Thermal Massaging Elbow Brace using Knit-Based Shape Memory Alloys

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Introduction

The uses of Shape Memory Alloys (SMAs), which has the property of returning to their original shape when the heat is applied, have expanded not only to medical and industrial products, but also to consumer products such as gloves or shapewear. Recently, practical applications have been attempted in various product forms by utilizing SMAs, and one of the potential applications is functional clothing. SMAs applied in functional clothing products were typically made in spiral forms, in a way to offer breathability to the fabricated material. In the study by Bartkowiak et al. (2020), the researchers described the fabrication process of SMAs in that the SMA fabric constructed in a spiral form tends to have the increased height in its structure. Further, Wang et al. (2019) suggested the optimized arrangement and size of SMA springs, which could be applied to thermal-protective clothing since it would create air gaps between the fabrics, thus providing with extra thermal comfort when exposing to the heat stimuli. Additionally, researchers (Ashir et al., 2019; Han & Ahn, 2017) have tried to convert SMAs into the form of yarns and examined the physical properties of those applications to explore whether SMAs were suitable for clothing or other wearable products. Although there are a considerable number of studies that explored the potential of SMAs in functional clothing applications, most were focused on the smart material's physical shape deformation. However, SMAs have another unique characteristic, which is that it generates heat when it changes its shape (Ahn & Han, 2019). Therefore, we aimed to develop a thermal massaging elbow brace by applying not only the physical deformation characteristic of the SMA-based knitting fabric, but also the aforementioned mechanical property of the heat generation during its physical deformation phase. Additionally, we analyzed the wearability of the prototyped elbow brace based on the quantitative measures such as clothing pressure, skin temperature, and blood flow.

Method

After analyzing the behavioral characteristics of SMAs knitting textiles (Ahn & Han, 2019), we selected the knitting techniques with curving and shrinking characteristics of 200 μm SMAs and analyzed their physical properties, respectively. Then, in order to devise the characteristics of curving and shrinking at the same time, a dual module knitting system was created by overlapping each knit pattern. After the change rate of physical properties (i.e., shrinkage and curvature rates) and strain force (i.e., dynamo test) of flat and dual knit patterns were analyzed, we prototyped an elbow brace by applying the dual knitting module. In order to analyze the wearability of the brace, we measured clothing pressure (AMI-3037, Sartorius, Japan), skin temperature (LT8B, GRAM corps, Japan), and blood flow (MoorVMS-LDF2, Moor Instruments

Inc, UK) in an environmental chamber (Temperature of 68°F and humidity of 65%), experienced by a human subject (male, age=41, height=174cm, weight=78kg). The clothing pressure and blood flow sensors were attached on a total of 6 positions of the upper and lower arm, and a temperature sensor to the tip of the right middle finger (Figure 1). The participant sat with his arms on the desk 1) without wearing the brace for 1 minute, then 2) he wore the brace in the same posture and was measured for clothing pressure, skin temperature, and blood flow for 1 minute. 3) To measure the pressure and temperature generated by the brace, the same condition was measured for 10 minutes when operating with a current of 0.3 A. Data were analyzed by comparing the means of the measures at the brace-wearing condition vs. no brace-wearing condition.

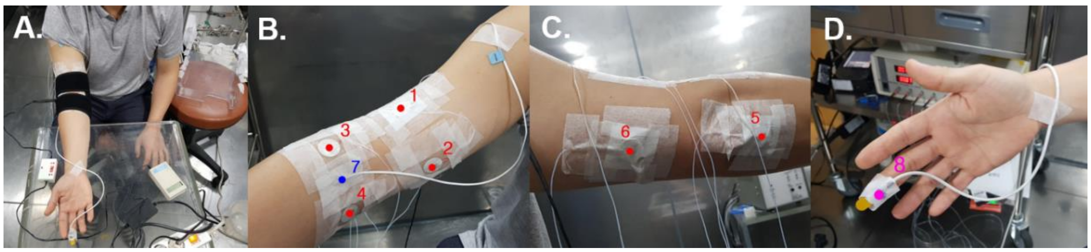

Figure 1. Wearability test: A. experimental process; B, C. positions attached clothing pressure and temperature sensors; D. blood flow sensor

Results

In order to generate the pressure function that can limit the range of motion for the elbow, a dual module was produced by overlapping plain and rib knitting patterns with curving and shrinking characteristics with SMAs (210mm x 50mm, 22 x 52). The curvature of the plain pattern was more than 180 degrees, the shrinkage rate of the rib pattern was 19%, and the strain force was 0.72N. As for the dual module, it was found that the curvature was more than 180 degrees, the shrinkage rate was 15%, and the strain force was 4.69N. In particular, the strain force was much larger than those of the plain pattern. Therefore, a thermal massaging elbow brace was manufactured with this dual module and added to the current controller. According to the evaluation results of the wearability for the brace, during supplying the current at 0.3A, clothing pressure was 7.97-17.6mmHg, which did not exceed 14.72-18.4mmHg, allowable values at the arm area (Baek et al., 2007). Until 7 minutes from the initial point of the current supply, the pressure values of all areas increased, and thereafter, they remained constant. During the heat generation phase from the SMAs module in the brace, skin temperature gradually increased at about 31℃ and maintained at 45℃ when about 10 minutes had passed, which temperature is considered appropriate for thermotherapy (Hayes, 1993). As the skin temperature increased, the blood flow increased from about 100mL/100g to 200mL/100g (Figure 2).

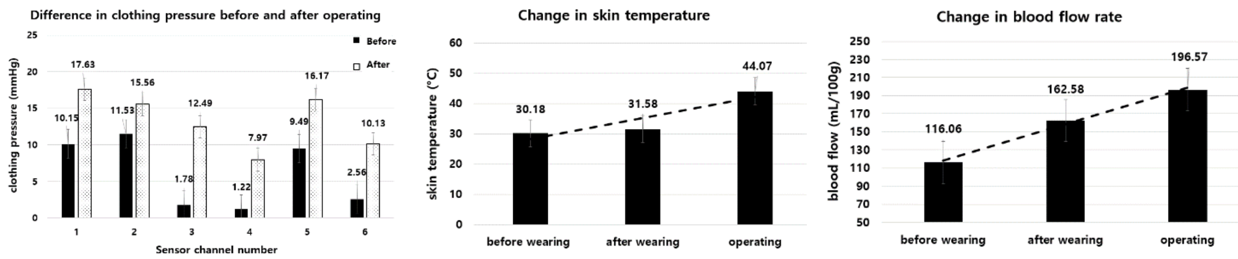

Figure 2. Results of measuring clothing pressure, skin temperature, and blood flow rate

Conclusion

This study developed a thermal massaging brace using a dual knitting module based on SMAs and evaluated the wearability of the massaging brace by determining whether the skin temperature and clothing pressure generated by the module during supplying the current could be suitable to be worn on the human body. This study demonstrated that the prototyped brace could be appropriate as a wearable massaging device that could help increase the skin temperature and blood circulation of a wearer by providing desirable compression and thermal regulation using only knitting fabric without additional auxiliary equipment. Further research is needed to validate the findings of this study with a larger number of human subjects who could be benefitted by wearing the massaging device, in order to understand necessary human factors requirements to mitigate any discomfort or pain caused by wearing the device, as it is further developed.

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