RESEARCH ON THE APPLICATION OF WEARABLE COLD AND HOT COMPRESS THERAPY BELT IN POSTOPERATIVE REHABILITATION OF TKA

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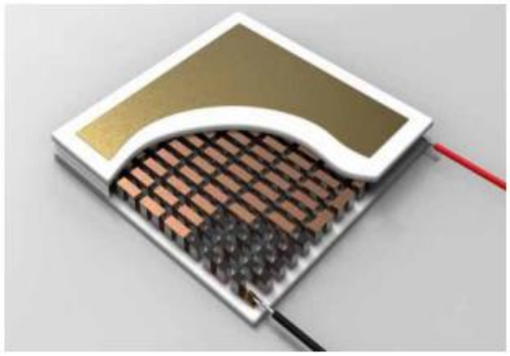
Introduction. Total knee arthroplasty (TKA) is currently the best treatment for knee osteoarthritis (KOA). Due to significant surgical trauma, patients may experience varying degrees of pain in their surgical limbs, and pain care is an important part of postoperative care.

Clinical studies have shown that alternating cold and hot treatment after surgery has a significant pain relief effect, but excessive cold or heat during the use of cold and hot therapy can cause frostbite or scalding in patients, and the treatment effect cannot be achieved when the temperature is insufficient. At the same time, the physical therapy products on the market are mainly focused on single heat therapy and health care, and the combination of cold and heat therapy is still in a blank stage in the market. Moreover, the performance and quality of heat therapy vary, and there is significant room for development and improvement.

Wei helped users better recover, and this study will use a semiconductor refrigeration device to design a cold and hot compress therapy belt.

Research Method. This article will focus on the postoperative recovery of total knee arthroplasty, and plan to design a wearable intelligent physical therapy product using semiconductor refrigeration elements as heating and cooling sources to achieve postoperative pain care for total knee arthroplasty. It includes the analysis of the electrothermal characteristics of the semiconductor refrigeration chip, the analysis of the heat transfer of the semiconductor refrigeration element fabric skin, the design and processing of the temperature control system of the cold and hot compress physiotherapy belt, and the Functional verification experiment of the cold and hot compress physiotherapy belt to ensure the feasibility of the scheme.

Research Contents. The calculation model in this article refers to a certain company's bismuth telluride based TEC1-127xx series semiconductor cooler on the market, and its internal structure is shown in Figure 1. The cross-sectional size of the device is 40mm × 40mm, the height varies with the model. The higher the device power, the lower the height, and the smaller the internal resistance. It can generate greater current under the same input voltage. The device contains 127 pairs of semiconductor thermoelectric components, and the dimensions of P-type and N-type semiconductor thermoelectric components are the same, with a cross-sectional area of 1.4mm × A 1.4mm square, the lower the height of the component, the lower the height of the component. The independent PN junction is electrically connected in series and thermally connected in parallel by welding with copper conductive sheets. The thickness of the upper and lower ceramic sheets is 0.75mm, which serves as electrical



insulation and thermal conductivity.

Fig 1 Schematic diagram of the internal structure of semiconductor refrigerators

The following assumptions are made regarding the heat transfer and thermoelectric conversion during the operation of semiconductor refrigeration devices:

(1) The research process is regarded as a steady state, that is, the temperature and potential fields at various points in space do not change with time;

(2) There is no convective heat transfer between various components inside the device;

(3) There is no radiation heat transfer between various components inside the device;

(4) There is no heat exchange between the sides of the device and the outside world;

(5) The semiconductor component materials inside the device are evenly distributed, and the material properties are the same.

The differential equation describing the physical problem in steady-state is:

$$\nabla \cdot (\lambda_i \nabla T) + \frac{j^2}{\sigma_i} - \beta_i \vec{j} \cdot \nabla T = 0$$

$$\nabla \cdot (\lambda_p \nabla T) + \frac{j^2}{\sigma_p} - \beta_p \vec{j} \cdot \nabla T = 0$$

$$\nabla \cdot (\lambda_n \nabla T) + \frac{j^2}{\sigma_n} - \beta_n \vec{j} \cdot \nabla T = 0$$

$$\beta = T \frac{d\alpha}{dT}$$

The cold and hot compress therapy belt should use low-power semiconductor refrigeration chip components, that is, components with the model TEC-12703.

By combining and integrating the internal components of semiconductor refrigerators as shown in the figure, the internal structure for semiconductor refrigerators is formed.

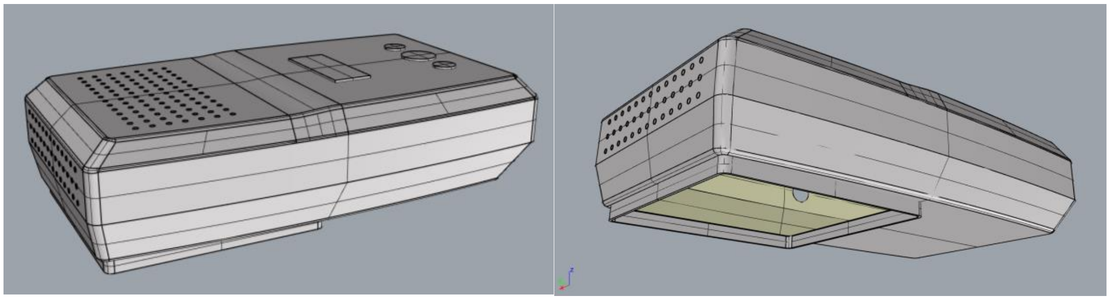


Fig 2 Semiconductor refrigeration system shell

The same geometric modeling was used in this experiment. The outer layer of skin tissue (epidermis 0.08mm, dermis 0.2mm, subcutaneous tissue 1mm) was covered with fleece (thickness 1.2mm, thermal conductivity 0.028W $\cdot M^{-1} \cdot K^{-1}$), and the inner layer of fabric in direct contact with the skin was pure cotton lining (thickness 0.018mm, thermal conductivity 0.072W $\cdot M^{-1} \cdot K^{-1}$). Set the ambient temperature to 22 ℃ and the convective heat transfer coefficient to 5.82W(m^2k).

This article applies a modular approach to the design of a temperature control system, completing a closed-loop control system through collaborative cooperation among various modules, achieving the function of cold and hot compress therapy. To meet the design constraints and functional requirements, this article selects the semiconductor refrigeration chip TEC1-12703 as the heating and cooling source for the cold and hot compress therapy belt.

This article uses the STM32F103C8T6 microprocessor to implement the algorithm, which not only supports a large number of control algorithms, but also provides a good development environment for the software design of the lower computer of the temperature control system.

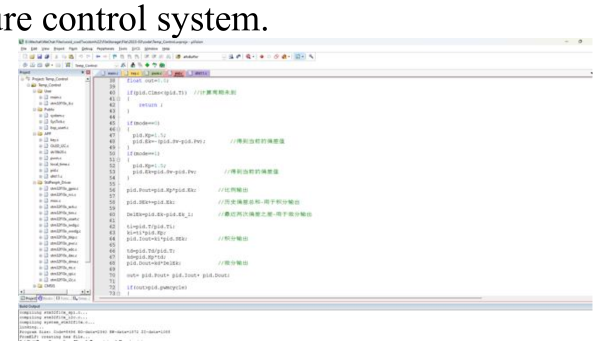


Fig 3 Screenshot of Keil development interface

After the hardware connection is completed, first conduct a power on test to see if there are any open or short circuits. As shown in the following figure5.

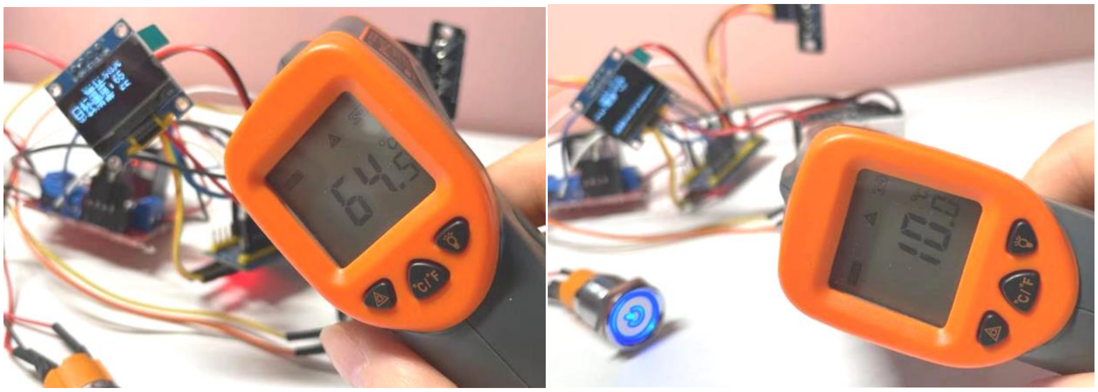


Fig 6 System test results (Left: Heating Right: Cooling)

The results indicate that the hardware system of this article has been processed and all functional modules are running normally and can be used. According to the housing design, the installation situation is shown in the figure7:

Fig 7 Installing the housing

In summary, the hardware design and processing part of this article has been successfully implemented. And the system is running normally, achieving the expected effect and accurate temperature control.

Taking into account the design of the appearance style of the cold and hot compress therapy strip, we aim to break through the traditional single and rigid appearance style. Therefore, in terms of style color matching, based on the color preferences of middle-aged and elderly people in user research, three color combinations are selected: sports silver green, Chinese retro red, and classic blue, using simple and popular geometric sporty graphics and textures.

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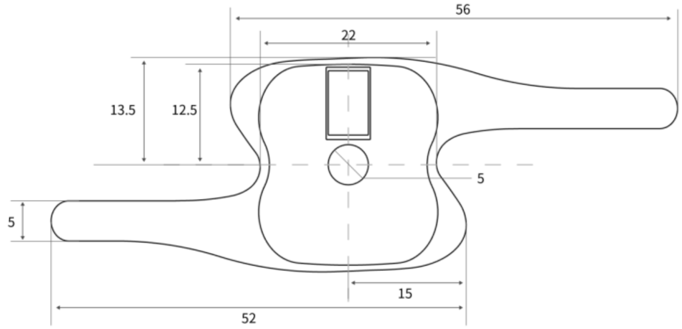

Fig 8 Sketch

Fig 9 Physical therapy tape fabric part sample

Experimental results:

Fig 10 2-minute test results (cooling)

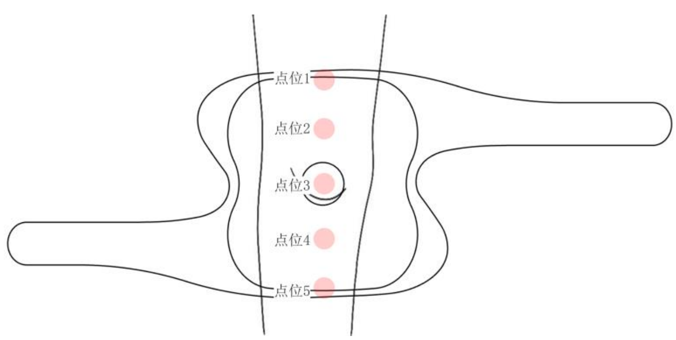

Fig 11 Schematic diagram of measurement points

a) Temperature measurement results

Calculate the average of the three measurement results of six experimenters, and obtain the final measurement results for different locations of each sample, as shown in figure 12.

Point / Person	2min	4min	6min	8min	10min	12min	14min	16min	18min	20min
1	12.6	12.8	12.5	12.7	13.0	12.8	12.7	12.9	13.1	14.8
2	11.2	11.5	11.0	11.3	11.9	11.6	11.4	11.8	12.0	11.4
3	13.2	13.2	13.1	13.5	13.8	13.6	13.5	13.7	13.9	13.5
4	16.8	17.0	16.6	16.9	17.1	16.7	16.5	16.8	17.2	16.8
5	17.4	17.6	17.3	17.5	18.0	17.9	17.6	17.8	18.1	17.6

Point / Person	2min	4min	6min	8min	10min	12min	14min	16min	18min	20min
1	55.8	56.0	56.1	55.6	55.8	56.6	55.1	55.6	55.8	55.5
2	64.6	64.0	63.8	63.5	63.8	64.1	63.3	63.4	63.6	63.3
3	50.3	50.4	50.2	49.8	50.3	50.9	50.2	50.5	50.6	50.2
4	44.2	44.5	44.3	43.9	44.1	44.6	43.8	44.2	44.4	44.1
5	42.4	43.0	43.2	42.8	43.1	43.3	42.8	43.1	43.2	42.9

Fig 12 The average of the measurement results of 6 experimenters

Afterwards, the subjects continued to wear clothes for 20 days, starting with 30 minutes of heat therapy every day, followed by normal mild activity. After the activity, they were given a cold compress for 20 minutes, during which time other treatment and health care were stopped. The experimental personnel conduct visits every 5 days to track the fitting situation, and then conduct an NRS evaluation based on the knee level of the fitting personnel.

Fig 13 Partial subjects

According to result, there is a significant difference in pain before and after fitting, and it can be considered that cold and hot compress therapy bands can effectively alleviate knee joint pain.

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