The Effect of Textiles Impregnated With Particles With High Emissivity in the Far Infrared, on the Temperature of the Cold Hand

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In engineering and medicine, there is a growing interest in using textiles made of composites with enhanced thermal properties. One such type of textile is fabric impregnated with ceramics and mineral particles. This material has high emissivity in the infrared range and may have therapeutic benefits for treatments of diseases, like Raynaud's syndrome. While there is significant clinical and commercial interest, there is an evident lack of fundamental studies on the heat transfer aspects of these fabrics. The goal of this technical brief is to present results from a fundamental study examining the thermal effects of fabric with ceramics and minerals (produced by Nanobionic, Inc., Athens, Greece) on the temperatures of the hands. With a confidence level of 90%, the results show that the textile with ceramics and minerals has an enhanced thermal effect on warming a cold hand in comparison to a placebo fabric without ceramics or minerals. Much more research is needed to increase the level of confidence and develop a fundamental understanding of the mechanism. [DOI: 10.1115/1.4042044]

Keywords: ceramics impregnated textile, infrared emissivity, bioheat transfer

Manuscript received September 4, 2018; final manuscript received November 5, 2018; published online January 18, 2019. Assoc. Editor: Ram Devireddy.

1 Introduction

Ceramics and minerals have mechanical and optical characteristics that enable them to be used in numerous industrial applications. The important properties include mechanical rigidity and high emissivity. Recently, substantial research has gone into studying the optical properties of ceramic composites [1]. There is also growing interest in developing textile fabrics with ceramics, and polymers with ceramics [2–4], for their high emissivity in the far infrared spectrum [5]. Of particular interest are ceramics that have high emissivity in the far infrared water window of between 600 nm and 1400 nm [6], a wavelength that can penetrate beyond the subcutaneous layer of the skin [7]. The far infrared can penetrate several cm into the body [5]. The use of these ceramics and minerals for biological applications is based on the hypothesis that, if a layer of ceramic particles with high emissivity in the far infrared is placed over the skin, either as part of a fabric [4] or as a cream [8], they would convert the broad range infrared waves emitted by the body at the body temperature into far infrared waves. The far infrared waves, when emitted by the ceramic particle, can penetrate deep in the body, with various beneficial health effects. Among the claimed beneficial effects of far infrared radiation are vasodilation for treatment of Raynaud's syndrome [9] and even treatment of concussion [10,11].

While the commercial activity around textile fabrics made with ceramics is rather extensive, the fundamental and systematic proof of a biological effect of these materials is scarce. The several papers that were published on studies concerning different textiles with ceramics seek to establish a secondary therapeutic effect to the radiative properties of the textile, such as reduction in body mass [12,13], treatment of patients with Raynaud's disease [9], or reduction of free radicals [14]. However, we did not find any paper that attempts a study on the fundamental physiological effects related to the thermal radiative properties of these textiles. In fact, one of the more thorough reviews of the field claims that "If it can be proven that non-heating far infrared has real and significant effects, then the possible future applications are wide ranging" [5]. The goal of this technical brief is to address this issue. In a fundamental study, we have compared the effect of a textile impregnated with far infrared emitting ceramics and mineral particles (Nanobionic® fabric), and the same fabric without the ceramic and mineral particles, on the temperature of the hand after immersion in cold water. The comparison shows that there is a clear and statistical effect of the Nanobionic fabric with ceramics on the temperature of the hand, confirming that textiles with ceramics have a fundamental physiological thermal effect on the human body.

2 Materials and Methods

The material used in this study is a fabric manufactured by Nanobionic based on polyurethane loaded with mineral oxides (ceramic) coated on a microfiber. Ceramic powder, composed basically of alumina, magnesium oxide, titanium oxide, and silica, was incorporated into the polymer from which the fabric was manufactured. In the manufacturing process, an amount of ceramic particles was added to the fused polymer in such a way that the particles became embedded on the textile after extrusion. Details on the composition and method of fabrication of this textile can be found in: "United States Patent Application Publication, U.S. 2016/0353818 A1; Next to skin garments manufactured from a fabric coated with a composite material based on metal oxides and aninorganic particles." The radiative properties of the Nanobionic material were studied and described in detail in Ref. [14]. The emission peak at 37 °C is between 600 nm and 1200 nm and the emissivity is close to one for frequencies higher than 800–1400 nm. Figures 1(*a*) and 1(*b*) show a typical radiative signature of such a textile, from [14].

The study was conducted according to the principles expressed in the Declaration of Helsinki and was approved by

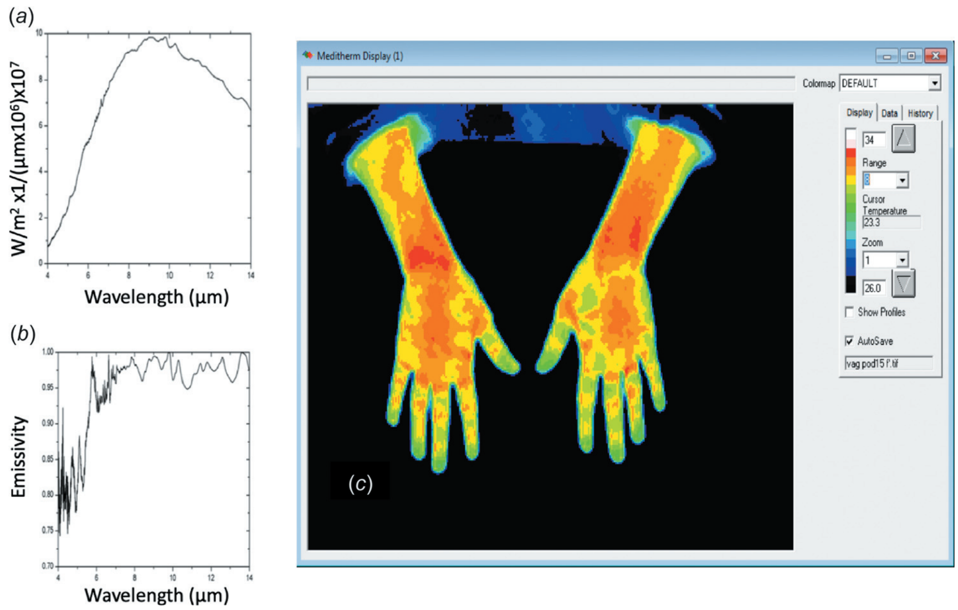

Fig. 1 (*a*) Emission spectrum at $T = 37\,^{\circ}$C, (*b*) Emissivity as a function of wavelength (*a* and *b* are from Ref. [14], with the authors permission), and (*c*) typical thermographic image of the two hands prior to the experiments. Note temperature scale bar on the right.

the "Research Ethics Committee" of the Orthobiotiki Clinic, as well as the Human Protection Committee at UC Berkeley. Volunteers were informed in the presence of witnesses about the experimental protocol as well as its potential risks. The inclusion criteria were female and males in excellent health. The study was done with four subjects. The volunteers participated in this study, with informed consent. The study was done with two pouches made from the Nanobionic supplied textile. One pouch was made with the textile containing ceramics and the other, which served as a placebo, was made of the same textile, albeit not impregnated with the ceramics. The weight of the textile was 2 g/cm for the ceramics impregnated material and for the placebo materials.

In a typical experiment, the participant will submerge both hands in water ($\sim 16 \pm 1\,^{\circ}$C) for 5 min. Then, hands are removed, and very gently wiped with a paper towel. A digital thermograph of the hand in air was taken immediately after, for both top surface of the hand and the palms. Following that, the participants put on the two pouches, the one with the ceramics textile on one hand (right), and the other with the placebo textile on the other (left). The pouches covered the hands to the wrist. The hands were kept comfortable in air at a room temperature of 22 °C. Participants were encouraged to discontinue the study at any time by contacting the investigator. Twenty minutes later, the pouches were removed and digital thermographs were immediately taken of both hands, top and palm, while placed on a wood table. The digital thermograph was taken with a thermal camera Mediterm® 2000. The volunteers did not express any discomfort. The digital camera displays the thermal images in relation to a temperature color bar and has the ability to evaluate the maximal temperature, minimal temperature, and average temperature in a prescribed surface around the hand. The average and standard deviation for each of these data were calculated for the group of four experiment subjects using the one-way ANOVA method and EXCEL software.

3 Results and Discussion

Figure 1(*c*) shows a typical image of the two hands on a wooden table, prior to the experiments. The right-hand side of Figure 1(*c*) shows the temperature/color bar, used to analyze the data. The camera has the ability to digitize the image and to calculate, the maximal temperature, the minimal temperature and the average temperature on a marked display. The results of the experiments in this study are displayed on Figs. 2 and 3, for the four subjects. The figures have marked the columns of photos taken after cold immersion and after 20 min in the pouch. In Fig. 2, arrows point to the rows in which the pouches were made of the placebo textile and those made from the Nanobionic fabric. The top two rows are for the dorsal surface of the hand and the bottom two layers are for the palmar surface.

The results in both Figs. 2 and 3, for subjects 1 and 2 and 3 and 4, respectively, are displayed in a similar way. The images in Figs. 2 and 3 give the maximal temperature, the minimal temperature and the average temperature on a marked display, for each photograph, as calculated by the digital camera.

To analyze the results in a systematic way, we calculated the value of the average temperature distribution on the dorsal side of the hand and on the palm side, between the hand with the ceramics and the placebo, before and after placing the pouch. Before placing the pouch, the percentage difference between the two hands was $1.26\% \pm 1.91\%$ for the dorsal side and $1.31\% \pm 1.94\%$ for the palm side. This verifies that there is no significant difference between the two hands after removal from the cold water and before insertion into the pouch.

After 20 min in the pouch, the percentage difference between the hand in the ceramics pouch and the placebo pouch was $6.34\% \pm 4.25\%$ for the dorsal side and $4.74\% \pm 2.63\%$ for the palm side. The significantly higher temperature of the hand in the ceramics pouch suggests that the Nanobionic fabric has a thermal effect over the placebo, verified with a level of confidence of over 90%.

This technical brief reports a first study on the fundamental heat transfer processes in a fabric containing ceramics. Larger numbers of subjects need to be tested to increase the level of confidence. Furthermore, the actual mechanism is of interest. A possible hypothesis is that the enhanced temperature elevation is associated with an increased blood flow. Figure 4 illustrates an accidental observation concerning the temperature of the wrist of the tested subject. It is evident that the temperature of the wrist in the subject with the ceramics textile is higher than that in the hand with the placebo. This result does not point to the

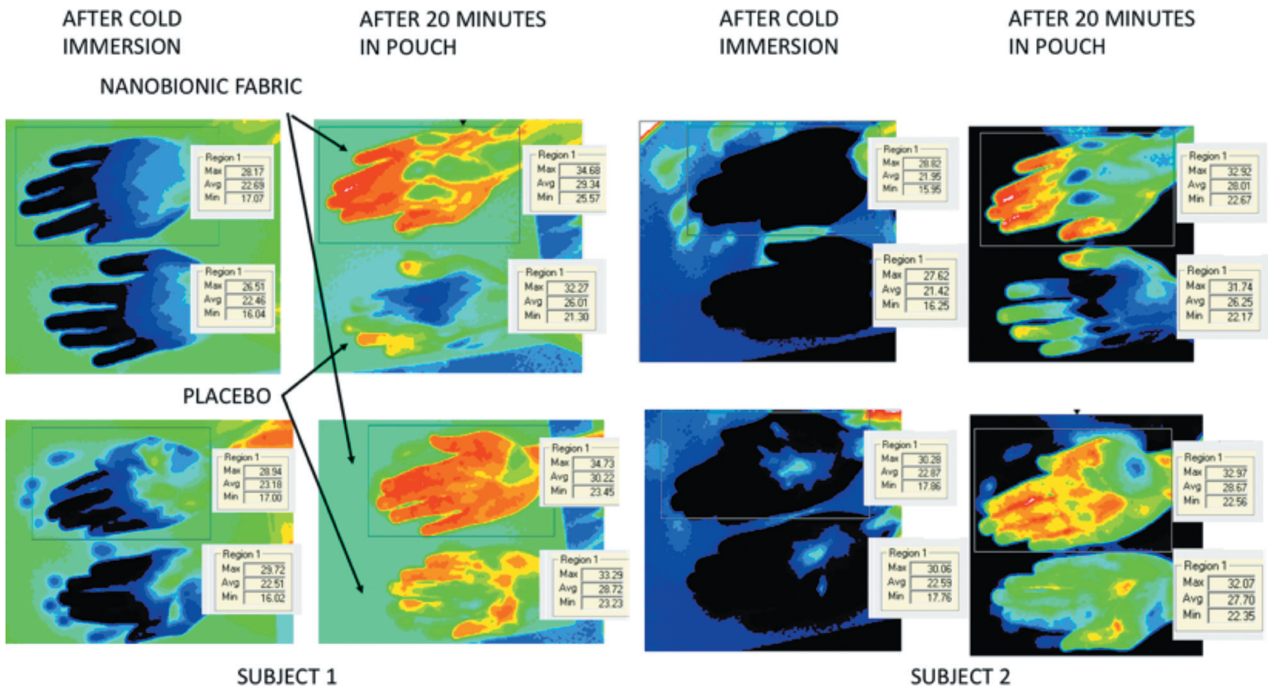

Fig. 2 Results from Subject 1 and 2. The figure has marked the columns of photos taken after cold immersion and after 20 min in the pouch. Arrows point to the rows in which the pouches were made of the placebo textile and those mate from the Nanobionic fabric. The top two rows are for the dorsal surface of the hand and the bottom two layers are for the palmar surface.

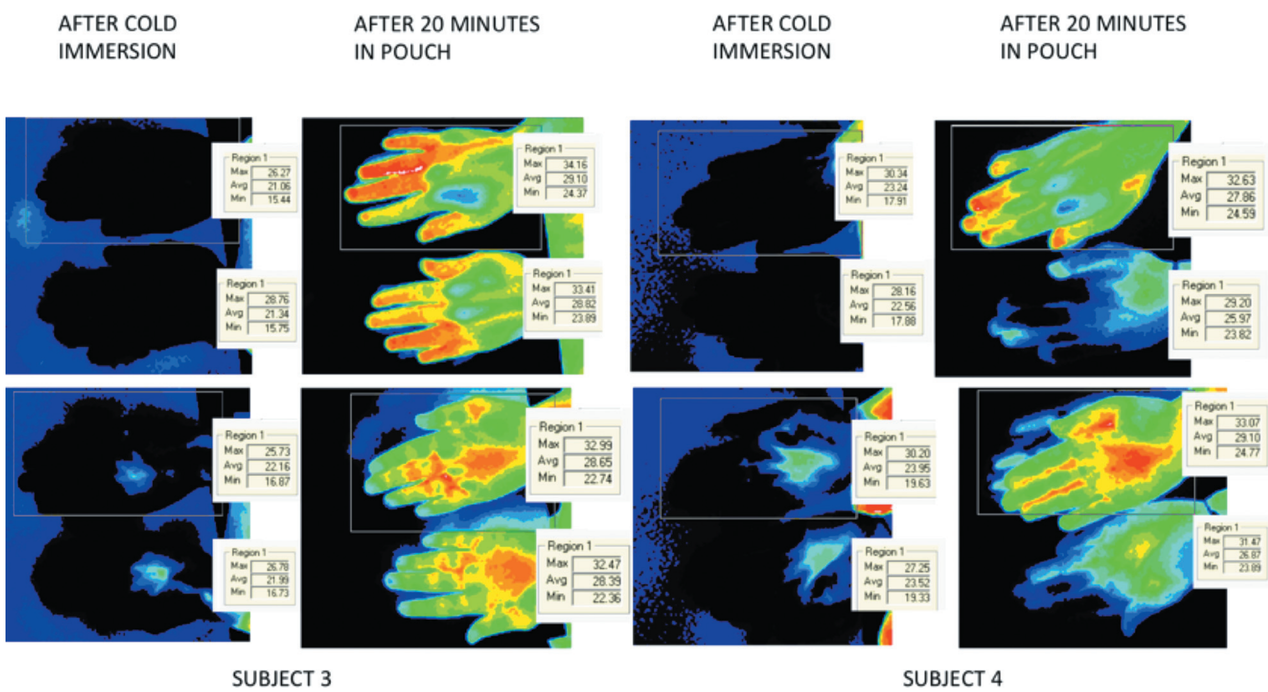

Fig. 3 Results from Subject 3 and 4. The figure has marked the columns of photos taken after cold immersion and after 20 min in the pouch. The configuration is the same like in Fig. 2. The top two rows are for the dorsal surface of the hand and the bottom two layers are for the palmar surface.

mechanism. One possibility is that the mechanism of action of the high emissivity far infrared particles is related to an effect on blood flow. Increasing the temperature of the hand may activate the thermoregulatory system and enhance blood flow in the capillaries.

Obviously, this mechanism requires substantial further investigation. It should be mentioned at this stage that, if indeed the blood flow circulation is enhanced by the effects of high emissivity ceramics in clothing, this would have several important applications, such as for patients with Raynaud Syndrome.

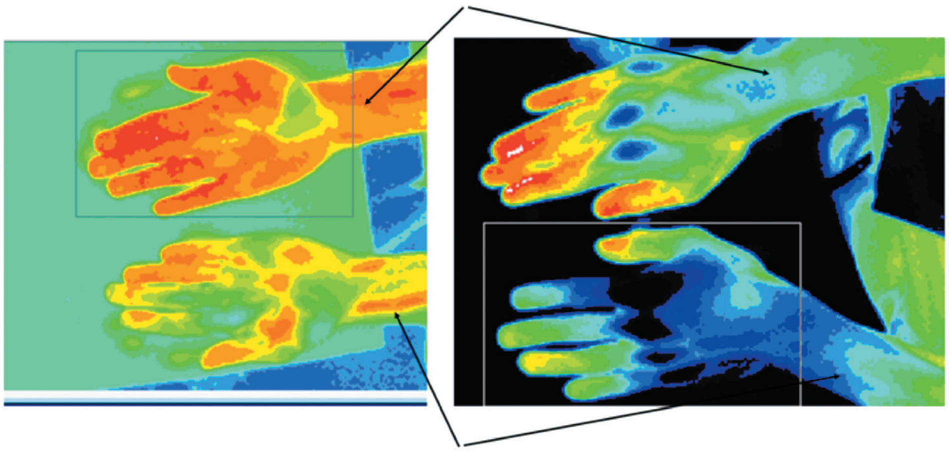

Fig. 4 Images of hands (dorsal to), palm (bottom) after wearing the textile with the ceramics and the placebo. Note the elevated temperature at the wrist of the hand with the ceramics textile.

Acknowledgment

The pouches were fabricated and donated by Nanobionic, Inc. The authors have no commercial interest of any kind in Nanobionic, Inc. and have not received funding for this research, neither directly nor indirectly.

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