Body temperature regulation: Sasang typology-based perspective

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Abstract

Global warming induces a dramatic elevation of heat-related morbidity and mortality worldwide. Individual variation of heat stress vulnerability depends on various factors such as age, gender, living area and conditions, health status, and individual innate characteristics. Sasang typology is a unique form of Korean traditional medicine, which is based on the hypothesis that constitution-specific traits of an individual determine the particular distinctive tendency in various aspects, including responses to the external environment. Recent scientific evidence shows that Sasang types differ in body composition, metabolic profile, susceptibility to certain disease patterns, and perspiration. This review aims to interpret these findings under the context of heat balance consisting of heat production (H\text{prod}), heat loss (H\text{loss}), and heat load (H\text{load}). Based on the published data, at a given body mass, the TaeEum type tended to have a lower H\text{prod} at rest and at the exhaustion state, which may indicate the lower metabolic efficiency of this type. Meanwhile, the surface-to-mass ratio and heat capacity of the TaeEum type appear to be lower, implying a lower heat dissipation capacity and heat storage tolerance. Thus, because of these characteristics, the TaeEum type seems to be more vulnerable to heat stress than the other constitutions. Differences in temperature regulation across constitutional types should be taken into account in daily physical activity, health management, and medical research.

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1. Introduction

Over the past several decades, climate change has become an emerging global threat to our planet and has induced a remarkable increase in morbidity and mortality by affecting the human health. According to an estimation by the World Health Organization, between 2030 and 2050, climate change may cause approximately 38,000 heat stress-related deaths annually. It has been demonstrated that some populations are at a higher risk of heat-related illness and damage than others. Elderly persons and children are most vulnerable to heat stress due to degeneration and immaturity in heat acclimation, respectively. Physical and mental illnesses also affect how the body responds to heat stress. Those who suffer from obesity, diabetes, hypertension, cardiovascular, and/or respiratory diseases have a higher incidence of heat-related disorders than healthy individuals of the same age and
gender. Although population-based factors related to heat stress have been reported, far too little attention has been paid to physiological traits as determinants of heat stress vulnerability.

Investigation on the impact of physiology traits on health could be dated back to the ancient time, with the “Four Humor” theory of Hippocrates and Galen in the West and constitution-based medicine, Ayurveda, in the East. Recently, there has been an emerging interest in body type and constitution-based approach in the fields of individualized and tailored medicine. The somatotype theory of Sheldon and Sasang constitutional medicine of Lee has been investigated thoroughly. Among these four available constitution-based approaches, Sasang constitutional medicine appeared to be a well-structured theory that provided not only a type classification, but also a comprehensive theory related to medical practice.

According to Sasang constitutional medicine, human beings can be classified into four constitutional types: the Taeyang, TaeEum (TE), SoEum (SE), and SoYang (SY) types. Scientific evidence revealed that these four body types have distinct genetic bases and differ in physical appearance, body composition, temperament traits, and vulnerability to particular diseases patterns. In thermoregulation, a few investigations suggested constitution-specific traits in skin structure, sweating capacity, and energy expenditure profile.

The current review aims to describe the constitution-specific characteristics of Sasang types in heat stress regulation capacity and discuss the factors that need to be taken into account in the studies of thermoregulation in Sasang typology.

2. Thermoregulatory response at rest and during exercise

Under basal condition (e.g., resting, thermoneutral, and fasting states), energy consumed for maintaining basal functional activities and body core temperature is the so-called basal metabolic rate (BMR). To some extent, BMR refers to the resting energy expenditure (REE), energy expenditure measured at the resting state. Most of the energy consumed under basal condition comes from heat generation and needs to be released into the environment via various heat loss (Hloss) pathways such as conduction, radiation, convection, respiration, and evaporation. At rest, 54–60% of total Hloss occurs by radiation, 25% by convection and conduction, 14% by respiration, and <7% by sweating. When heat production (Hprod) and Hloss are balanced, body core temperature can be maintained at nearly a constant level of 37 °C.

In daily life, energy used for digestion and absorption of food and for muscle contraction accounts for 30% of total energy expenditure. During exercise, 40% of total body energy expenditure is used to produce adenosine triphosphate for functional activities, whereas >60% is converted to heat. During heat exposure, when the ambient temperature is higher than the skin temperature, the gradient results in a heat load (Hload) to the body. The increment in the body core temperature induced by Hload consequently initiates a negative feedback loop that stimulates cutaneous vasodilation, promoting skin blood flow and enhancing the heat dissipating function, particularly via evaporation. When the core temperature returns to normal, this thermoregulation process terminates and sweating stops. In case the heat dissipation process is insufficient to compensate for the Hload, the heat stored inside the body elevates the body core temperature to a thermal threshold at which heat-related illnesses such as heat stroke, heat cramp, and eventually death occur.

Heat flow can be described as Hprod = Hloss + Hload, in which Hprod is the heat converted from energy expenditure and refers to metabolic heat production, Hloss is the heat dissipated to the environment, and Hload is the heat stored in the body. The next section describes constitution-specific characteristics of Sasang types according to these three factors.

3. Metabolic heat production and Sasang typology

Metabolic heat production (Hprod) strongly determines heat dissipation and heat storage at rest and during exercise. An equilibrium between the rates of Hprod and Hloss should be maintained in every thermal condition. Since Hprod is mainly determined by the body mass, particularly fat-free mass (FFM), comparative studies on thermoregulation response among groups of different body size should take into account the proportional relationship between Hprod and body size.

Recently, there has been more attention on the metabolic basis of Sasang types. Based on the original text of Lee JeMa, Kim and Pham raised a hypothesis that the physical principles of Sasang types may be interpreted under a context of two major seesaw processes, anabolic/catabolic seesaw and intake/discharge seesaw. Shim et al then developed a more specific assumption that the distinction in metabolic profiles of the TE and other Sasang types may be due to a reduction of the mitochondrial metabolism of the TE type, which consequently results in a low REE per unit of body mass and a higher risk of weight gain in the TE type. Using an estimated equation, Chae et al calculated BMR for Sasang types using simple anthropometric indices, such as weight, height, age, and gender, and reported that the TE type has a higher BMR than other Sasang types. Shim et al calculated the BMR using weight and height, and then normalized it to the body mass to calculate the so-called cellular metabolic rate. They reported a lower cellular metabolic rate in the TE type in comparison with other Sasang types. However, as BMR or REE mainly originates from non-fat tissue, normalizing BMR or REE to the whole body mass may underestimate the real cellular metabolic rate. Data based on indirect calorimeter revealed that REE adjusted for FFM was identical among Sasang types, whereas the correlation between REE adjusted for FFM and body mass index was positively significant in the SY types only. However, these findings were of a study involving a relatively small sample size of young men only. In our recent study on 304 males and females aged 20–50 years, REE was higher in the TE type. However, when normalized to FFM, REE was identical across Sasang types. Normalization of REE to weight showed a significantly low REE only in men of the TE type (Fig. 1). These
findings therefore underline the need to investigate $H_{prod}$ of Sasang types by a real measurement approach, and not by estimation.

Very few studies have been conducted to visualize the energy expenditure of Sasang types during exercise. Almost all the studies were focused on maximal oxygen uptake ($VO_2\text{max}$), the highest level of oxygen consumption during exercise. Pham et al.\textsuperscript{24} reported no difference in the $VO_2\text{max}$ normalized to body weight among Sasang types in young men. However, in a larger sample size with age ranges from 20 years to 50 years, the $VO_2\text{max}$ normalized to the body weight of the TE type was the lowest among Sasang types in men and women.\textsuperscript{23} In addition, the TE type had a tendency to reach the stage of $VO_2\text{max}$ earlier than the other types. From those results, we assume that the $H_{prod}$ threshold of the TE type during heat stress is lower than that of other Sasang types.

4. Heat dissipation capacity and Sasang typology

Heat exchange between the body and environment at rest contributes mostly to dry $H_{loss}$, whereas evaporation accounts for a major proportion of the total $H_{loss}$ during exercise.\textsuperscript{16} Although the dry $H_{loss}$ and evaporation are body surface area (BSA)-dependent factors, it has been revealed that high BSA-to-mass ratio is a favorable condition for heat dissipation.\textsuperscript{23} It has consistently been described in various studies that the TE type has a larger BSA than other types. However, when normalized to body weight, the TE type had the smallest ratio of BSA to body mass, whereas that in the SE type was the highest.\textsuperscript{23} Since it has consistently been reported that the TE type has a higher percentage of fat,\textsuperscript{14,20,23,34–36} a higher body mass index,\textsuperscript{14} and a higher risk of being obese,\textsuperscript{18} it is reasonable to assume that the subcutaneous adipose tissue, which functions as a thermal insulating layer inhibiting heat transfer from the body core to the skin when skin blood flow is low, is thicker in the TE type. Kim et al.\textsuperscript{22} found that the skin of the TE type has higher viscoelasticity, which may be due to a thicker subcutaneous fat layer of this Sasang type. Several studies indicate that the TE type tends to have a higher rate of evaporation.\textsuperscript{21,23} In our recent study, we found that the TE type has an elevation in sweating rate only in the middle of exercise, when confounding factors such as work load, $H_{prod}$, and temperature load, are taken into account.\textsuperscript{23} Work-load-dependent evaporation in the TE type needs to be investigated in future studies. Moreover, other determinants of the heat dissipating capacity, such as skin blood flow, sweat gland function, and biochemical response during heat stress, have not yet been explored.

5. Heat load and Sasang typology

During heat stress, the increment of $H_{loss}$ should proportionally match the elevation of $H_{prod}$ to minimize $H_{load}$ to maintain a normal body core temperature. When the increase of $H_{prod}$ is larger than $H_{loss}$, $H_{load}$ ascends rapidly to raise the body temperature. At a given $H_{load}$, the temperature increment of an object is conversely correlated with its heat capacity (HC). The HC of the body was defined as the energy required to increase the body temperature by 1 °C. Since the HC of fat (1.88 kJ/kg/°C) is lower than that in fat-free tissues (3.72 kJ/kg/°C),\textsuperscript{37} 200 kJ of $H_{load}$ after 90 minutes of intensive exercise\textsuperscript{38} induces a temperature increment of 0.83 °C in a body of 70 kg weight with 15% fat, whereas the increment is 0.90 °C in the same weight of body with 30% fat.

It has been demonstrated that Sasang types differ in body mass index and body composition. The very first investigation on body composition of Sasang typology using bioelectric impedance analysis indicated a relatively higher fat mass, a larger body size, and a higher body mass index in the TE type.\textsuperscript{14} Since then, various studies employed advanced body composition analysis such as multifrequency bioelectric impedance analysis\textsuperscript{23,36} or dual energy X-ray absorptiometry.\textsuperscript{39} According to the recently published studies by Cho et al.\textsuperscript{20} and Pham et al., the average body fat varied between 28.6% and 28.7% for the TE type, between 20.2% and 22.2% for the SE type, and between 22.1% and 26.2% for the SY type (Table 1). As the body of TE individuals contains more fat, the HC at a given body mass of this body type is consequently lower than that in other Sasang types. Thus, a given $H_{load}$ induces a higher temperature increment in the TE type than in other Sasang types.
6. Heat balance in Sasang typology and future studies

In the original text, Lee, the founder of Sasang typology, described that the TE type has a relatively weak lung function and profuse perspiration indicates a healthy state in the TE type. It has been hypothesized that the lung function resembles catabolism, and pathogenesis of the TE type is related to a relatively low $H_{\text{prod}}$. It has also been demonstrated that the evaporation $H_{\text{loss}}$ of this type is higher than that of other Sasang types. However, no concrete explanation has been established so far. System investigations on the balance between $H_{\text{prod}}$, $H_{\text{loss}}$, and $H_{\text{load}}$ may shed light not only on the thermoregulation response, but also on the metabolic function and pathological aspects of Sasang types.

In terms of $H_{\text{prod}}$, although $\text{REE} (H_{\text{prod}}$ at the resting state) and $\text{VO}_{2\text{max}}$ (the maximal physical endurance determinant) are higher in the TE type, normalization of these values to the unit of body mass reverses the pattern. In terms of $H_{\text{loss}}$, because BSA per unit of body mass is lower in the TE type, dry $H_{\text{loss}}$ seems to be not favorably performed and then compensated by the functional excess in evaporation. In terms of $H_{\text{load}}$, because the HC per unit of body mass is lower in the TE type, this type appears to be more sensitive to temperature increment than other Sasang types. Fig. 2 shows a three-dimensional relation between $H_{\text{prod}}$ with proxy as $\text{REE}$ per unit of body mass, $H_{\text{loss}}$ with proxy as BSA per unit of body mass, and $H_{\text{load}}$ endurance capacity with proxy as HC per unit of body mass. There is a clear pattern in men and women that the TE individuals are distributed toward the region where $\text{REE}$ per unit of body mass, BSA per unit of body mass, and HC per unit of body mass are the lowest, whereas the SE individuals are distributed in the opposite direction; the SY individuals are distributed in the region between the TE and SE individuals. Taken together, the TE type has metabolic and anthropometric characteristics that are not favorable to dealing with heat stress. Evidence also revealed that patients with obesity, diabetes, and hypertension are vulnerable to heat stress, while these illnesses belong to the constitution-specific disease pattern in the TE type. However, whether the heat control characteristics of the TE type are related to those diseases has not been explored.

Although several explanations have been given to interpret the pathological principles of the TE type, such as two seesaws of catabolism/anabolism and intake/discharge and a hypofunctional mitochondria activity, a concrete theoretical model based on the flow and balance of heat/energy should be established. To investigate $H_{\text{prod}}$ and $H_{\text{loss}}$, the whole-body energy expenditure should be measured, and the comparison should take into account the difference in body size and surface area of Sasang groups.

In the modern era, climate change and global warming contribute to an extremely high risk of heat-related illnesses in vulnerable individuals. Some well-known factors of heat stress vulnerability such as age, gender, living condition, diseases, and individual variation of heat stress tolerance can be explained partially by the constitutional approach. As

| Authors             | Measuring method | Population                  | TE       | SE       | SY       |
|---------------------|------------------|-----------------------------|----------|----------|----------|
| Cho et al (2013)    | BIA              | $n = 2460$ (M = 1100; F = 1360) | 28.7 ± 6.8| 22.2 ± 7.0| 26.2 ± 6.4|
|                     |                  | Age: 40–69 y                |          |          |          |
| Pham et al (2015)   | Multifrequency BIA | $n = 304$ (M = 178; F = 126) | 28.6 ± 6.8| 20.2 ± 6.4| 22.1 ± 6.3|
|                     |                  | Age: 20–49 y                |          |          |          |

BIA, bioelectrical impedance analysis; F, female; M, male; SE, SoEum type; SY, SoYang type; TE, TaeEum type.

Fig. 2 – Three-dimensional relation between resting energy expenditure, body surface area, and heat capacity in 1 kg of body weight across Sasang types.

Note. Data were extracted from Pham et al.

BSA, body surface area; REE, resting energy expenditure; SE, SoEum type; SY, SoYang type; TE, TaeEum type.
research on the thermoregulation response in Sasang typology is in infancy, well-designed and long-term experiments focusing on this issue should be performed.

**Conflicts of interest**

The authors declare no conflicts of interest.

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