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原　　著

Reverification of the effect of hot springs on arteriosclerosis based on a mathematical model of the development of arteriosclerosis using an improved analysis method Ⅱ: in case of weak radioactive springs

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解析手法の改良による動脈硬化症進行の数理モデルに基づく温泉の動脈硬化症への効能の再検証Ⅱ：弱放射能泉の場合

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要　　旨

呼鶴温泉（山口県，日本）の動脈硬化症に対する効能を，入浴後のコレステロールエステルの吸収スペクトルの「山」と「谷」の差の変化に基づいて再検証を試みた．コレステロールエステルの測定原理は，中赤外領域の光を皮膚に照射し，その吸収スペクトル強度から皮膚のコレステロールエステル量を測定するものである．放射能泉である呼鶴温泉の動脈硬化症に対する効能を再検証した結果，改良された分析法によると，放射能泉への入浴は，コレステロール値の変化に寄与しないことが分かったため，動脈硬化症への効能がないことが明らかとなった．

キーワード：中間赤外域，温泉，効能，動脈硬化，数理モデル

Abstract

The efficacy of Yobizuru Onsen (Yamaguchi, Japan) for arteriosclerosis was tried to be reverified based on the change of the difference between the “peak” and “valley” of the absorption spectrum of cholesterol ester after bathing. The measurement principle of cholesterol ester is to irradiate the skin with light in the mid-infrared region and determine the cholesterol ester level of the skin from the absorption spectrum intensity. As a result of

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reverification of the efficacy of Yobizuru Onsen, a radioactive spring, for arteriosclerosis, the improved analysis method found that radioactive hot springs have not any efficacy on arteriosclerosis because bathing in radioactive springs does not contribute to changes in cholesterol levels.

Key words : mid-infrared region, hot spring, efficacy, arteriosclerosis, mathematical model

I. Introduction

Research on the efficacy of hot springs has been conducted based on various methods and perspectives[1). In this study, the efficacy of hot springs on arteriosclerosis is examined based on the mathematical model and the minimally invasive cutaneous cholesterol ester level measuring device.

The efficacy of several hot springs on arteriosclerosis has so far been verified based on the mathematical model of arteriosclerosis onset[2,3) and measurements of changes in skin cholesterol levels before and after bathing using a minimally invasive cutaneous cholesterol ester level measuring device[4-8).

The measurement principle is to irradiate the skin with light in the mid-infrared region and determine the cholesterol ester level of the skin from the absorption spectrum intensity.

Initially, the increase or decrease in cholesterol before and after bathing was determined by the change in the absolute values of the peaks and valleys of the absorption spectrum of cholesterol ester. However, since the absolute value of the absorption spectrum may change depending on the environment, the analysis method to judge based on the change of the difference between the "peak" and "valley" of the absorption spectrum of cholesterol ester after bathing is more appropriate.

Therefore, when the above improved analysis method was used to reverify the efficacy of Yuno Onsen (a weakly radioactive alkaline simple sulfur spring, Yamaguchi Prefecture (Japan)) to arteriosclerosis based on the above measurement results at Yuno Onsen in 2021, the results that were slightly different from the previous results were obtained[8).

Therefore, in this study, regarding the above measurement results at Yobizuru Onsen (a simple weakly radioactive cold mineral spring, Yamaguchi Prefecture (Japan)) in 2022, the efficacy of Yobizuru Onsen for arteriosclerosis is tried to be reverified based on the change of the difference between the "peak" and "valley" of the absorption spectrum of cholesterol ester after bathing. It should be noted that the radon content of Yobizuru Onsen is 0.79×10^{-10} [Ci/kg] (surveyed by Kagawa Gakuen Ube Environmental Technology Center on 24 May 2013), which means that the radon content is not very high.

II. Methodology

A. Principle of measurement of blood cholesterol level

Though principle of measurement of blood cholesterol level is already explained[6), it is briefly explained again here.

Cholesterol levels were measured using CLE-80, a minimally invasive cutaneous cholesterol ester level measuring device from Photoscience Co., Ltd. (Photoscience). Measurement of the concentration of cholesterol ester levels in the skin with this device provides an estimate of the total cholesterol concentration in the blood.

The measurement principle is to irradiate the skin with light in the mid-infrared region and determine the cholesterol ester level of the skin from the absorption spectrum intensity.

The valley portion (1724 [cm^{-1}]) next to the cholesterol ester peak in the absorption spectrum is called the "ester valley", and the peak portion (1742 [cm^{-1}]) is called the "ester peak". Changes in these values were used to determine the increase or decrease in blood total cholesterol concentration (Fig. 1).

On the other hand, the cholesterol ester level to the total cholesterol level is approximately constant at about 70%. And according to Photoscience, the correlation coefficient between blood total cholesterol level and skin cholesterol ester level is as high as 0.997. From these facts, it can be considered that the cholesterol ester level obtained by this measurement method almost accurately reflects the total blood cholesterol level.

In this study, it is assumed that the skin cholesterol ester level measured by this device reflects the total cholesterol level in the blood.

B. The mathematical model of arteriosclerosis onset and its fruits

Kagami (2019) mathematically modeled the process of developing arteriosclerosis[3] and then improved it to derive the following equation as the time evolution equation for the blood vessel volume of arteriosclerosis-developed parts[2].

$$\frac{d^2V}{dt^2}+\frac{r}{V}\frac{dV}{dt}-\frac{r}{V}p_i k_1 k_2 u(k_3+k_4 p_k) u_0 e^{-k_5 t}=0 \qquad (1)$$

where V is the volume of the blood vessel in the arteriosclerosis-causing part, r is the flow rate of the blood, p_i is the concentration of monocytes in the incoming blood, p_k is the cholesterol

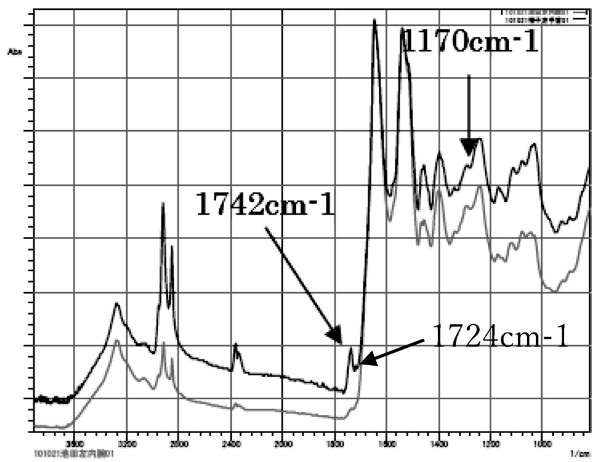

Fig. 1　FT-IR spectrum of measurement subject[9] (added by the author to the original figure). The graph above shows the spectrum of a person with high cholesterol levels and the graph below shows the spectrum of a person with low cholesterol levels.

concentration in blood, u is the number of flaws per unit area of the intima, u_0 represents u when $t=0$ and k_1, k_2, k_3, k_4 or k_5 is a coefficient, respectively.

From the numerical simulation results of (1), it is found that the lower the cholesterol concentration in the blood, the stronger the development of arteriosclerosis is suppressed.

C. Method for measuring cholesterol levels after bathing

Among the customers who visited Yobizuru Onsen during the 11 business days from February 4 to March 4, 2023, 200 people who gave their consent were measured for cholesterol ester levels in the skin after one bath.

Excluding missing data, the number of data obtained by age group is 15 people in 10's to 30's, 44 people in 40's to 50's and 140 people in 60's and older. Of these, excluding the data of 4 people whose sweat was detected in the measurement after bathing, finally 195 people's data in 10's to 30's : 15 people, 40's to 50's : 44 people and over 60's : 136 people were included.

Concerning these data, the difference between the "peak" and "valley" of the absorption spectrum of cutaneous cholesterol ester before and after bathing is calculated. If the difference becomes smaller after bathing, it is judged that the cholesterol value in the skin has decreased. In addition, if the difference between the "peak" and "valley" of the absorption spectrum of cholesterol ester before bathing is negative concerning these data, it is assumed that the "peak" of the absorption spectrum of cholesterol ester does not exist and the data are not added to the analysis data.

III. Results and Discussion

Among the data of 195 people, excluding the data in which the difference between the "peak" and "valley" of the absorption spectrum of cholesterol ester before bathing was negative, 42 valid data were obtained. It was investigated whether the difference between the "peak" and "valley" was increased or decreased after bathing for the valid data of 42 people and the results shown in Table 1 were obtained.

Table 1　NUMBER OF PEOPLE WHOSE CHOLESTEROL LEVEL DECREASES OR INCREASES AFTER BATHING (ALL AGES)

	n (%)
descent	23 (54.8)
rise	19 (45.2)

chi-square test: p = 0.537

Concerning this result, from the chi-square value of "the difference" is 0.381 and $\chi^2_{0.05}=3.84$ statistically significant decrease of the cutaneous cholesterol level after bathing is not confirmed (significance level : 0.05). The results that statistically significant change of cutaneous cholesterol levels after bathing were not obtained in all ages category.

This result differs significantly from the results obtained with above mentioned previous analysis methods[6]. According to the results of the previous analysis method, the increase rate in “ester valley” or “ester peak” after bathing was 0.610 or 0.672, respectively, and from the chi-square value of “ester valley” or “ester peak” is 9.48 or 23.0, respectively and $\chi^2_{0.01} = 6.64$ statistically significant increase of the cutaneous cholesterol level after bathing is confirmed (significance level : 0.01)[6].

To analyze this result in more detail, in the following, the same investigation results by age group are shown.

Among the above-mentioned valid data of 42 people, only one was in 10’s to 30’s. It was investigated whether the difference between the “peak” and “valley” was increased or decreased after bathing for the only one and the result that the decrease of cutaneous cholesterol levels after bathing was obtained. However, the results are not sufficient as the amount of data is too small.

For the reference, according to the results of the previous analysis method in 10’s to 30’s, the decrease rate in “ester valley” or “ester peak” after bathing was 0.600 or 0.533, respectively, and from the chi-square value of “ester valley” or “ester peak” is 0.600 or 0.0667, respectively and $\chi^2_{0.05} = 3.81$ statistically significant change of the cutaneous cholesterol level after bathing is not confirmed (significance level : 0.05)[6].

Similarly, it was investigated whether the difference between the “peak” and “valley” was increased or decreased after bathing for the data of people in 40’s to 50’s and the results shown in Table 2 were obtained. Concerning this result, from the chi-square value of “the difference” is 0.0909 and $\chi^2_{0.05} = 3.84$ statistically significant change of the cutaneous cholesterol level after bathing is not confirmed (significance level : 0.05). The results that statistically significant change of cutaneous cholesterol levels after bathing were not obtained in 40’s to 50’s.

Table 2 NUMBER OF PEOPLE WHOSE CHOLESTEROL LEVEL DECREASES OR INCREASES AFTER BATHING (IN 40’S TO 50’S)

	n (%)
descent	5 (45.5)
rise	6 (54.5)

chi-square test: p = 0.763

This result is similar to the results obtained with above mentioned previous analysis methods[6]. According to the results of the previous analysis method, the increase rate in “ester valley” or “ester peak” after bathing was 0.614 or 0.636, respectively, and from the chi-square value of “ester valley” or “ester peak” is 2.27 or 3.27, respectively and $\chi^2_{0.05} = 3.84$ statistically significant change of the cutaneous cholesterol level after bathing is not confirmed (significance level : 0.05)[6].

Similarly, it was investigated whether the difference between the “peak” and “valley” was increased or decreased after bathing for the data of people in 60’s and older and the results shown in Table 3 were obtained. Concerning this result, from the chi-square value of “the difference” is 0.533 and $\chi^2_{0.05} = 3.84$ statistically significant change of the cutaneous cholesterol level after bathing is not confirmed (significance level : 0.05). The results that statistically significant change of cutaneous cholesterol levels after bathing were not obtained in 60’s and older.

Table 3　NUMBER OF PEOPLE WHOSE CHOLESTEROL LEVEL DECREASES OR INCREASES AFTER BATHING (IN 60'S AND OLDER)

	n (%)
descent	17 (56.7)
rise	13 (43.3)

chi-square test: p = 0.465

This result differs significantly from the results obtained with above mentioned previous analysis methods[6]. According to the results of the previous analysis method, the increase rate in "ester valley" or "ester peak" after bathing was 0.632 or 0.706, respectively, and from the chi-square value of "ester valley" or "ester peak" is 9.53 or 23.1, respectively and $\chi^2_{0.01} = 6.64$ statistically significant increase of the cutaneous cholesterol levels after bathing is confirmed (significance level : 0.01)[6].

From the above results, the previous analysis method found that statistically significant increase in cutaneous cholesterol levels after bathing was observed in all ages group and in the age group over 60 years old, whereas this improved analysis method found that statistically significant change was not observed in all ages group and in each age group (the age group under 40 years old are excluded due to lack of data). In other words, it has become clear that bathing in radioactive springs does not contribute to changes in cutaneous cholesterol levels.

This result does not change the previous conclusion that among the above mentioned three properties (radioactive, alkaline, and sulfurous) that have the potential to lower cholesterol levels after bathing, radioactive springs are excluded from the list, while alkaline springs and sulfur springs remain as candidates. Namely, the previous conclusion that radioactive hot springs have not any efficacy on arteriosclerosis is not altered.

IV.　Conclusion

Regarding the previous measurement results at Yobizuru Onsen (a simple weakly radioactive cold mineral spring, Yamaguchi Prefecture (Japan)) in 2022, the efficacy of Yobizuru Onsen for arteriosclerosis is tried to be reverified based on the change of the difference between the "peak" and "valley" of the absorption spectrum of cutaneous cholesterol ester after bathing.

As a result, the improved analysis method found that bathing in radioactive springs does not contribute to changes in cholesterol levels.

The result does not change the previous conclusion that among the three properties (radioactive, alkaline, and sulfurous) that have the potential to lower cholesterol levels after bathing, radioactive springs are excluded from the list, while alkaline springs and sulfur springs remain as candidates. Namely, the previous conclusion that radioactive hot springs have not any efficacy on arteriosclerosis is not altered. However, as mentioned above, the radon content of Yobizuru Onsen cannot be said to be high, so it would be desirable to re-examine hot springs with high radon content in the future to reach a more accurate conclusion.

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