Radial Pulse and Electrocardiography Modulation by Mild Thermal Stresses Applied to Feet: An Exploratory Study with Randomized, Crossover Design*

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ABSTRACT  Objective: To investigate the changes in radial pulse induced by thermal stresses (TSs). Methods: Sixty subjects were enrolled. Using an open-label, 2 × 2 crossover randomization design, both feet of each subject were immersed in 15 °C water for cold stress (CS) and in 40 °C water for heat stress (HS) for 5 min each. Radial pulse, respiration and electrocardiogram (ECG) signals were recorded before, during and immediately after the TSs. Results: The analysis of heart rate variability revealed that CS increased the low-frequency (LF) and high-frequency (HF) components (P<0.05) and that HS reduced the LF and HF components (P<0.01). Both TSs reduced the normalized LF, increased the normalized HF, and reduced the LF/HF ratio. The differences in the ECG signals were more dominant during the TS sessions, but those in the radial pulse signals became more dominant immediately after the TS sessions. CS decreased the pulse depth (P<0.01) and increased the radial augmentation index (P<0.1), and HS increased the pulse pressure (P<0.1) and subendocardial viability ratio (P<0.01). There were no significant differences in pulse rate during the three time sequences of each TS. The respiration rate was increased (P<0.1), and the pulse rate per respiration (P/R ratio) was significantly decreased (P<0.05) with CS. The HF region (10–30 Hz) of the pulse spectral density was suppressed during both TSs. Conclusions: CS induced vasoconstriction and sympathetic reactions, and HS induced vasodilation and parasympathetic reactions. Based on definitions used in pulse diagnosis, we made the novel discoveries that the pulse became slower (decreased P/R ratio), more floating and tenser under CS and that the HF region of the spectral power decreased significantly under both TSs.

KEYWORDS  radial pulse, pulse diagnosis, thermal stress, electrocardiography, heart rate variability

Physiological indicators, such as heart rate, respiration, blood pressure and body temperature, are primary vital signs that are widely used to assess basic physiological conditions. These simple biosignals are very useful and straightforward to interpret. In this work, we introduce another simple and somewhat overlooked physiological indicator that has been used in pulse diagnosis in several forms of traditional East Asian medicine (TEAM), including Chinese medicine (CM), Korean medicine (KM) and traditional Kampo medicine. According to a foundational classic of CM theory, Fei (Lung) gathers the vessel qi in the entire body and supervises the regulation of the pulse energy. Additionally, Fei plays critical roles in regulating blood circulation and carrying qi and blood by supporting the function of the Xin (Heart). In pulse diagnosis, the pulse rate per respiration (P/R ratio) has been used as an indicator to determine the pulse speed. Some attempts to determine the clinical implications of the P/R ratio have been reported. For instance, the P/R ratio was quantified to establish the normal range of moderate pulse, and the temperature characteristics of several acupoints were examined with a cold-heat pattern identification defined by the P/R ratio.¹² When defining the P/R ratio, the respiration rate of either the patient or the physician...
can be counted. In the former case, the P/R ratio is defined distinctively from other physiological signs, and in the latter case, the P/R ratio does not differ from the heart rate. In this work, we defined the P/R ratio using the respiration of the patient and considered the heart rate an independent vital sign, and used both vital signs for the analysis of clinical study. The Task Force of the European Society recommends that heart rate variability (HRV) should be measured from fluctuations in autonomic inputs to the heart rather than from the mean level of autonomic inputs. Additionally, respiratory function can be more strongly activated than cardiovascular function in particular environments, and the opposite can occur as well. These abnormal examples suggest the P/R ratio as a potential complementary clinical indicator.

Physical stress can influence the cardiovascular system. In particular, the application of thermal stresses (TSs) to the human body causes physiological responses and significant changes in aortic hemodynamic markers, which might induce adverse cardiovascular events. Lowered body temperature generally results in increased arterial blood pressure, stroke volume and heart rate. Additionally, the cardiac workload, the central venous pressure (as a measure of the right ventricular filling pressure) and myocardial oxygen demand are higher in cold-stressed humans. In addition to these hemodynamic responses, sympathetic stimulation by cold stress (CS) induces a change in the conduit artery diameter, which causes peripheral vasoconstriction and leads to a decrease in vasomotion. Many other studies have demonstrated that cold stimulation results in an increase in arterial wave reflection intensity due to the increased peripheral resistance of the blood vessels. The radial augmentation index (Alr) can reflect these phenomena, and a higher value of Alr is induced by a higher degree of reflected waves.

In a previous HRV study, skin surface cooling increased the high-frequency (HF) component and decreased the ratio of the low-frequency (LF) to the HF component, indicating increased cardiac vagal nervous activity. Spectral analysis of the radial pulse can capture some significant features that provide a wider perspective on the pulse characteristic thermally stressed humans. The HF domain of the pulse under TSs has been reported to contain more physiological characteristics than the LF range.

Most of these responses, with some exceptions, are reversed if the temperature is increased. These reactions mainly occur through an autonomic nervous reaction (ANR), regardless of the type of stressor. Because the above mentioned characteristics of the radial pulse are regulated by an ANR, TSs will naturally cause a change in the radial pulse as well. Some studies have examined the effects of TSs on radial pulse. Individuals with untreated hypertension, type-2 diabetes mellitus, high levels of depressive symptoms and concurrent isometric handgrip exercise participated in clinical studies that used CS tasks; these studies showed increases in aortic hemodynamics, left ventricular load and myocardial oxygen consumption. In most of these studies, the radial pulse was used only as a supportive tool to estimate the central aortic blood pressure. In this study, we aimed to explore the effects of TSs on radial pulse through the perspective of traditional pulse diagnosis and to investigate physiological indicators, including the P/R ratio and electrocardiogram (ECG).

METHODS

Study Design and Participation

This study had an open-label 2 × 2 crossover design with random assignments to cold-to-heat- or heat-to-cold-stressed groups.

Healthy men and women aged 20 to 29 years were enrolled in the study. All participants visited a medical center and were asked to provide signed informed consent. Participants were excluded from the study if they had cognitive inability to complete the study; any medical surgeries or therapies within the previous month; intake of any drugs that affect the signals of the radial pulse, such as blood pressure, hyperglycemic, somniferous, and sedative drugs, before the screening; pregnancy; vascular malformation of the radial artery; wrist fracture; or excessive exercise or diet control for the purpose of weight loss in the previous month. The study was conducted at Kyung-Hee University Korean Medicine Hospital in Seoul, Republic of Korea, from August to October of 2014. The study was approved by the Ethics Committee of the Institutional Review Board (No. KOMCIRB-2014-70) and the Korea Food and Drug Administration (No. 463) before the first participant was included. The trial registration number (No. KCT0002302) was retrospectively obtained from...