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Asymmetric Thermal Response of Human Feet to Hopping Detected by Digital Infrared Imaging

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Authors' contributions

This work was carried out in collaboration between all authors. Authors BKK and ECJ designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors HJS and KSS managed the literature searches and analyses of the study. Author ECJ managed the experimental process and author KSS participated in recruitment of volunteers. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aims: The purpose of this study was to evaluate the effect of asymmetric exercise, hopping, on skin temperature at the foot and ankle subregions by infrared thermography.
Study Design: Prospective volunteer study.
Place and Duration of Study: Department of Orthopaedic Surgery and Department of Radiology, Chung-Ang University Hospital, between June 2013 and March 2014.
Methodology: Ten healthy male volunteers hopped with their dominant limb 1,000 times or for 15 min. Thermography was taken by using an infrared imaging device at 24°C. Each volunteer had four thermographic images of the dorsum, plantar and calf views of both limbs before hopping, and at 5, 20 and 30 min after hopping. Temperatures were measured at the dorsum of the foot (subregion 1), lower tibialis anterior (subregion 2), medial plantar (subregion 3), lateral plantar (subregion 4), calf (subregion 5) and Achilles tendon (subregion 6).

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Results: Hopping changed the temperature with different patterns depending on 12 subregions after hopping. At 5 min, except for subregion 3 and 4 of the hopping limb, the other ten subregions showed decreases in skin temperature. Temperatures of all subregions of the hopped limb were higher than that of non-hopped limb ranging from the lowest, 0.54°C atsubregion 1 at 5 min, to the highest, 1.18°C atsubregion 6 at 5 min. Each subregion of the hopped limb was 0.5°C or higher than that of non-hopped limb from 5 till 30 minutes after exercise ($P < 0.05$).

Conclusion: Heat changes in the foot and ankle by exercise can be imaged and evaluated. After asymmetric exercise, hopping, the subregions of the foot and ankle respond differently. For proper image interpretation, knowing whether asymmetric exercise occurred in the limb of interest is important before image acquisition.

Keywords: Thermography; hopping; asymmetric exercise; foot; skin temperature.

1. INTRODUCTION

Infrared thermography is a noncontact imaging of skin temperature [1-3], where infrared radiation is emitted with a constant emissivity value [4]. Thermograms are well suited to detect changes in blood perfusion, which might occur due to inflammation, angiogenesis or other causes [5]. The skin surface temperature distribution of a healthy human body exhibits a bilateral symmetry. Generally, if the temperature difference is higher than 0.5°C [6], asymmetric distribution of skin temperature usually indicates an abnormality of the body, and there might be thermal asymmetry due to disease or suspicious pain [6,7].

When imaging a skin temperature of patients with infrared thermography, it is performed in the steady state. And, stress of cold or hot is given to look at the body temperature response when needed [8,9]. However, if compensation is required for disability, there might be a deliberate manipulation. Because a lot of exercise of the patient before the test can affect the skin temperature, it may cause confusion in image analysis, especially if there is the asymmetric exercise. However, there was no study on asymmetric thermal response of human feet to asymmetric exercise.

Only a few papers on thermographic images of foot and ankle have been published [10-13]. Almost all papers are on skin temperature changes by internal diseases such as the feet of diabetic patients, abnormal sympathetic skin responses and early detection of stress fractures. There have been few reports on thermal changes of lower limbs, but not feet, induced by exercise as a kind of stress [14-16]. In particular, we do not know whether asymmetric exercise like hopping can cause thermal changes in each foot. This is important to know since changes in temperature assessed by thermography from exercise may alter image interpretation when examining limbs for pathologic conditions.

There are no reports of the response of body surface temperature to asymmetric exercise, such as hopping. The purpose of this study was to evaluate the effect of asymmetric exercise, hopping, on skin temperature at the foot and ankle subregions by infrared thermography.

2. MATERIALS AND METHODS

2.1 Volunteers

This study was approved by Institutional Review Board at Chung-Ang University Hospital. All volunteers provided written informed consent. Because it was expected to be no difference of results between male and female, only male was recruited. Healthy male volunteers which had no acute and chronic disease including diabetes mellitus, hypertension and autonomic imbalance disease were enrolled. Their age range was 22-28 years old (n=10, 25±0.7). They were checked for and were within normal range for ankle brachial blood pressure index.

2.2 Digital Infrared Thermography Device

Thermography was taken using a digital infrared thermographic imaging device (IRIS-5000 system; Medicore Co, Seoul, Korea) at a room temperature of 24°C shielded from outdoor light and heat. The IRIS-5000 system is developed for commercialized use with a narrow calibration range of temperature from 17.0 to 40.2°C, and has a 0.1°C temperature resolution, 240 (vertical) x 256 (horizontal) in pixel size and 22.5 degrees (vertical) x 24 degrees (horizontal) in angle of view. It has a liquid nitrogen cooled detector, and one image is taken at 2.6 sec per frame.

2.3 Thermography

The volunteers wore operative suits with short sleeve and shorts. They hopped with their dominant limb 1,000 times or for 15 min at a room temperature outside the infrared imaging room. Thermographic images of both feet were taken for each volunteer: that is, before hopping as a baseline, and at 5, 20 and 30 min after hopping. At each time, three views were taken: a dorsum view, plantar view and calf view of both feet (Fig. 1).

2.4 Measurement

With each view, temperature in Celcius was measured at each region of interest (ROI) with the image processing software (Medicore Co, Seoul, Korea) for IRIS-5000 (Fig. 1). On dorsum view, one square of ROI was put and measured at the dorsum of the foot below with the exclusion of the high temperature area of the dorsalis pedis artery (subregion 1). Another square ROI was put and measured at lower tibialis anterior (subregion 2). On plantar view, oval to ellipse ROIs were at each medial (subregion 3) and lateral (subregion 4) plantar. On calf view, one square ROI was at the calf (subregion 5) and another square at the Achilles tendon (subregion 6). The temperature values were averaged within each subregion for each time.

2.5 Statistical Analysis

All data are expressed as means±standard errors of mean. Nonparametric variables between the subregions of both feet and ankles at each time were compared with the use of Wilcoxon-signed rank test. A probability value of $P < 0.05$ indicated statistical significance. All analyses were performed with SPSS V 18.0 (PASW Statistics Base 18.0.0; IBM, Chicago, IL, USA).

3. RESULTS

In the baseline study, six subregions of foot and ankle had different mean temperatures. Each subregion of both limbs had symmetry in temperature. Among the subregions, calf (27.88°C±0.21 at hopping limb vs 27.87°C±0.2 at non-hopped limb, P > 0.05), lower tibialis anterior (27.55±0.14 vs 27.52±0.14, P > 0.05), dorsum of foot (27.43±0.17 vs 27.42±0.20, P > 0.05), medial plantar area (27.24±0.17 vs 27.26±0.15, P > 0.05), Achilles tendon (27.25±0.13 vs 27.23±0.15, P > 0.05) and lateral plantar (26.78±0.21 vs 26.80±0.20, P > 0.05) showed the higher temperature in that order (Figs. 2, 3, 4).

Fig. 1(a)

Fig. 1(b)

Fig. 1(c)

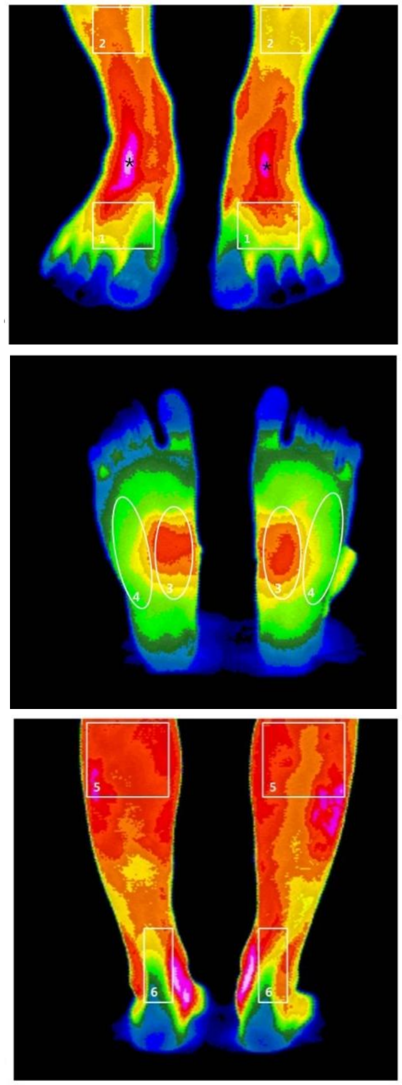

Fig. 1. Baseline measurements of skin temperature for six subregions of interest after three thermographic views of both feet and ankles; A: On dorsum view, one ROI square is put and measured at the dorsum (1) of foot below for exclusion of the high temperature area (asterisks) of the dorsalis pedis artery. Another ROI square is placed at lower tibialis anterior (2). B: On plantar view, oval to ellipse ROIs are placed at each medial (3) and lateral (4) plantar. C: On calf view, two square ROIs are at the calf (5) and Achilles tendon (6), respectively

Hopping caused temperature changes with different patterns depending on the 12 subregions of the hopping and non-hopped limbs. At 5 min, only the medial (subregion 3) and lateral (subregion 4) plantar of hopping limb showed increased skin temperatures (27.39±0.24 and 26.84±0.26, respectively) compared to baseline (27.24±0.17 and 26.78±0.21, respectively; Fig. 3). The other ten subregions of six non-hopped subregions and four hopped subregions showed decreases in skin temperature (Figs. 2, 3, 4).

In all subregions, there were differences in temperature of the hopped limb compared to the subregions of the non-hopped limb. Temperatures of all subregions of the hopped limb were higher than that of non-hopped limb with the lowest increase of 0.54°C at the dorsum of foot at 5 min, and the highest increase to 1.18°C at the Achilles tendon at 5 min. The differences did not subside 30 min after hopping, where differences of more than 0.5°C were still noted ($P < 0.05$) (Figs. 2, 3, 4).

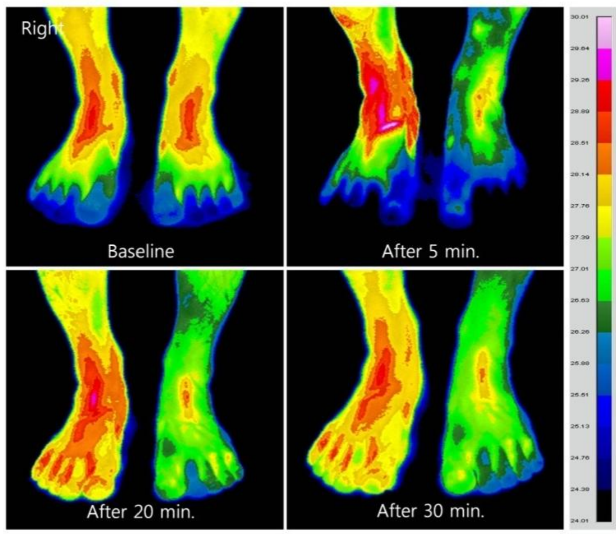

Fig. 2(a)

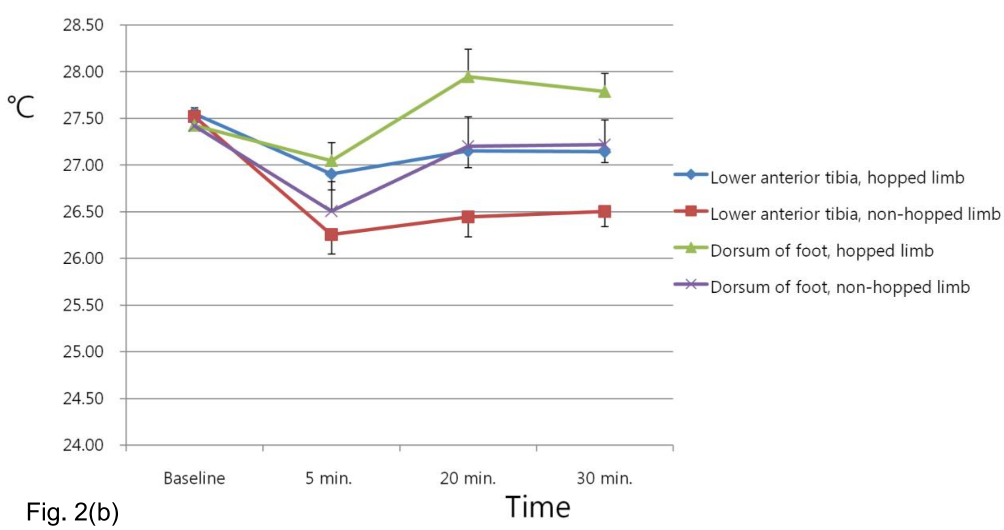

Fig. 2(b)

Fig. 2. Serial changes in skin temperature on dorsum view after hopping with right limb in a volunteer (group mean data). A: After hopping, skin temperature of left dorsum shows prominent decreases compared with right. B: The asymmetric temperature lasts for 30 min ($P < 0.05$)

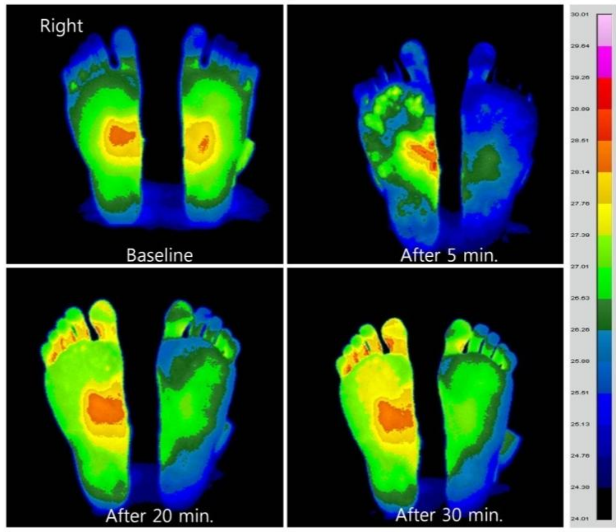

Fig. 3(a)

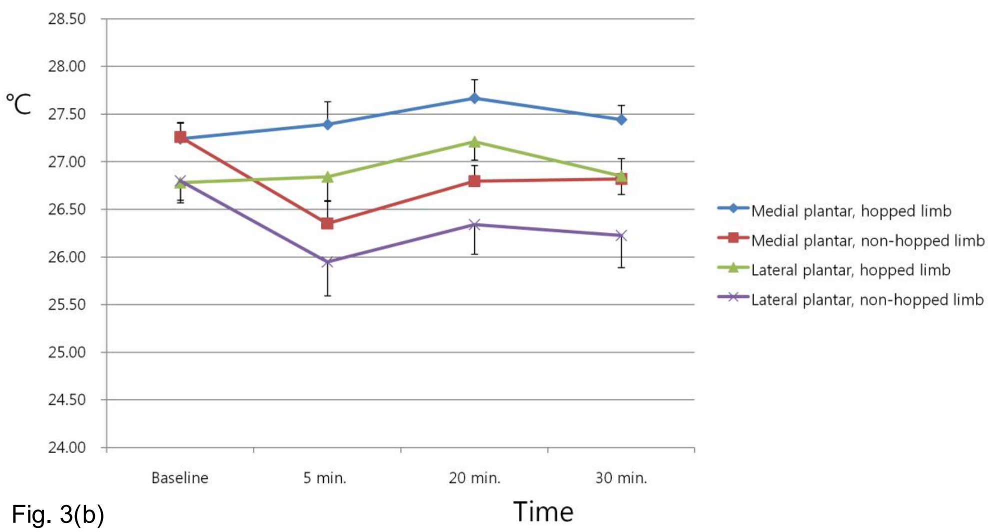

Fig. 3(b)

Fig. 3. Serial changes of skin temperature on plantar view after hopping with the right limb in a volunteer (group mean data); A: After hopping, skin temperature of the left plantar decreases compared with the right; B: The asymmetric temperature occurs for 30 min (P < 0.05)

4. DISCUSSION

The blood supply for the muscles during the initial part of exercise is accompanied by vasoconstriction in the skin while a vasodilator thermoregulatory response occurs when the body temperature rises, allowing heat loss through the surface of the skin [14,16-18]. During intense physical activity, the body surface heat sets about to increase again, which can be thought of as an increase in heat production by active muscle mass and in blood flow. Peripheral vasoregulation controlled by sympathetic nerve regulation lowers body temperature and then returns it to baseline. In this study, with the exception of the medial and lateral plantar after exercise, skin temperature decreased at four subregions of the foot and ankle of the hopping limb and six subregions of non-hopping limb. Depending on each subregion, the degree of lowered skin temperature was different from each other. With respect to the medial and lateral plantar of the hopping limb, one possible explanation for the increases in temperature may be that the plantar area is not accompanied by vasoconstriction as much as other subregions. However, the reason cannot be mentioned through this study.

The hopped and non-hopped limb showed different responses to this asymmetric exercise. A report on different responses in skin temperature of both lower limbs after asymmetric exercise have been published [14], but not for feet. Hopped limb generates more heat than the contralateral, non-hopped limb due to intense exercise. In this study, temperature differences between the feet were sustained from 5 to 30 min after hopping, even though the difference was reduced slightly after 30 min (Figs. 2, 3, 4).

Because of these differences of skin temperature after asymmetric exercise, the evaluator of the thermographic images should be careful not to misinterpret them due to asymmetric exercise prior to imaging. The overall mean plantar temperature stabilized in the imaging room after 15 min, and thus, 15 min has been recommended for clinical thermographic measurement in healthy volunteers [13]. However, if there is asymmetric exercise, more than 30 min are needed to stabilize skin temperature to pre-exercise values.

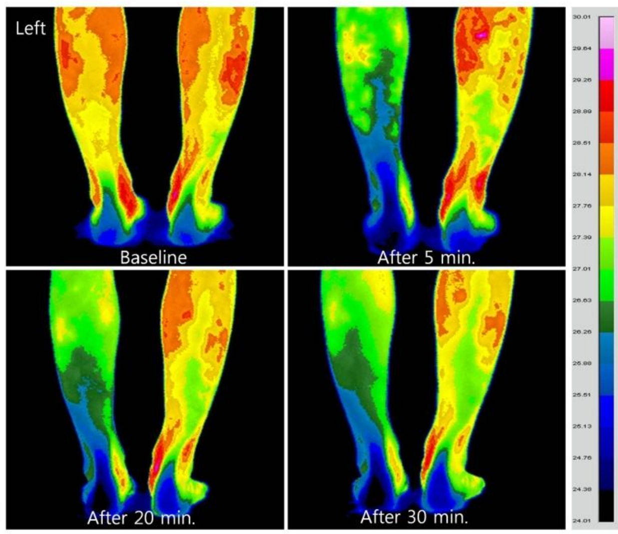

Fig. 4(a)

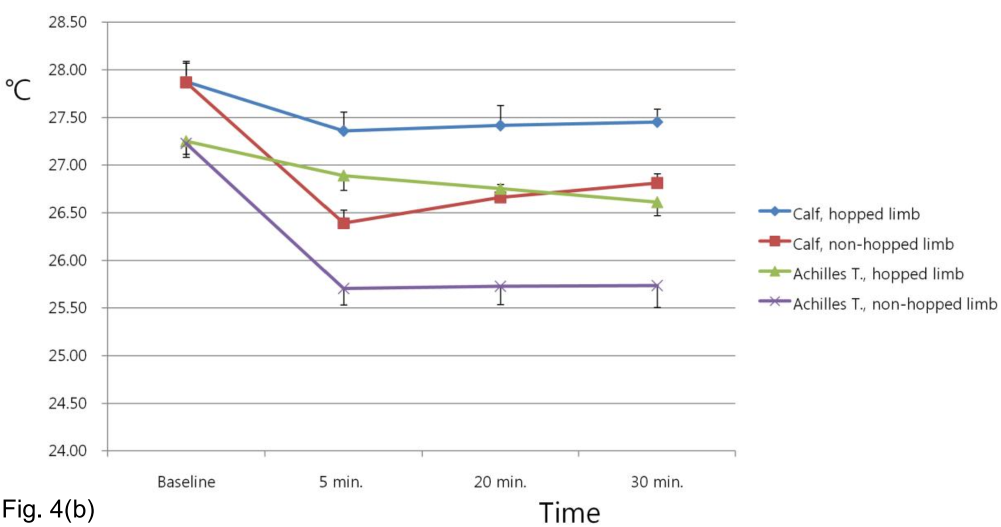

Fig. 4(b)

Fig. 4. Serial changes in skin temperature on calf view after hopping with right limb in a volunteer(group mean data). A: After hopping, skin temperature shows a decrease in both calves and Achilles tendons. The decrease of temperature in the left limb is more prominent in compared with the right. B: The reduced asymmetric temperature lasts for 30 min (P < 0.05)

Observation of asymmetric temperature on infrared thermography is a basic and important point in the interpretation of thermal images. In general, diseases showing asymmetric skin temperature at feet and ankles are unilateral lumbosacral radiculopathy [19], arterial occlusive disease in one limb [20], complex regional pain syndrome [21], inflammatory condition on one side such as tendinitis, bursitis and osteoarthritis [22]. As a result of present study, because an asymmetric exercise can make the asymmetry of skin temperature, it should be prohibited before exam. And, if there is a possibility of asymmetric exercise like compensation for disability, the exam should be performed after resting for a longer time. A limitation of this study was that images were limited to 30 min after hopping. To understand the amount of time needed for temperature to return to normal, a longer time was needed to observe temperature normalization after exercise.

5. CONCLUSION

In conclusion, heat changes in the foot and ankle by exercise can be imaged and evaluated. After asymmetric exercise, hopping, the subregions of the foot and ankle respond differently. For proper image interpretation, knowing whether asymmetric exercise occurred in the limb of interest is important before image acquisition.

ETHICAL APPROVAL

This study was approved by Institutional Review Board at Chung-Ang University Hospital. All volunteers provided written informed consent.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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