the BSt and W conditions, the blood glucose levels, peaks, and area under the curve at 45 and 60 min after glucose loading were significantly lower than those in the C condition. Therefore, dynamic stretching in a seated or supine position suppressed blood glucose level elevation after glucose loading in young adult women with post-load hyperglycemia wearing a maternity simulation jacket.

Keywords: dynamic stretching, maternity simulation jacket, post-load hyperglycemia

「妊婦体験ジャケットを着用した若年成人女性における

臥位または座位での動的ストレッチングが血糖値に及ぼす影響」

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妊娠時、胎盤から分泌される内分泌因子によって生理的インスリン 抵抗性が亢進される。それによる妊娠合併症の代表例として妊娠糖尿病があり、治療の代表例として運動療法が用いられる。静的ストレッチングの血糖値に対する急性効果は知られているが、座位または臥位での動的ストレッチングの効果は明らかではない。本研究では、座位または臥位での動的ストレッチングの血糖値への影響を明らかにすることを目的とした。本研究では、妊婦体験ジャケットを着用した負荷後高血糖の若年成人女性において、座位または臥位での動的ストレッチングが血糖値に及ぼす影響を検討した。対象は、月経周期の黄体期にあり、ブドウ糖負荷 30 分後の血糖値が 140mg/dl を超える健康な女性 11 名とした。運動条件は、座位または臥位で動的ストレッチングを行う BSt 条件、立位で動的ストレッチングを行う SSt 条件、快適な速度でトレッドミル歩行を行う W 条件、安静座位を保持する C 条件の 4 種類とした。10〜14 時間の絶食後、ベースライ

ン時およびその後 120 分間 15 分ごとに自己血糖測定法を用いて血糖値を測定した。BSt および W 条件では、グルコース負荷後 45 分および 60 分の血糖値、糖負荷後ピーク血糖値、iAUC が C 条件よりも有意に低かった。したがって、立位、歩行、安静時に比べ、座位または臥位での動的ストレッチングは、妊婦体験ジャケットを着用した負荷後高血糖の若年成人女性において、ブドウ糖負荷後の血糖値上昇を抑制した。

Introduction

During pregnancy, the placenta secretes various endocrine factors, such as estrogen and progesterone, that alter autonomic nervous system activity and cellular glucose uptake, causing increased heart rate, psychological stress, physiological insulin resistance, and postprandial hyperglycemia (*1, 2*). Gestational diabetes mellitus (GDM) is a typical complication of pregnancy with a global standardized prevalence of 14.7% in the Western Pacific region as of 2021 (*3*). A meta-analysis evaluating more than 1.3 million individuals reported that the incidence of type 2 diabetes was approximately 10 times higher in women with a history of GDM than those with normoglycemic levels (*4*).

Currently, exercise, such as walking or aerobics, is generally recommended to treat GDM and improve hyperglycemia. However, although public health guidelines advise that adults engage in 30–150 min of moderate-intensity exercise at approximately 60% heart rate reserve (HRR) or 50–60% maximal oxygen uptake (VO_2max) per week, the rate of achievement remains low (*5, 6*). Stretching is generally recommended as a form of low-intensity exercise and can be divided into two main categories: static and dynamic. Stretching can be performed in a standing, sitting, or supine position. However, pregnant women are prone to back pain while standing because of uterine expansion and lumbar kyphosis, which shift the center of gravity forward and increases pressure on the lower back (*7*). Reports indicate that habitually implemented stretching performed in a seated or supine position can be effective in treating back pain and preventing GDM and preeclampsia in pregnant women with sedentary behavior (*8, 9*). Dynamic stretching involves active movements that elongate the target muscle through isotonic contraction of the antagonist muscle, whereas static stretching involves holding a stretched position for a specific duration. Various studies have addressed the acute effects of static stretching on lowering blood glucose after glucose loading (*10, 11*). The mechanisms by which dynamic stretching improves muscular performance have been suggested to be elevated muscle and body temperature, post-activation potentiation in the stretched muscle caused by voluntary contractions of the antagonist, stimulation of the nervous system, and/or decreased inhibition of antagonist muscles (*12*). Considering these facts, we hypothesized that dynamic stretching may be one of the potential safety exercise therapies that can contribute to the suppression of blood glucose level elevation after glucose loading.

Therefore, this study aimed to clarify the effects of dynamic stretching in a seated or supine position on blood glucose levels and compare the effects with those observed while sitting at rest, dynamic stretching in a standing position, and walking. Moreover, young adult normoglycemic women were included to provide a basis for proposing an effective exercise regimen for patients with GDM.

Materials and Methods

Participants

This study included young adult women with a fasting blood glucose level <110 mg/dL and a blood glucose level of ≥140 mg/dL 30 min after consuming 500 mL of a commercially-available glucose-loaded beverage (200 kcal/50 g carbohydrate/0 g protein/0 g fat; Fanta Grape, The Coca-Cola (Japan) Company, Shibuya, Tokyo, Japan). The blood glucose management target for pregnant women with diabetes is to achieve a postprandial hourly value of less than 140 mg/dL, and participants were screened for possible deviations from the target level (*13*). Since the purpose of this study was not to diagnose diabetes, and merely aimed to obtain basic data on non-pregnant healthy women, the glucose load was reduced from 75 g with side effects such as nausea to 50g, commercial beverages were used, which are available to everyone. The exclusion criteria were musculoskeletal diseases, comorbid medical conditions, medium- or high-dosage pill (Estrogen-Progesteron) usage, premenstrual syndrome that hinders exercise, and irregular menstruation (defined as deviating from the following Japanese Society of Obstetrics and Gynecology criteria: menstrual cycle, 25–38 days; menstruation duration, 3–7 days). Among the 13 participants screened, 11 met the eligibility criteria and were included in the study. The participants had a mean age of 22.2±1.0 years, height of 159.7±5.4 cm, weight of 52.6±5.2 kg, and body mass index (BMI) of 20.6±1.6 kg/m². The full demographic, clinical, and exercise-related characteristics of the participants are shown in Table 1.

[Insert Table 1 here]

A sample size of 8 participants was calculated using G*Power 3.1.9.4 (effect size f: 0.25, α err prob: 0.05 and Power (1-β err prob): 0.95), but set at approximately 10 to account for drop-outs since the participants were asked to take part in the study five times.

This study was approved by the Ethics Committee of Health Sciences, Graduate School of Health Sciences, Kobe University (approval no. 1093) and performed in accordance with the Declaration of Helsinki. The purpose, content, and risks of the study were fully explained orally and in writing to the participants, and written consent was obtained before the study was conducted.

Study protocol

The exercises were performed under the four following conditions after glucose loading: bed-stretching (BSt), in which participants performed dynamic stretching in a supine, lateral, or seated position; standing-stretching (SSt), in which participants performed dynamic stretching in a standing position; walking (W), in which participants walked on a treadmill at a comfortable speed; and control (C), in which the participants remained in a seated resting position. The order of experimentation for the four conditions was randomly assigned to each participant using a random number table to conduct a randomized crossover study design. Each condition was performed at the same time of day on different days, at least two days apart.

Luteal phase estimation

To mimic the hormonal dynamics of gestation, all experimental schedules were conducted during the post-ovulatory luteal phase of the participant's menstrual cycles, when progesterone levels were highest (*14*). No measurements of various hormone concentrations were taken. The participants underwent daily basal body temperature charting. After determining the point at which the basal body temperature increased after a low-temperature phase, which is generally used as an indicator of ovulation, the luteal phase was estimated and the dates of each experiment were scheduled.

Experimental procedure

After fasting for a duration of 10–14 h, electrodes were placed on the participant's chest and an electrocardiogram was recorded while wearing a maternity simulation jacket (LM-054; Koken Co., Ltd., Tokyo, Japan) (Fig. 2). Generally, a total of three blood tests, including blood glucose measurements, are performed during antenatal checkups in the first, second, and third trimesters of pregnancy. To investigate effective exercises for preventing GDM, we selected the mid-pregnancy period, when a higher percentage of pregnant women can comfortably ingest food after symptoms such as morning sickness have subsided. In addition, the percentage of high blood glucose levels increases as the gestational period progresses, however, the fact that there is no difference in pregnancy and delivery outcomes associated with appropriate interventions, that approximately half of those diagnosed with GDM in early pregnancy have no GDM pattern in second trimester, and that the majority of abortions are in first trimester, indicates the importance of interventions using physical activity from the middle of pregnancy onwards. Second trimester was set because it was considered to be more important (*15, 16*). Additionally, the weight of the jacket was set to 4.2 kg to reflect mid-pregnancy. Next, the finger-C7 distance, which is the distance from the spinous process of the 7th cervical vertebra (C7) to the apex of the thumb when the upper limb is rotated from behind and below the trunk, was measured in the sitting position, while the knee socket angle was measured in the supine position as an index of range of joint motion (ROM). The fasting blood glucose level was measured while sitting at rest for 15 min. The degree of lower back pain was assessed using a visual analog scale (VAS). Baseline cardiac parasympathetic nervous system (PNS) activity was also measured by electrocardiography. Then, the designated glucose-loaded beverage was consumed over a 10 min period. The rate of perceived exertion (RPE) was measured in the upper extremities, trunk, and lower extremities in the BSt and SSt conditions using the Borg Scale, and after each minute in the W condition. Back pain was measured using the VAS during the rest period between sets. The heart rate was continuously measured during the experiment, and self-monitoring of blood glucose (SMBG) was measured using a blood glucose meter (One Touch Ultra View, LifeScan Japan, Inc., Tokyo, Japan) on nine occasions: immediately before glucose loading and every 15 min after glucose loading for a total of 120 min. Cardiac PNS activity was measured in a sitting position while controlling respiration (inhaling and exhaling for 2 s each) using an electronic metronome for 5 min. High-frequency (HF) components of heartbeat variability within 0.15–0.40 Hz were recorded using a real-time heartbeat fluctuation analysis program (MemCalc/Tarawa, Suwa Trust, Tokyo, Japan).

[Insert Fig. 1 and 2 here]

Condition setting

The BSt and SSt conditions, each comprising 13 dynamic stretching exercises involving the neck, upper limbs, trunk, and lower limbs, were performed at a speed determined by a metronome and within each participant's full ROM as follows: one set of 14 min, a 10-s rest between stretches, and a 2-min rest between sets. The BSt condition was conducted in a supine, lateral, or end-sitting position on a bed, while the SSt condition was conducted in a standing position on a hard surface with a handrail for assistance, if needed. While under the W condition, participants walked on a treadmill and were asked to indicate their Borg RPE every 1 min. The treadmill walking speed and inclination angle were adjusted to correspond to an RPE of 11 (easy). The C condition involved resting for 30 min in an end-sitting position.

[Insert Fig. 3 here]

Statistical analysis

All measurements are shown as the mean ± standard deviation, with the exception of RPE (median ± standard error). The incremental area under the blood glucose response curve (iAUC) from immediately before and 120 min after the start of glucose loading was calculated using the trapezoidal method. Cardiac PNS activity was calculated as the natural log-transformed value of the HF (LnHF). Changes in VAS scores were calculated as the difference in back pain during and before the intervention (Δ during intervention) and the difference in back pain after and before the intervention (Δ after intervention).

Two-way repeated-measures analysis of variance (ANOVA) was performed to determine the condition and time effects for blood glucose, LnHF, finger-C7 distance, and knee ROM angle <2 h after the start of glucose loading. One-way repeated-measures ANOVA was performed for low VAS change, post-loading peak blood glucose, iAUC, and exercise intensity (%HRR). Mauchly's sphericity test was used to validate the ANOVA. If the assumption of sphericity was rejected ($p<0.05$), the epsilon was adjusted using the Greenhouse–Geisser method. The Holm method was used for post-hoc analysis. All statistical analyses were performed using R for Windows (version 4.1.2; R Core Team, Vienna, Austria). P-values <0.05 were considered statistically significant.

Results

RPE was 11±0.4, 11±0.3, and 11±0.1 in the BSt, SSt, and W conditions, respectively. Exercise intensity (%HRR) was -0.83% in the C condition, 7.84% in the BSt condition, 14.7% in the SSt condition, and 21.5% in the W condition ($p<0.01$, *partial* $\eta^2=0.79$, $F=36.8$, $df=10$). Regarding exercise intensity, post-hoc analysis revealed that the BSt condition was significantly lower than the SSt and W conditions, the SSt condition was significantly lower than the W condition, and the C condition was significantly lower than the other three conditions (all $p<0.05$).

The blood glucose levels of all participants are shown in Fig. 4. Under all conditions, blood glucose levels increased after the start of glucose loading, peaked at 30 min, and decreased until 120 min after the start of glucose loading at the final measurement. Moreover, we found significant differences in the time ($p<0.01$), condition ($p<0.001$), and interaction ($p<0.001$, *partial* $\eta^2=0.46$, $F=8.39$, $df=24$). Regarding blood glucose levels measured after the start of glucose loading, post-test analysis revealed that the BSt condition was significantly lower than the C condition at 30, 45, and 60 min and the W condition at 60 min, the W condition was significantly lower than the C condition at 30, 45, and 75 min, while the SSt condition was significantly lower at 45 and 60 min than the C condition (all $p<0.05$).

[Insert Fig. 4 here]

The iAUCs for each condition are shown in Fig. 5. There was a significant difference in the main effect of conditions ($p<0.01$, *partial* $\eta^2=0.52$, $F=10.87$, $df=1.61$), with post-hoc analysis revealing that the BSt and W conditions were significantly lower than the C condition ($p<0.05$).

[Insert Fig. 5 here]

The post-loading peak blood glucose levels in each condition showed a significant difference in the main effect of conditions ($p<0.01$, *partial* $\eta^2=0.40$, $F=6.65$, $df=3$), with post-hoc analysis revealing that the BSt (147.4±18.6 mg/dL) and W (142.6±11.4 mg/dL) conditions were significantly lower than the C (171.6±21.1 mg/dL) condition (all $p<0.05$).

No significant inter-condition differences in LnHF were found over time before and after the intervention or in the main effect of conditions and interaction effects. The changes in VAS scores for back pain under each condition are shown in Figure 6. No significant differences in the main effect of conditions during and after the intervention (Δintervention: $p=0.12$, $\eta^2=0.13$, $F=2.61$, $df=1.40$; Δpost-intervention: $p=0.056$, $\eta^2=0.21$, $F=4.06$, $df=1.32$) were found.

[Insert Fig. 6 here]

The finger-C7 distance in each condition showed significant differences in the main time and interaction effects ($p=0.05$, *partial* $\eta^2=0.33$, $F=4.96$, $df=2.51$), but not in the main effect of conditions. Post-test analysis showed a significant increase in ROM from pre-intervention (11.4±4.4 cm) to post-intervention (9.7±3.6 cm) in the BSt condition ($p<0.05$), but not in the SSt condition.

No significant differences in knee socket angles in each condition over time before and after the intervention or in main condition and interaction effects were found.

Discussion

This study examined the effects of dynamic stretching in a seated or supine position on blood glucose levels in young adult women with post-load hyperglycemia wearing maternity simulation jackets. We found that participants in the BSt condition compared to the C condition had significantly lower blood glucose levels at 30, 45, and 60 min after glucose loading, blood glucose peaks after glucose loading, and iAUC ($p<0.05$). These results are similar to those obtained in the W condition. Postprandial hyperglycemia and blood glucose spikes <2 h after consuming food are considered risk factors for cardiometabolic disorders not only in patients with diabetes, but also in healthy individuals (*17, 18, 19*). The present study showed that exercising under the BSt condition could effectively resolve post-load glucose spikes and reduce the increase in blood glucose within 120 min after glucose loading compared with the controls. In contrast, the iAUC and blood glucose levels at 60 min after initiating glucose loading were not significantly different in the SSt condition than those in the C condition. During acute exercise or stretching, skeletal muscle contraction causes glucose transporter 4 (GLUT4) translocation to the plasma membrane (*20*) and activates insulin-independent glucose transport, ultimately promoting glucose uptake and improving glycemic control (*11, 21*). The reason why the blood glucose trend was significantly higher at the end of the exercise (45 minutes) compared to the BSt condition is that the exercise intensity was significantly higher in the W condition than in the other conditions, although the RPE was the same (in terms of perception), and the load applied to the front of the trunk required the participant to contract muscles that would not contract in the non-pregnant state, this may be due to the higher heart rate induced by catecholamines and the increase in blood glucose induced by glucocorticoids (*22*). The BSt condition showed significantly improved ROM before and after the intervention compared to the finger intervertebral distance, suggesting stretching of the target muscle, accompanied by contraction of the antagonist muscle. In contrast, the SSt condition showed no significant difference in pre- and post-intervention finger-C7 distance, and the stretching effect of correcting blood glucose levels was lower than that of the BSt condition. Reports indicate that dynamic balance in the standing position is reduced when wearing a maternity simulation jacket (*23*); thus, instability may have impacted ROM while stretching under the SSt condition.

Although there were no significant inter-condition differences in VAS scores, there was a trend towards reduced back pain after exercise in the BSt condition (Δ post-intervention effect size, η^2=0.21). Because back pain can hinder physical activity engagement, exercising under the BSt condition may be easily adopted during pregnancy to promote good exercise habits.

No significant differences were observed in LnHF, a stress indicator of cardiac PNS activity, either over time or between conditions. Although there are examples of enhanced PNS activity after static stretching and yoga, Farinatti et al. (*24*) reported that PNS activity in individuals with low flexibility and isometric antagonist muscle contractions during static stretching did not differ significantly before and after the intervention. Moreover, Michael et al. (*25*) found that PNS activity recovery was delayed after high-intensity exercises and was not significantly different before and after the intervention in pregnant women. Low-intensity exercise that does not decrease PNS activity may be beneficial to reduce stress in pregnant women, whose PNS activity tends to be suppressed due to hormonal changes.

These findings suggest that dynamic stretching in a seated or supine position significantly reduced blood glucose levels in young adult women wearing a maternity simulation jacket with post-load hyperglycemia more than when resting, sitting, and walking. Moreover, stretching in this position improved glycemic control, tended to reduce back pain, and suppressed PNS activity.

This study has some limitations. First, since the participants were young adult non-pregnant women, their condition differed from the hormonal dynamics of pregnancy, and the results were limited to blood glucose variability during frontal trunk loading. Second, VO_2max and energy expenditure were not measured using expiratory gas analysis; hence, exercise intensity was not matched across conditions, making it difficult to examine and directly compare the effects of exercise on blood glucose correction. Lastly, blood glucose data were obtained by SMBG using a glucometer and sensor, which have a specific margin range of error. Therefore, future studies with larger sample sizes should be conducted to validate the results of this study, as well as those examining the effects of different energy expenditure-matched exercise modalities on blood glucose correction and of dynamic stretching in both normo- and hyperglycemic pregnant women.

This study found that dynamic stretching in a seated or supine position significantly reduced blood glucose levels and blood glucose peaks within 120 min after glucose loading in young adult women with post-load hyperglycemia wearing a maternity simulation jacket during the luteal phase of their menstrual cycle. This suggests that dynamic stretching in a seated or supine position is superior to exercising while standing and walking in terms of lowering back pain and controlling blood glucose levels in young hyperglycemic women. These findings may also provide a basis for proposing an effective exercise regimen for patients with GDM.

Contributions

OK conceptualized the research design and protocol, and carried out the interpretation of data. NM conceptualized the study design and protocol, collected and assembled the data, and carried out the analysis and interpretation of data. OJ, YY, and YR collected and carried out the interpretation of data. OK and NM drafted the manuscript. All authors have critically reviewed, revised, and approved the manuscript.

Clinical trial registration

This study was registered with the University Hospital Medical Information Network (UMIN) Clinical Trials Registry (registration number: UMIN000052137).

Conflict of Interest

All authors declare that there is no conflict of interests regarding the publication of this article.

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References

1）Izumi M, Manabe E, Uematsu S, Watanabe A and Iwasa K. 2019. Autonomic nervous system activity from gestation to the postpartum period. *J JSPOG* 24: 149-156. doi: 10.18977/jspog.24.2_149.

2) Fukui T and Imoto H. 2019. Practical guide to gestational diabetes care for midwives. *In: Josanshi no tame no ninshintounyoubyou kea jissen gaido* (*in* Japanese), 13, Ishiyaku Publishers Inc., Tokyo, Japan.

3）Wang, H, Li N, Chivese T, Werfalli M, Sun H, Yuen L, Hoegfeldt CA, Elise Powe C, Immanuel J, Karuranga S and Divakar H. 2022. IDF Diabetes Atlas: Estimation of global and regional gestational diabetes mellitus prevalence for 2021 by International Association of Diabetes in Pregnancy Study Group's Criteria. *Diabetes Res Clin Pract* 183: 109050. doi: 10.1016/j.diabres.2021.109050.

4）Vounzoulaki, E, Khunti K, Abner SC, Tan BK, Davies MJ and Gillies CL. 2020. Progression to type 2 diabetes in women with a known history of gestational diabetes: Systematic review and meta-analysis. *BMJ* 369: m1361. doi: 10.1136/bmj.m1361.

5）Savvaki D, Taousani E, Goulis DG, Tsirou E, Voziki E, Douda H, Nikolettos N and Tokmakidis SP. 2018. Guidelines for exercise during normal pregnancy and gestational diabetes: A review of international recommendations. *Hormones* 17: 521-529. doi:

10.1007/s42000-018-0085-6.

6) Skjold I, Benvenuti MB and Haakstad LA. 2022. Why do so many pregnant women give up exercise? An Italian cross-sectional study. *Womens Health (Lond)* 18: 1-10. doi: 10.1177/17455057221117796.

7) Fiat F, Merghes PE, Scurtu AD, Almajan Guta B, Dehelean CA, Varan N and Bernad E. 2022. The main changes in pregnancy-therapeutic approach to musculoskeletal pain. *Medicina (Kaunas)* 58:1115. doi: 10.3390/medicina58081115.

8) Carvalho AF, Dufresne SS, De Oliveira MR, Furlanetto KC, Dubois M, Dallaire M, Ngomo S and da Silva RA. 2020. Effects of lumbar stabilization and muscular stretching on pain, disabilities, postural control and muscle activation in pregnant woman with low back pain. *Eur J Phys Rehabil Med* 56: 297-306. doi: 10.23736/S1973-9087.20.06086-4.

9) Yeo S and Kang JH. 2021. Low-intensity exercise and pregnancy outcomes: An examination in the Nurses' Health Study II. *Womens Health Rep (New Rochelle)* 2: 389-395. doi: 10.1089/whr.2021.0011.

10) Gurudut P and Rajan AP. 2017. Immediate effect of passive static stretching versus resistance exercises on postprandial blood sugar levels in type 2 diabetes mellitus: A randomized clinical trial. *J Exerc Rehabil* 13: 581-587. 10.12965/jer.1735032.516.

11) Nagasawa T and Shiroishi K. 2015. Effect of stretching on suppressing the rise in

blood glucose levels after a glucose tolerance test and correcting postprandial hyperglycaemia. *Ther Res* 36: 673-678.

12）Behm DG, Chaouachi A. 2011. A review of the acute effects of static and dynamic stretching on performance. *Eur J Appl Physiol* 111: 2633–2651. doi: 10.1007/s00421-011-1879-2.

13）Araki E, Goto A, Kondo T, Noda M, Noto H, Origasa H, Osawa H, Taguchi A, Tanizawa Y, Tobe K, Yoshioka N. 2020. Japanese Clinical Practive Guideline for Diabetes 2019. *Diabetology International* 11:165-223.

14）Okaniwa Y. 2018. Visible Illness: Gynaecology and breast surgery. *Byouki ga mieru Hujinka ・Nyuusengeka* (*in* Japanese), 4th edition, 9: 20, Medic Media Co., Ltd., Tokyo, Japan.

15）Hagiwara Y, Kasai J, Nakanishi S, Saigusa Y, Miyagi E, Aoki S. 2018. Should the IADPSG criteria be applied when diagnosing early-onset gestational diabetes? *Diabetes Res Clin Pract* 140, 154-161, doi: 10.1016/j.diabres.2018.03.048.

16）Nakanishi S, Aoki S, Kasai J, Shindo R, Obata S, Hasegawa Y, Mochimaru A, Miyagi E. High probability of false-positive gestational diabetes mellitus diagnosis during early pregnancy. *BMJ Open Diabetes Res Care* 8: e001234, doi: 10.1136/bmjdrc-2020-001234.

17) Ceriello A and Genovese S. 2016. Atherogenicity of postprandial hyperglycemia and

lipotoxicity. *Rev Endocr Metab Disord* 17: 111-116. doi: 10.1007/s11154-016-9341-8.

18) Haxhi J, Scotto di Palumbo A and Sacchetti M. 2013. Exercising for metabolic control: Is timing important? *Ann Nutr Metab* 62: 14-25. doi: 10.1159/000343788.

19) Monnier L, Colette C and Owens DR. 2008. Glycemic variability: The third component of the dysglycemia in diabetes. Is it important? How to measure it? *J Diabetes Sci Technol* 2: 1094-1100. doi: 10.1177/193229680800200618.

20) Richter EA and Hargreaves M. 2013. Exercise, GLUT4, and skeletal muscle glucose uptake. *Physiol Rev* 93: 993-1017. doi: 10.1152/physrev.00038.2012.

21）Park SH. 2015. Effects of passive static stretching on blood glucose levels in patients with type 2 diabetes mellitus. *J Phys Ther Sci* 27: 1463-1465. doi: 10.1589/jpts.27.1463.

22） translation Suzuki and Onose. 1999. The Adrenocortical hormones. UNIT XIV Chapter 77 *In: Guyton & Hall ：Textbook of Medical Physiology, 9th edition*, *Japanese edition,* 967-979, Igaku-Syoin Ltd., Tokyo, Japan.

23) Inoue-Hirakawa T, Ito A, Iguchi S, Watanabe H, Kato C, Sugiura H and Suzuki S. 2021. The effect of simulated gestational weight gain on balance, gait, and fear of falling. *Nagoya J Med Sci* 83: 41-49. doi: 10.18999/nagjms.83.1.41.

24) Farinatti PT, Brandão C, Soares PP and Duarte AF. 2011. Acute effects of stretching exercise on the heart rate variability in subjects with low flexibility levels. *J Strength*

Cond Res 25: 1579-1585. doi: 10.1519/JSC.0b013e3181e06ce1.

25) Michael S, Jay O, Graham KS and Davis GM. 2017. Higher exercise intensity delays postexercise recovery of impedance-derived cardiac sympathetic activity. *Appl Physiol Nutr Metab* 42: 834-840. doi: 10.1139/apnm-2017-0049.

Figure Legends

Fig. 1: Study details and protocols.

Fig. 2: The maternity simulation jacket.

Fig. 3: Blood glucose level measurements from immediately before glucose loading to 120 min after the start of glucose loading.

Blood glucose levels in the bed-stretching (BSt) condition is significantly lower than those of the control (C) condition at 30, 45, and 60 min after glucose loading.

Fig. 4: Area under the elevated blood glucose concentration curve 120 min after glucose loading.

Blood glucose levels in the bed-stretching (BSt) and walking (W) conditions are significantly lower than those of the C conditions.

Fig. 5: Changes in visual analog scale (VAS) scores from baseline back pain levels.

(A) showed intervention phase. (B) showed after intervention phase. The bed-stretching (BSt) condition shows a decreasing trend, but is not significantly different than the other conditions.

Tables

Table 1. Characteristics of participants under each condition.

Number of Participants	11
Age (years old)	22.4±1.0
Height (cm)	159.7±5.4
Body Weight (kg)	52.6±5.2
Body Mass Index (kg/m^2)	20.6±1.6
Fasting Blood Glucose (mg/dL)	91.1±7.4
Peak Blood Glucose after Glucose Load (mg/dL)	171.6±21.0
Walking Speed (km/h)	3.9±1.0
Walking Slope Angle (%)	1.3±0.8

(Mean ± Standard Deviation)

Fig. 1: Study details and protocols

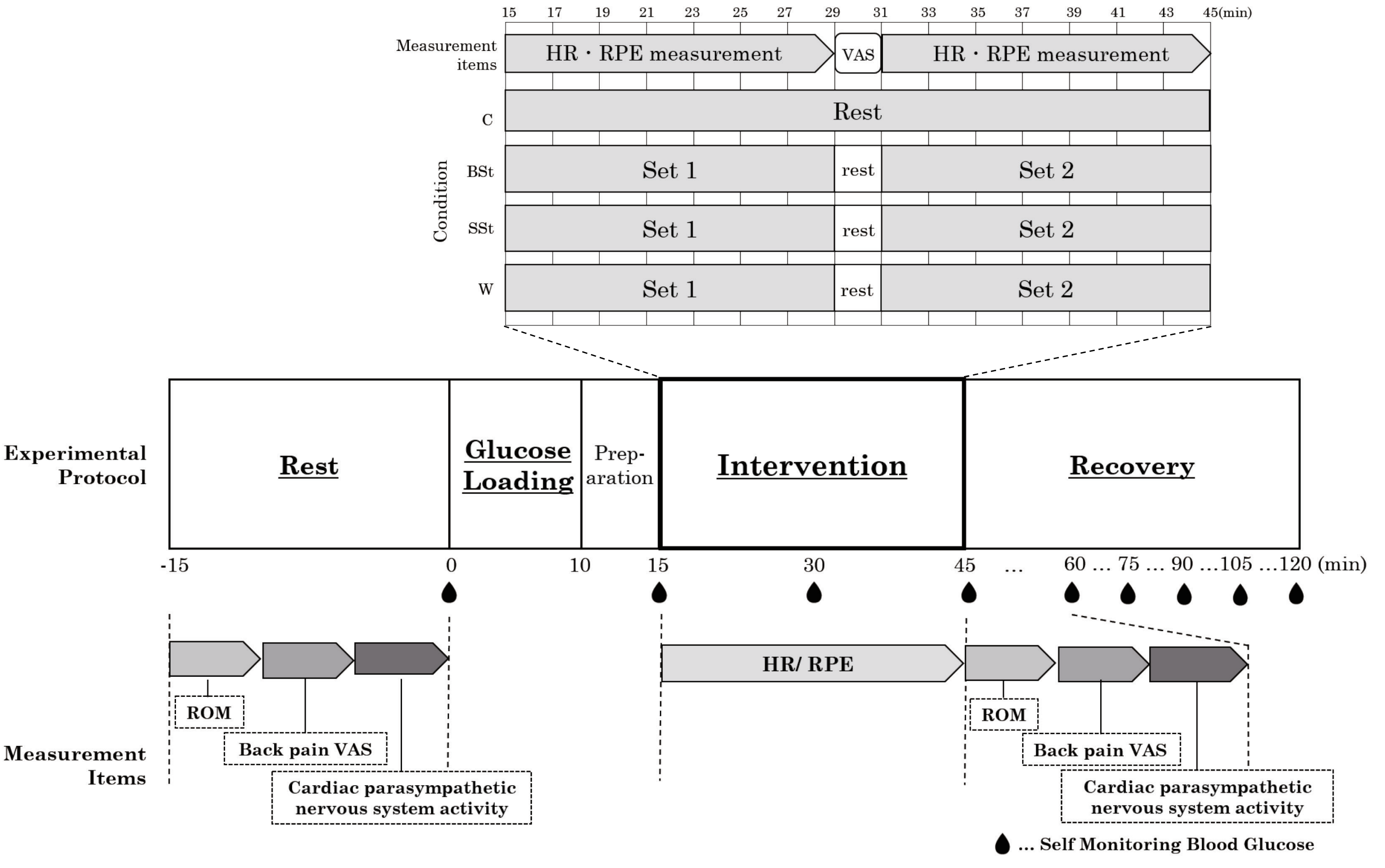

Fig. 2: The maternity simulation jacket

Fig. 3: Description of the stretching condition

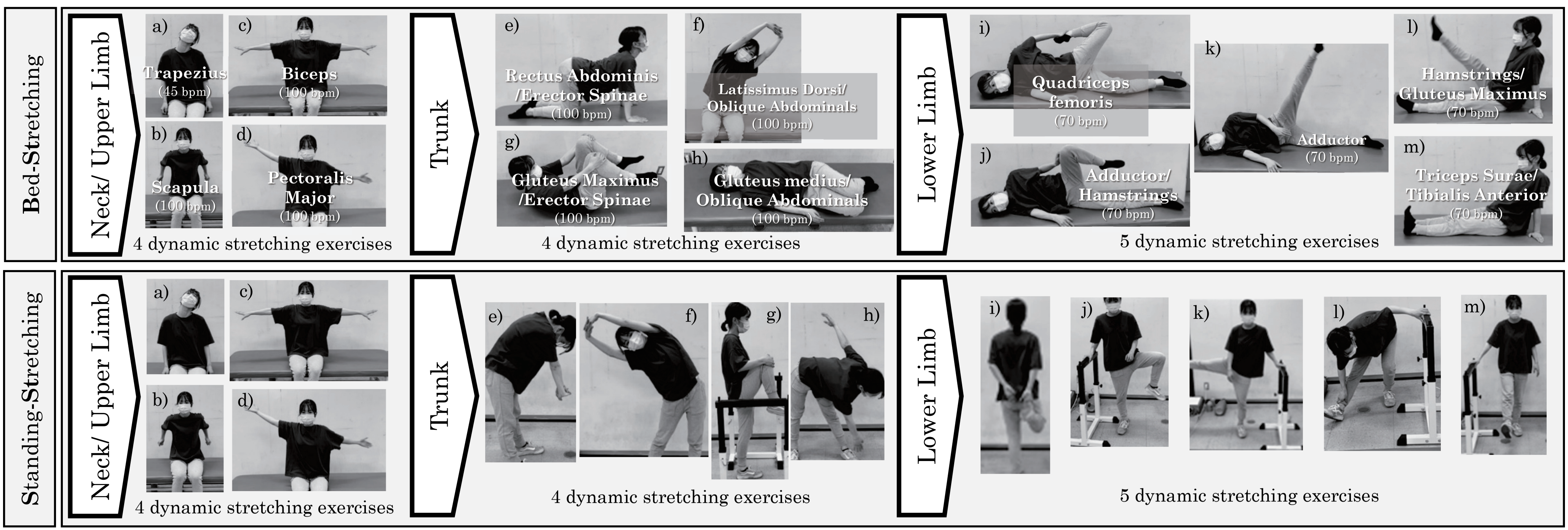

Fig. 4: Blood glucose level measurements from immediately before glucose loading to 120 min after the start of glucose loading

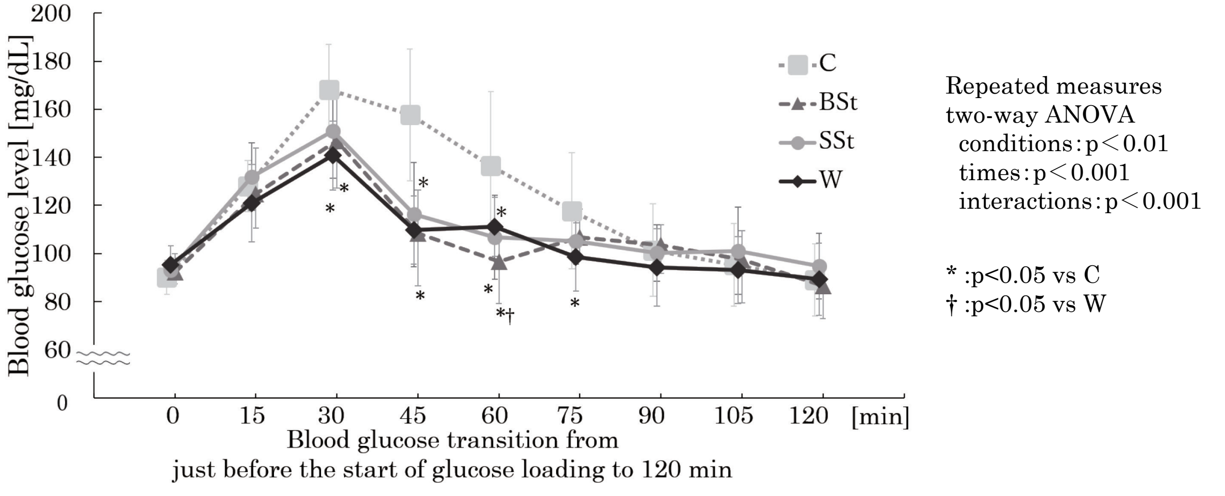

Fig. 5: Area under the elevated blood glucose concentration curve 120 min after glucose loading.

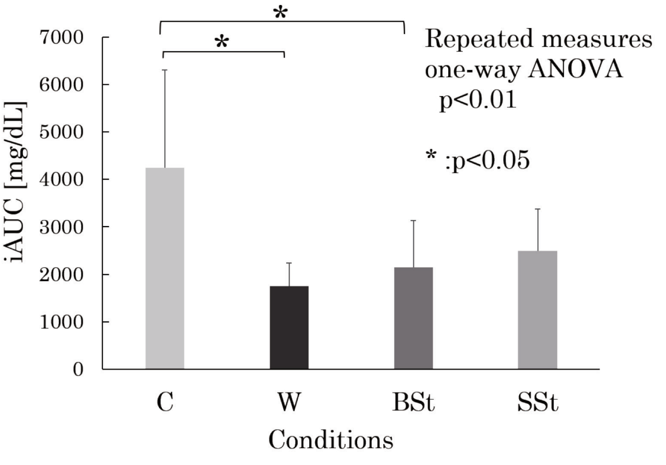

Fig. 6: Changes in visual analog scale (VAS) scores from baseline back pain levels.