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Development of a Multi-Stage Thermoelectric Cryosurgery Prototype for Skin Cancer Treatment

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ABSTRACT

Skin cancer is caused by the uncontrolled growth of cells or tissues in the skin layer, often characterized by the appearance of spots, lumps, or moles with abnormal sizes and shapes. Prolonged exposure to ultraviolet (UV) rays from sunlight can trigger abnormal cell growth, increasing the risk of skin cancer. Cryosurgery, a widely used treatment method, employs low temperatures to destroy abnormal cells or tissues. Traditional Cryosurgery methods utilize argon gas or liquid nitrogen to achieve the required low temperatures. This study aims to develop a prototype Cryosurgery device using multi-stage thermoelectric technology as an alternative cooling system, replacing argon gas and liquid nitrogen. The prototype was evaluated by measuring the time required to reach low temperatures in a cooling assembly refrigerator, the cooling time of the Cryosurgery device itself, and temperature differences between the Cryosurgery gun and the probe tip. The results demonstrate that the multi-stage thermoelectric Cryosurgery prototype achieves very low temperatures rapidly, operates with improved energy efficiency and requires minimal maintenance. This innovative system provides better temperature control, safer operation, and a more cost-effective solution compared to traditional methods. However, managing heat dissipation from the thermoelectric modules remains a key challenge for future optimization.

KEYWORD skin cancer, Cryosurgery, low temperature, thermoelectric cooling, medical device innovation

I. INTRODUCTION

Skin cancer is a disease caused by the uncontrolled growth of cells or tissue in the layers of the skin such as the epidermis, dermis, and subcutaneous tissue.[1][2]. This growth can cause changes to the skin in the form of spots, lumps, or moles that develop abnormally. In tropical countries like Indonesia, where sunlight shines all year round, the risk of skin cancer is higher. Excessive exposure to ultraviolet (UV) light, especially in areas that are frequently exposed, is a major risk factor for the development of skin cancer, especially non-melanoma types.

Indonesia is ranked 63 in the world in the number of skin cancer cases, according to data from the Global Cancer Observatory (GLOBOCAN) [3]. Types of non-melanoma skin cancer, such as basal cell carcinoma, show a significant increase in Indonesia every year. [4]. Meanwhile, melanoma skin cancer, although less common, remains one of the leading causes of cancer death. The high presence of non-melanoma skin cancer in Indonesia is largely due to the high intensity of UV rays that people face in their daily activities, especially outdoors.

Various methods of skin cancer treatment have been developed, including surgery, radiotherapy, and chemotherapy. However, Cryosurgery technology has gained attention as an effective and minimally invasive alternative treatment method. Cryosurgery works by using very low temperatures to freeze and destroy cancer cells, so that the affected tissue becomes frozen and the cells die [5]. This technology is mainly relied on to treat tumors or cancer that are located on the surface of the skin or close to the surface.

Currently, Cryosurgery generally uses liquid nitrogen as a cooling medium, which can reduce temperatures to -196°C [6]. Although effective, the use of liquid nitrogen has several disadvantages, such as its volatile nature, difficulty in temperature control, and special storage requirements. To overcome this problem, several studies have been carried out to develop thermoelectric-based cooling systems as an alternative that is safer and easier to control. This system uses a Peltier module to achieve the low temperatures required in Cryosurgery procedures without the risks associated with liquid nitrogen. [7][8], [9], [10], [11], [12].

In this research, we developed a multistage thermoelectric-based Cryosurgery prototype designed to reach a temperature of -20°C on the probe, to efficiently freeze and kill cancer cells.

This prototype integrates a Peltier and refrigerator technology cooling system, which is expected to be an innovative solution for treating skin cancer in Indonesia. This development not only aims to increase the effectiveness of treatment but also to minimize risks and shorten the duration of surgery, making Cryosurgery a more practical and safe treatment option.

II. RESEARCH METHODS

A. RESEARCH DESIGN

This research is quantitative, namely a process of searching for knowledge that uses data in the form of numbers to analyze information about everything you want to know. Using linear regression analysis, the authors explored the effect of time on temperature at temperatures of 0°C, -5°C, -10°C, and -20°C.

The results of this analysis are expected to explain whether there is a relationship between time duration and temperature changes, as well as how much time influences the achievement of the desired temperature. Apart from that, this research also uses qualitative methods to select probe materials that can conduct temperature well and are not too affected by room temperature.

B. CONCEPTUAL FRAMEWORK

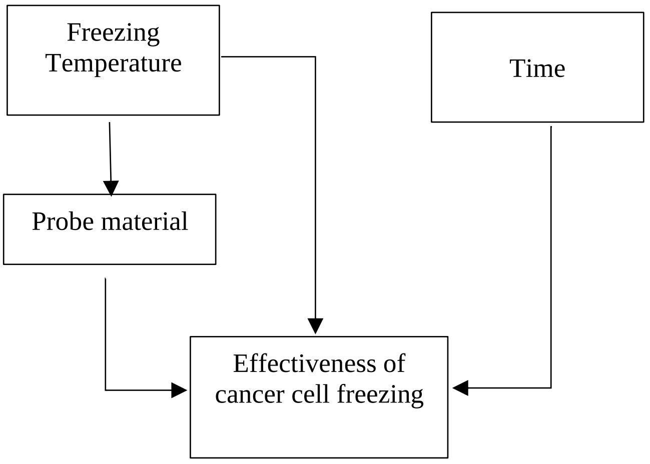

FIGURE 1. Conceptual Framework

Figure 1 can be explained as follows:

1. Freezing Temperature: This is the temperature used in the Cryosurgery process, such as 0°C, -5°C, -10°C, and -20°C. The freezing temperature affects how effectively cancer cells can be frozen and destroyed, as well as the performance of the probe material used, as lower temperatures can increase the effective freezing of cancer cells.
2. Time: The length of time in the freezing procedure affects the effectiveness of freezing cancer cells. The longer the freezing time, the greater the chance that the low temperature can penetrate deeper and completely freeze the cancer cells, ensuring more effective destruction.
3. Probe material: The type of material used to make probes in Cryosurgery must be able to conduct low temperatures efficiently without being too affected by room temperature. These ingredients influence the transfer of temperature to cancerous tissue, which in turn influences the effectiveness of freezing according to the freezing temperature used.
4. Effectiveness of Freezing Cancer Cells: Measuring the success of Cryosurgery in freezing and destroying cancer cells, this effectiveness is influenced by freezing temperature, time duration, and probe material. The relationship between these three variables determines how optimal the results of the cancer cell freezing procedure are.

C. DATA COLLECTION TECHNIQUES AND RESEARCH INSTRUMENT

1. Data collection technique

The method of data collection in this research involves primary data collection conducted during the study. The author utilizes a primary data method, specifically measuring the time taken for 1 liter of water to reach a temperature of -5°C. Additionally, the author measures the time required to achieve different cryosurgery temperatures, specifically 0°C, -5°C, -10°C, and -20°C. The measurements are performed three times, starting when the water temperature is at 28°C, and once the water reaches -5°C, the measurement continues with the probe temperature. Data collection is performed using copper probes due to their high thermal conductivity, which allows for more effective cooling and temperature reduction.

2. Research Instruments

Research instruments are all tools used to collect, examine, and investigate a problem, or systematically and objectively process, analyze, and present data to solve a problem or test a hypothesis. In this study, data collection was carried out quantitatively. Quantitative testing measures the correlation between temperature and micropipette calibration results.

This research utilizes the following instruments:

1. Thermometer Controller W2809
2. Digital Thermometer Freezers
3. Stopwatch from a smartphone

These instruments were used to ensure precise and accurate data collection throughout the study.

D. DATA ANALYSIS TECHNIQUES AND METHODS OF DATA PRESENTATION

Data Analysis Technique

1. The descriptive statistical analysis method was chosen to analyze the data, aiming to determine the effectiveness of thermoelectric systems as a cooling system for cryosurgery, replacing argon and liquid nitrogen gas.
2. The results of the measurement at each point were presented, with data analysis using the following formulas:
   - Mean (average value): calculated by summing up all the data values in a sample group and dividing by the number of samples.

$$\bar{x} = \frac{\sum_i^n = 1x_i}{n_i} \tag{1}$$

Where,
$\bar{x}$ = Average value (mean)
$\sum_i^n = 1x_i$ = Sum of all values
n_i = Amount of data

The data will be presented in a table and graph format, showcasing the changes in temperature over time. The graphical presentation will illustrate the decline in temperature as time passes, providing a visual representation of the data.

III. RESULT AND EXPLANATION

Cryosurgery devices are engineered with a multi-stage thermoelectric system to achieve the precise cooling required for medical procedures. This advanced setup allows for better control over the cooling process by stacking multiple thermoelectric modules, which work together to reach significantly low temperatures. One of the critical aspects of this system is the efficient management of the heat generated on the hot side of the Peltier modules. To ensure the system operates effectively, the heat on this side is dissipated using water that has been cooled in a refrigerator. The chilled water circulates the hot side of the Peltier, absorbing the excess heat and maintaining the necessary temperature differential to keep the system functioning optimally. This method not only enhances the overall efficiency of the cryosurgery device but also ensures consistent cooling performance during procedures, minimizing the risks associated with traditional cooling methods.

Based on the results of time measurements of changes in water temperature to reach 5°C.

TABLE 1
RESULT TIME MEASUREMENT OF WATER TEMPERATURE

No	Water Temperature (°C)	Time Measurement (Minute)			Average (Minute)
		1	**2**	**3**	
1	**25**	**9**	**9**	**7**	**8.33**
2	**20**	**29**	**32**	**28**	**29.67**
3	**15**	**53**	**59**	**53**	**55**
4	**10**	**83**	**95**	**84**	**87.33**
5	**5**	**120**	**135**	**125**	**126.67**

In TABLE 1, the comparison of water temperature with time. This measurement was carried out 3 times starting at a water temperature of 28°C, and it can be concluded that the lower the desired temperature, the longer it will take. Apart from that, there is a tendency for the time required to increase as the experiment is carried out repeatedly. Therefore, it can be concluded that before the prototype tool, *Cryosurgery* multilevel thermoelectric is switched on, the *refrigerator* must be turned on at least 2 hours beforehand to reduce the temperature of the water which will be the main cooling element of *cryosurgery*.

In Fig.2 the time required to reach the setting temperature tends to fluctuate actively. The measurement points were carried out at cryosurgery temperature settings of 0°C, -5°C, -10°C, and -20°C. In the first experiment with a temperature setting of 0°C, it took 60 seconds to reach that temperature. Once a temperature of 0°C is reached, the Peltier will turn off and turn on again when the temperature drops below 0°C, to adjust the temperature in cryosurgery. In the second experiment, the cryosurgery temperature setting was changed to -5°C, and it took 150 seconds to reach it because the lower temperature required a longer time compared to the first experiment. In the third experiment, with a temperature setting of -10°C, it took 240 seconds to achieve this. Meanwhile, in the fourth experiment, with the cryosurgery temperature set at -20°C, it took 420 seconds to reach that temperature. Measurements were carried out 3 times to ensure consistency of results.

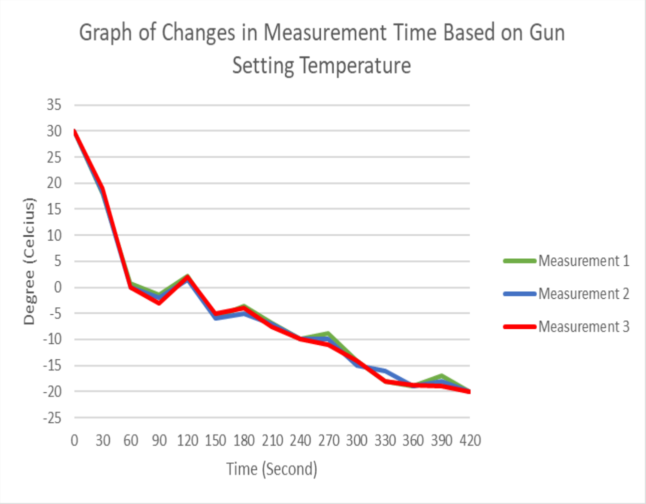

FIGURE 2. **Graph of Changes in Measurement Time Based on Gun Setting Temperature**

During this process, the Peltier will turn on to reach the desired temperature. Once the temperature is reached, the measured temperature may be slightly lower as the Peltier will adjust. When the temperature is far from the set point, the control will turn the peltier back on, causing a slight temperature spike. This phenomenon is known as a negative feedback control system. This is because the temperature of the water used has reached the desired specifications, namely 5°C. Therefore, the time required by Cryosurgery to reach the setting temperature is not too long. The measurement point is carried out on a copper plate flanked by a Peltier as shown in Fig. 3..

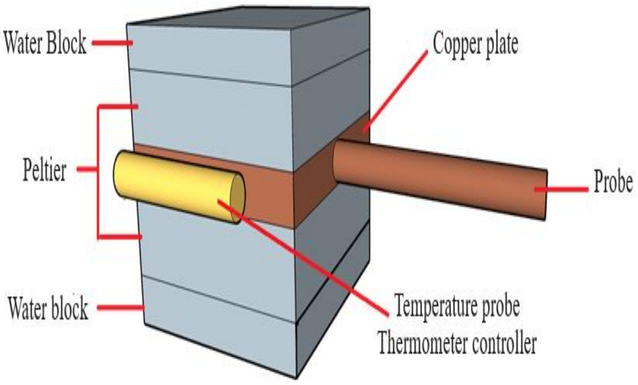

FIGURE 3. **Inside Cryosurgery**

The comparative analysis of using copper as a probe material with other materials is also crucial to consider. Thermal conductivity is the ability of a material to conduct heat or cold. The higher the thermal conductivity of a material, the better it is at transferring heat or cold. For example, as seen in TABLE 2, silver has a higher thermal conductivity value compared to other metallic materials, enabling it to transfer temperature from one place to another quickly.

Thermal inertia, on the other hand, is the ability of a material to store heat or cold. Materials with high thermal inertia take longer to heat up or cool down compared to those with low thermal inertia. In this context, the ideal material for use as a cryosurgery probe should possess high thermal conductivity but low thermal inertia.

TABLE 2
LIST OF THERMAL CONDUCTIVITY AND THERMAL INERTIA VALUES

No	Material name	Conductivity thermal (W/(m.K))	Thermal Inertia (J/(g.K))
1	Copper	401	0.39
2	Alumunium	237	0.9
3	Silver	429	0.24
4	Iron	80	0.45
5	Stainless steel	16 - 24	0.5
6	Gold	315	0.13

In previous research, copper coated with gold at its edges proved effective as a probe. [11]. Nevertheless, copper was chosen for this study because it has a high thermal conductivity value, second only to silver, allowing it to quickly transfer temperature. However, the downside of using copper is its high thermal inertia, which causes it to rapidly adjust to changes in ambient temperature. As a result, there is a temperature difference between the copper plate and the final sample, as copper quickly adjusts its temperature according to the surrounding conditions.

TABLE 2 Shows a list of thermal conductivity and thermal inertia values for various materials. From the table, it is evident that copper has high thermal conductivity but also a relatively high thermal inertia, causing it to rapidly adapt to ambient temperature changes. Therefore, although copper excels in thermal conductivity, its drawback in terms of thermal inertia must be carefully considered when selecting materials for a cryosurgery probe.

IV. CONCLUSION

This cryosurgery prototype was designed using multistage thermoelectric technology, which utilizes four Peltier modules as the main cooling components. The hardware and mechanical design of this tool includes an additional system in the form of a refrigerator which is used to cool the hot side of the Peltier module, thereby significantly increasing the efficiency and cooling capacity of the tool. To evaluate the performance of the prototype, tests were carried out using a stopwatch to measure the time required for water to reach a temperature of 5°C, where the average time required was recorded at around 131 minutes. In addition, in other tests, the average time required to reduce the water temperature to -20°C was recorded as only 7 minutes, demonstrating the efficient performance of the developed cooling system.

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