Original Article

Study on time-based variation of blood circulation index, pulse wave energy, and RAI of healthy adult men after different eating times

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ABSTRACT

Background: The purpose of this study is to examine the effects of different eating times on blood circulation index, pulse wave energy (E), and radial augmentation index (RAI) of healthy adult men.

Methods: Blood circulation index, E, and RAI were measured using a three-dimensional (3-D) pulse imaging system (3-D MAC) at before, right after, 30 minutes after, 1 hour after, and 2 hours after eating.

Results: In the blood circulation index, heart rate (HR), estimated cardiac output (ECO), and estimated cardiac output index (ECI) increased significantly right after eating compared to before eating. By contrast, estimated circulation resistance (ECR) and estimated circulation resistance index (ECRI) decreased significantly right after eating compared to before eating. E had a tendency to increase right after eating compared to before eating and decrease gradually at every experimental point (left and right Chon, Kwan, and Cheok). RAI had a tendency to decrease right after eating compared to before eating and increase gradually at every experimental point.

Conclusions: Different eating times can bring about changes on blood circulation index, E, and RAI. These changes show a certain tendency and coincide with the physiological factors that eating causes a rise of HR, an increase of systolic cardiac pump performance, and a reduction of peripheral vascular resistance.

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1. Introduction

Arterial stiffness and excessive pressure pulsatility have emerged as important risk factors for cardiovascular disease. Generally, it increases with age and in the presence of traditional cardiovascular disease risk factors, such as obesity, hypercholesterolemia, type 2 diabetes mellitus (T2DM), hypertension, and so on.

Pulse wave diagnosis is a unique diagnostic system in oriental medicine. In the early times of development of this diagnostic system, diagnosis by pulse wave was performed on many points of the human body. However, due to convenience, the points used by this diagnostic system were focused on the Chon, Kwan, and Cheok, the points where the radial artery can be palpated.  

In studies of diagnosis using pulse wave, research on specific diseases commands a large majority, especially hypertension, arteriosclerosis, etc.  

Like pathological factors, many types of physiological factors can cause variations of the pulse wave. These factors include climate, seasons, geographic environment, sex, age, physique, affectivity, labor, eating, and so on. However, few studies have examined the relationships between physiological factors and pulse wave of healthy adult men. The category of pulse can be divided into pathological section and physiological section. Therefore, the categorization of pulse is important to clinical applications.

Moreover, pulse wave velocity was associated with skeletal muscle decline. Pulse wave velocity represents arterial stiffness. It was reported that supervised walking activity had a beneficial effect on subclinical vascular damage, particularly in hypertensive patients. 

Eating is a physiological factor that can cause changes of pulse wave. Generally, eating brings about a concentration of blood flow in the gastrointestinal system, a rise of systolic cardiac pump performance, and a reduction of peripheral vascular resistance.

It was generally reported that metabolic syndrome is extremely correlated with vascular damage. Abdominal obesity and hypertriglyceridemia are important predictors of vascular damage. Hyperglycemia has a deleterious effect on arterial function, suggesting that diabetic people have impaired glucose homeostasis.

A literature of oriental medicine shows that eating can cause variations of pulse wave. In oriental medicine, generally, eating is known to cause a rise of pulse wave rate, or an increase in pulse wave energy (E). Moreover, eating time is also considered to be very important. However, there is little research on this.

As part of a preventative medicine approach, it is important to analyze the blood circulation index, E, and radial augmentation index (RAI) in healthy adult men, as well as in patients. We measured blood circulation index, E, and RAI by three-dimensional MAC (3-D MAC) (DAEYOMEDI, Ansan, Korea) of healthy men before eating, right after, 30 minutes after, 1 hour after, and 2 hours after eating to examine the influences of eating time on variations of pulse wave.

2. Methods

2.1. Participants

As for the G-power program, 21 healthy men were recruited as participants. At the recruitment stage, the men who had blood pressure problems, gastrointestinal diseases, cardiovascular diseases, and past medical history of treatment for gastrointestinal and cardiovascular diseases were ruled out of the study. Men who had specific pharmacotherapy or dietary therapy in the previous 6 months or who had consumed alcohol or drugs within 1 day were ruled out. Also, the men who had individual physical features disturbing measurement of pulse wave were excluded. Finally, 21 healthy men who understood the research objectives and agreed to the study with written content were recruited.

2.2. Measurements

On the day before the experiment, the participants had a light meal at 6:00 pm and fasted from foods, except water, from 8:00 pm. In the morning of the experiment day, the participants remained in a stable condition for 10 minutes without food. Then, blood pressure measurement and a questionnaire about general characteristics were carried out.

Before breakfast, the individuals’ blood circulation index, E, and RAI were measured by 3-D MAC in the medial point of the radial styloid process (where the radial artery can be palpated). This measurement was performed in the order of left to right and Kwan, Chon, to Cheok. The average time for measurement of each individual was about 20 minutes.

Then, each participant had a meal composed of the same foods (total weight 565 g) containing: steamed rice (260 g), a hamburger (60 g), cuttlefish cutlet (55 g), chicken (50 g), kimchi (35 g), dried slices of radish (30 g), gherkin (25 g), pepper preserved in soy sauce (25 g), steak sauce (10 g), and fruits (15 g). There was a time limit of 30 minutes to consume the meal.

Participants’ blood circulation index, E, and RAI were measured right after, 30 minutes, 1 hour, and 2 hours after the meal. In the meanwhile, to control physical activity, the individuals were encouraged to sit down. They were permitted to drink water to minimize the alterations due to eating.

During the whole process, the temperature was kept at around 23 °C. Each measurement was performed by a person who was experienced with the use of 3-D MAC for more than 2 years.

2.3. Analysis factors

We evaluated HR, calculated mean blood pressure (CMBP), estimated stroke volume (ESV), estimated stroke index (ESI), estimated cardiac output (ECO), estimated cardiac output index (ECI), estimated circulation resistance (ECR), estimated circulation resistance index (ECRI), E, and RAI right after, 30 minutes after, 1 hour after and 2 hours after eating to know the influences of eating time on variations of pulse wave.
Table 1 – General characteristics of participants.

| Variables       | Category                        | n (%) | Mean (SD)    |
|-----------------|---------------------------------|-------|--------------|
| Age (y)         | 18–21                           | 7 (33.4) | 23.57 (4.38) |
|                 | 22–25                           | 10 (47.6) |
|                 | 27–37                           | 4 (19.2)   |
| Height (cm)     | Below 170                       | 3 (14.4)  |
|                 | 170–180                         | 13 (62)   |
|                 | Over 180                        | 5 (23.8)   |
| Weight (kg)     | Below 70                        | 8 (38.2)  |
|                 | 70–80                           | 8 (38.1)   |
|                 | Over 80                         | 5 (23.9)   |
| BMI (kg/m2)     | Normal weight (18.5–22.9)       | 9 (43.1)  |
|                 | Overweight (23–24.9)            | 4 (19.2)  |
|                 | Obesity (25–29.9)               | 8 (38.4)  |
| SBP (mmHg)      |                                  | 113.90 (5.67) |
| DBP (mmHg)      |                                  | 76.90 (2.74) |
| Abdominal obesity rate | Below 0.9                     | 19 (90.7) |
|                 | Over 0.9                        | 2 (9.6)   |
| Body fat percentage (%) | Below 15                      | 2 (9.6)   |
|                 | 15–19                           | 8 (38.3)  |
|                 | 20–24                           | 3 (14.4)  |
|                 | 25–29                           | 6 (28.7)  |
|                 | Over 30                         | 2 (9.6)   |

BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation.

Table 2 – Changes of blood circulation index according to passage of time.

| Variables       | Before the meal | Just after the meal | 30 minutes after the meal | 1 hour after the meal | 2 hours after the meal | F   | p   |
|-----------------|-----------------|---------------------|---------------------------|-----------------------|------------------------|-----|-----|
| HR (beats/min) | 76.67 (10.57)   | 79.81 (10.16)       | 76.86 (9.90)              | 76.05 (9.92)          | 74.10 (8.33)           | 11.394 | 0.000* |
| CMBP (mmHg)    | 100.10 (11.55)  | 100.86 (8.50)       | 99.86 (10.10)             | 101.14 (9.62)         | 98.33 (9.70)           | 2.178 | 0.115 |
| ESV (mL/beat)  | 80.81 (13.50)   | 78.81 (12.49)       | 79.71 (13.08)             | 80.76 (10.62)         | 81.71 (11.61)          | 1.285 | 0.283 |
| ESI (mL/beat/m²) | 42.81 (6.10)   | 41.71 (5.37)        | 42.14 (6.17)              | 42.86 (4.95)          | 43.24 (5.21)           | 1.332 | 0.265 |
| ECO (L/min)    | 5.91 (0.56)     | 6.18 (0.61)         | 6.02 (0.62)               | 6.06 (0.49)           | 5.98 (0.55)            | 3.519 | 0.011* |
| ECI (L/min/m²) | 3.14 (0.22)     | 3.29 (0.24)         | 3.21 (0.26)               | 3.21 (0.25)           | 3.18 (0.22)            | 3.173 | 0.018* |
| ECR (dyne s cm⁻⁵) | 1390.14 (138.81) | 1336.05 (117.98)   | 1362.33 (150.86)          | 1369.05 (112.20)      | 1352.62 (140.79)       | 1.619 | 0.178 |
| ECRI (dyne s cm⁻⁵) | 2611.62 (246.06) | 2509.71 (198.98)   | 2557.14 (245.45)          | 2573.62 (210.98)      | 2339.76 (230.45)       | 1.688 | 0.161 |

* Repeated measures ANOVA, p < 0.05.
ANOVA, analysis of variance; CMBP, calculated mean blood pressure; ECO, estimated cardiac output; ECR, estimated circulation resistance; ECRI, estimated circulation resistance index; ESI, estimated stroke index; ESV, estimated stroke volume; SD, standard deviation.

2.4 Statistical analysis

Computational processing of collected data was performed by SPSS Win 12.0 (SPSS Inc., Chicago, IL, USA). Changes of blood circulation index, E, and RAI according to time were analyzed by using repeated measures of the analysis of variance (ANOVA) test. Differences of blood circulation index, E, and RAI between before and after eating and during and after eating were analyzed by using a paired t test. A p < 0.05 was taken to be significant in the two-tailed test.

3. Results

Participants’ age (years), height (cm), weight (kg), body mass index (BMI; kg/m²), systolic blood pressure (SBP; mmHg), diastolic blood pressure (DBP; mmHg), abdominal obesity rate, and body fat percentage(%) were measured before eating. The outcomes are shown in Table 1.

HR, ECO, and ECI were increased significantly right after eating compared to before eating. ECR and ECRI were decreased significantly right after eating compared to before eating. HR was decreased significantly at 30 minutes, 1 hour, and 2 hours after eating compared to right after eating. ECO and ECI were decreased significantly at 30 minutes and 2 hours after eating compared to right after eating (Tables 2–4).

There were significant differences of E in average of left and right Kwan, and average of right pulse according to passage of time. The average of left and right Kwan, and average of right pulse increased significantly right after eating compared to before eating. In particular, the average of right pulse increased significantly right after, 30 minutes, and 1 hour after eating compared to before eating. Left Kwan and average of left pulse decreased significantly at 30 minutes, and 1 hour after eating compared to before eating. Right Kwan and average of right pulse decreased significantly at 2 hours after eating compared to right after eating (Tables 5–7).
### Table 3 – Differences in blood circulation index before and after eating.

| Variables | 1–2 Mean (SD) | 1–3 Mean (SD) | 1–4 Mean (SD) | 1–5 Mean (SD) |
|-----------|---------------|---------------|---------------|---------------|
| HR (beats/min) | 5.14 (4.04) | 2.19 (5.23) | 1.38 (6.68) | -0.57 (7.52) |
| CMBP (mmHg) | 0.76 (8.37) | -0.24 (8.09) | 1.05 (7.11) | -1.76 (6.19) |
| ESV (mL/beat) | -2.00 (5.37) | -1.10 (6.03) | -0.05 (6.58) | 0.91 (8.47) |
| ESI (mL/beat/m²) | -1.10 (2.91) | -0.67 (3.37) | 0.05 (3.54) | 0.43 (4.61) |
| ECI (L/min/m²) | 0.27 (0.36) | 0.14 (0.19) | 0.06 (0.22) | 0.07 (0.25) |
| ECO (L/min) | 3.425 (0.003) | 1.292 (0.211) | 1.558 (0.135) | 0.617 (0.544) |
| ECR (dyne s cm⁻¹) | 54.10 (95.66) | -27.81 (115.78) | -21.10 (98.79) | -37.52 (110.28) |
| ECRI (dyne s cm⁻¹) | -101.91 (176.91) | -54.48 (212.49) | -38.00 (180.19) | -71.86 (206.76) |

* Variables: 1, before the meal; 2, just after the meal; 3, 30 minutes after the meal; 4, 1 hour after the meal; 5, 2 hours after the meal.
* Paired t test, p < 0.05.

### Table 4 – Differences in blood circulation index before and after eating.

| Variables | 2–3 Mean (SD) | 2–4 Mean (SD) | 2–5 Mean (SD) |
|-----------|---------------|---------------|---------------|
| HR (beats/min) | -2.95 (4.30) | -3.76 (5.21) | -5.71 (6.21) |
| CMBP (mmHg) | -1.00 (5.48) | 0.29 (4.86) | -2.52 (5.86) |
| ESV (mL/beat) | 0.91 (5.83) | 1.95 (6.61) | 2.91 (8.47) |
| ESI (mL/beat/m²) | 0.43 (3.06) | 1.14 (3.61) | 1.52 (3.84) |
| ECO (L/min) | -0.16 (0.26) | -0.12 (0.34) | -0.20 (0.30) |
| ECR (dyne s cm⁻¹) | -1.898 (0.058) | -21.10 (98.79) | -37.52 (110.28) |
| ECRI (dyne s cm⁻¹) | -38.00 (180.19) | -71.86 (206.76) | -15.59 (0.135) |

* Variables: 1, before the meal; 2, just after the meal; 3, 30 minutes after the meal; 4, 1 hour after the meal; 5, 2 hours after the meal.
* Paired t test, p < 0.05.

### Table 5 – Changes in pulse wave energy (E) according to passage of time.

| Variables | Before the meal Mean (SD) | Just after the meal Mean (SD) | 30 min after the meal Mean (SD) | 1 h after the meal Mean (SD) | 2 h after the meal Mean (SD) | F | p |
|-----------|---------------------------|------------------------------|-------------------------------|-------------------------------|-------------------------------|---|---|
| Left Chon | 748.71 (285.14) | 874.19 (310.98) | 840.05 (263.24) | 816.52 (254.30) | 814.29 (270.42) | 1.232 | 0.304 |
| Left Kwan | 594.24 (250.50) | 637.10 (271.68) | 541.29 (245.46) | 569.00 (331.80) | 584.48 (240.96) | 0.708 | 0.589 |
| Left Cheok | 633.00 (255.86) | 748.24 (290.30) | 660.10 (252.18) | 737.76 (294.95) | 734.86 (232.57) | 1.601 | 0.182 |
| Average of left pulse | 658.65 (193.29) | 753.17 (219.46) | 680.48 (176.56) | 707.76 (211.00) | 711.21 (207.95) | 3.217 | 0.045* |
| Right Chon | 782.57 (305.72) | 872.29 (401.14) | 897.00 (362.00) | 882.05 (348.99) | 776.57 (346.04) | 1.175 | 0.328 |
| Right Kwan | 551.43 (251.20) | 642.81 (237.78) | 626.81 (319.79) | 606.76 (253.75) | 504.24 (204.07) | 3.119 | 0.049* |
| Right Cheok | 615.86 (208.23) | 690.57 (231.57) | 727.00 (274.49) | 676.90 (255.24) | 620.14 (224.06) | 1.995 | 0.103 |
| Average of right pulse | 649.95 (183.26) | 735.22 (212.11) | 750.27 (236.25) | 721.90 (219.14) | 633.65 (194.36) | 4.246 | 0.004* |

Unit: div³ (cubing of digital value for pressure).
* Repeated measures ANOVA, p < 0.05.
ANOVA, analysis of variance; SD, standard deviation.
ANOVA, analysis of variance; RAI, radial augmentation index; SD, standard deviation.

| Variables       | Before the meal | Just after the meal | 30 min after the meal | 1 h after the meal | 2 h after the meal | F     | p     |
|-----------------|-----------------|----------------------|-----------------------|-------------------|-------------------|-------|-------|
| Left Cheok RAI  | 59.81 (11.42)   | 56.71 (10.62)        | 55.36 (13.63)         | 55.37 (8.56)      | 52.39 (12.96)     | 1.780 | 0.141 |
| Left Kwan RAI   | 55.94 (14.10)   | 51.48 (11.43)        | 47.47 (12.40)         | 52.19 (10.00)     | 51.12 (12.41)     | 2.829 | 0.058 |
| Left Cheek RAI  | 59.16 (12.85)   | 57.00 (11.83)        | 55.45 (12.96)         | 55.51 (15.98)     | 54.91 (11.81)     | 0.732 | 0.573 |
| Right Cheek RAI | 57.54 (7.60)    | 53.93 (8.37)         | 45.12 (11.53)         | 52.67 (10.72)     | 48.27 (12.77)     | 6.379 | 0.005*|
| Right Cheek RAI | 53.55 (10.81)   | 47.78 (12.79)        | 48.23 (13.80)         | 47.47 (11.01)     | 46.45 (12.67)     | 2.572 | 0.044*|

* Repeated measures ANOVA, p < 0.05.
ANOVA, analysis of variance; RAI, radial augmentation index; SD, standard deviation.
Table 9 – Differences in amplitude of RAI before and after eating.

| Variables | 1–2 Mean (SD) | 1–3 Mean (SD) | 1–4 Mean (SD) | 1–5 Mean (SD) |
|-----------|---------------|---------------|---------------|---------------|
| Left Chon | –3.09 (13.37) | –4.44 (15.63) | –4.43 (9.61)  | –7.72 (11.51) |
| Left Kwan | –4.46 (14.95) | –8.47 (14.37) | –3.75 (14.57) | –4.82 (19.82) |
| Left Cheok| –2.16 (10.24) | –3.70 (13.56) | –3.64 (13.56) | –4.24 (14.19) |
| Right Chon| –3.61 (11.87) | –12.42 (11.83)| –4.87 (11.82)| –9.27 (13.96) |
| Right Kwan| –5.77 (9.67)  | –5.32 (9.20)  | –6.08 (10.88) | –7.10 (12.96) |
| Right Cheok| –6.55 (17.40)| –5.41 (12.60) | –3.34 (13.05) | –7.03 (15.03) |

Variables: 1, before the meal; 2, just after the meal; 3, 30 minutes after the meal, 4, 1 hour after the meal; 5, 2 hours after the meal. * Paired t test, p < 0.05.

RAI, radial augmentation index; SD, standard deviation.

There were significant differences of RAI in right Chon and Kwan according to the passage of time. The RAI decreased at all after-eating time points compared to before eating. The RAI of right Kwan decreased significantly at every point of time. The RAI of left Kwan and right Chon decreased significantly at 30 minutes after eating compared to right after eating (Tables 8–10).

4. Discussion

Diagnosis by means of pulse wave is not valid unless factors that adjust the body condition, such as shape, position, intensity, and HR, etc., are taken into account. At present, in oriental medicine, diagnosis by pulse mainly means a process to identify the cause of a disease and the condition of a patient by analyzing the pulse waves of Chon, Kwan, and Cheok. However, this method of diagnosis is disputed with regard to objectivity and repeatability. To set up the diagnosis by pulse in an objective way, there has to be a clear division between the pathological pulse section and the physiological pulse section. For this reason, we studied the relationships between pulse wave and eating time in healthy men.

The blood circulation index, HR, ECO, and ECI increased significantly right after eating compared to before eating. On the contrary, ECR and ECRI decreased significantly right after eating compared to before eating. The increases in HR, ECO, and ECI indicate that blood volume per minute spouting from the left ventricle to the aorta had increased due to eating. The decreases in ECR and ECRI mean that blood flow resistance had been lowered by eating.

HR decreased significantly at 30 minutes, 1 hour, and 2 hours after eating compared to right after eating. ECO and ECI decreased significantly at 30 minutes and 2 hours after eating compared to right after eating, but there was no significant difference between right after eating and 1 hour after eating. These outcomes suggest that the effects of eating on the blood circulation (rise of HR and cardiac output, reduction of blood flow resistance) decreased as time passed by.

The results of HR, ECO, ECI, ECR, and ECRI coincide with the physiological facts that eating generally causes a rise of
HR, an increase of systolic cardiac pump performance, and a reduction of peripheral vascular resistance. However, judging from the fact that there was no significant difference in ESV and ESI and these decreased right after eating compared to before eating, the rise of cardiac output can be interpreted as an effect of the increase in HR, not an effect of the increase of stroke quotient. This result also coincides with the outlook of oriental medicine that eating causes an increase in HR.13

E is a 3-D volume that represents the intensity of the pulse wave.15 The variation of participants’ E was not regular, but had a tendency to increase right after eating compared to before eating and decrease gradually in every experimental point (left and right Chon, Kwan, and Cheok). These results are in accordance with the fact, as suggested in oriental medicine, that eating causes a variation in the intensity of the pulse wave.6,11,12

There were significant differences of RAI in right Chon and Kwan according to the passage of time. The RAI decreased at all after-eating time points compared to before eating. In particular, the RAI of right Kwan decreased significantly at every point of time. The RAI of left Kwan and right Chon decreased significantly at 30 minutes after eating compared to right after eating.

RAI is an index of cardiovascular elasticity,16 which is related to aging of the blood vessels in the long-term.2,16,17 In the short-term, the RAI increases with a decline in arterial peripheral resistance and a rise of cardiac contractile force. The RAI is calculated as the proportion of (h1 and h3 are pulse heights) (RAI = h3/h1).12 Mostly, the variation of an individual’s RAI has a tendency to decrease right after eating compared to before eating, and then increase gradually. These results coincide with the physiological facts that eating generally causes a reduction of peripheral vascular resistance.10

Although some significant results were found through this research, this study has limitations. One of these is the point that women had not participated in the study. Therefore, more studies on the physiological factors that cause variation in pulse wave, such as gender, climate, seasons, geographic environment, age, physique, affectivity, and labor, are required.

5. Conclusion

Eating can bring about changes in blood circulation index, E, and RAI. These changes show a certain tendency and coincide with the physiological fact that eating causes a rise in HR, an increase in systolic cardiac pump performance, and a reduction of peripheral vascular resistance, and the fact that in oriental medicine it is thought that eating causes an increase in HR and a variation in pulse wave intensity.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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