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# Verification of the effect of hot springs on arteriosclerosis based on the mathematical model of arteriosclerosis onset Ⅱ: in case of weak radioactive springs

***Abstract***. *In order to narrow down the characteristics of hot springs that have efficacies on arteriosclerosis, changes in skin cholesterol levels after bathing at the Yobizuru Onsen, which is classified as a simple weakly radioactive cold mineral spring, were measured. As a result, based on the results from the mathematical model of arteriosclerosis onset, it was indirectly shown that the nature of a radioactive spring may not have an efficacy on arteriosclerosis. In the future, in order to clarify which of the two characteristics (alkaline, sulfur spring) has the efficacy on arteriosclerosis, it is necessary to investigate hot springs that have only one characteristic, alkaline or sulfur spring.*

***Streszczenie.*** *Aby zawęzić charakterystykę gorących źródeł skutecznych w leczeniu miażdżycy, zmierzono zmiany w poziomie cholesterolu w skórze po kąpieli w Yobizuru Onsen, które jest klasyfikowane jako proste, słabo radioaktywne zimne źródło mineralne. W rezultacie, na podstawie wyników matematycznego modelu początku miażdżycy, pośrednio wykazano, że charakter źródła radioaktywnego może nie mieć wpływu na miażdżycę. W przyszłości, aby wyjaśnić, która z dwóch właściwości (alkaliczne, siarkowe źródło) ma skuteczność w leczeniu miażdżycy, konieczne jest zbadanie gorących źródeł, które mają tylko jedną charakterystykę, źródło zasadowe lub siarkowe. (**Weryfikacja wpływu gorących źródeł na miażdżycę w oparciu o matematyczny model początku miażdżycy Ⅱ: w przypadku słabych źródeł radioaktywnych**)*

**Keywords:** hot spring, efficacy, arteriosclerosis, mathematical model
**Słowa kluczowe:** gorące źródło, skuteczność, miażdżyca, model matematyczny

## 1. Introduction

The mathematical model of arteriosclerosis onset by Kagami (2021) mathematically shows that improvement of blood cholesterol levels can be a factor in suppressing the progression of arteriosclerosis [1].

On the other hand, although radioactive springs are said to be effective against arteriosclerosis, no scientific verification has been done yet.

In past research results, Nakagawa et al. (2008) found that radon inhalation in mice decreased the amount of lipid peroxides produced by the oxidation of cholesterol in various organs over time [2]. This result suggests that radioactive springs containing radon may reduce blood cholesterol levels in humans.

Based on this speculation, an experiment to verify whether the blood cholesterol level decreased after bathing at Yuno Onsen (Yamaguchi Prefecture, Japan. Fig. 1), which is a weakly radioactive alkaline simple sulfur spring, in 2021. As a result, it was clarified that a statistically significant reduction in blood cholesterol levels after bathing was observed even after bathing only once [3 - 5]. As a result, based on the above mathematical model, it was indirectly verified that Yuno Onsen has an efficacy on arteriosclerosis.

Fig.1. Yuno Onsen town (Yamaguchi Prefecture, Japan)

On the other hand, Yuno Onsen has three characteristics: (1) radioactive spring, (2) alkaline, (3) sulfur spring. It is not yet known which of these three characteristics contributed to the post-bathing reduction in blood cholesterol levels described above.

Therefore, in this study, similar measurements were carried out at Yobizuru Onsen (Yamaguchi Prefecture, Japan), which is classified as a simple weakly radioactive cold mineral spring and has only the characteristics of (1) radioactive spring among the above three characteristics. Then it is verified whether the characteristics of the radioactive spring cause a decrease in blood cholesterol levels after bathing.

## 2. Methodology

### *2.1 Principle of measurement of skin cholesterol level*

Cholesterol levels were measured using CLE-80 (Fig. 2), a minimally invasive cutaneous cholesterol ester level measuring device from Photoscience Co., Ltd. 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.

Fig.2. CLE-80 (a minimally invasive cutaneous cholesterol ester level measuring device from Photoscience Co., Ltd.)

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.

On the other hand, the cholesterol ester level to the total cholesterol level is approximately constant at about 70%. And according to Photoscience Co., Ltd., 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.

*2.2 The mathematical model of arteriosclerosis onset and its fruits*

In the beginning, the process of developing arteriosclerosis is outlined. First, when blood vessels are loaded on by high blood pressure etc. and the endothelial cells of blood vessels are damaged, LDL (bad cholesterol) in the blood enters the inner lining and is oxidized to oxidized LDL. To process oxidized LDL, monocytes enter the intima and turn into macrophages. Macrophages take up oxidized LDL and die, but at this time, the fat contained in LDL accumulates in blood vessels as plaque and the intima becomes thicker and thicker. As a result, the volume per unit length of the blood vessel becomes smaller and the blood flow deteriorates.

Kagami (2019) mathematically modeled the above process [6] and then improved it to derive the following equation as the time evolution equation for the blood vessel volume of arteriosclerosis-developed parts [1].

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

where $V$ is the volume of the blood vessel in the arteriosclerosis-causing part, $r$ is the flow rate of the blood, $p_l$ is the concentration of monocytes in the incoming blood, $p_k$ is the cholesterol 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 smaller $p_k$, that is, the lower the cholesterol concentration in the blood, the not smaller the volume of blood vessels where arteriosclerosis develops, that is, the stronger the development of arteriosclerosis is suppressed.

*2.3 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 analyzed.

## 3. Results and Discussion

*3.1 Results*

It was investigated whether the values of "ester valley" or "ester peak" was increased or decreased after bathing in the hot springs for the valid data of 195 people and the results shown in Table 1 were obtained.

Table 1. Changes in cholesterol ester levels after bathing in hot springs (all ages)

| | "ester valley" | "ester peak" |
|---|---|---|
| descent | 76 | 64 |
| rise | 119 | 131 |
| descent rate | 0.390 | 0.328 |
| rise rate | 0.610 | 0.672 |

Concerning this result, from the chi-square value of "ester valley" or "ester mountain" is 9.48 or 23.0, respectively and $\chi^2_{0.01}=6.64$ statistically significant increase of the cholesterol level after bathing is confirmed (significance level: 0.01).

In the following, the same investigation results by age group are shown.

It was investigated whether the values of "ester valley" or "ester peak" was increased or decreased after bathing in the hot springs for the data of people in 10's to 30's and the results shown in Table 2 were obtained.

Table 2. Changes in cholesterol ester levels after bathing in hot springs (in 10's to 30's)

| | "ester valley" | "ester peak" |
|---|---|---|
| descent | 9 | 8 |
| rise | 6 | 7 |
| descent rate | 0.600 | 0.533 |
| rise rate | 0.400 | 0.467 |

Concerning this result, from the chi-square value of "ester valley" or "ester mountain" is 0.600 or 0.0667, respectively and $\chi^2_{0.05}=3.81$ statistically significant variation of the cholesterol level after bathing is not confirmed (significance level: 0.05).

It was investigated whether the values of "ester valley" or "ester peak" was increased or decreased after bathing in the hot springs for the data of people in 40's to 50's and the results shown in Table 3 were obtained.

Table 3. Changes in cholesterol ester levels after bathing in hot springs (in 40's to 50's)

| | "ester valley" | "ester peak" |
|---|---|---|
| descent | 17 | 16 |
| rise | 27 | 28 |
| descent rate | 0.386 | 0.364 |
| rise rate | 0.614 | 0.636 |

Concerning this result, from the chi-square value of "ester valley" or "ester mountain" is 2.27 or 3.27, respectively and $\chi^2_{0.05}=3.81$ statistically significant variation of the cholesterol level after bathing is not confirmed (significance level: 0.05).

It was investigated whether the values of "ester valley" or "ester peak" was increased or decreased after bathing in the hot springs for the data of people in 60's and older and the results shown in Table 4 were obtained.

Table 4. Changes in cholesterol ester levels after bathing in hot springs (in 60's and older)

| | "ester valley" | "ester peak" |
|---|---|---|
| descent | 50 | 40 |
| rise | 86 | 96 |
| descent rate | 0.368 | 0.294 |
| rise rate | 0.632 | 0.706 |

Concerning this result, from the chi-square value of "ester valley" or "ester mountain" is 9.53 or 23.1, respectively and $\chi^2_{0.01}=6.64$ statistically significant increase of the cholesterol level after bathing is confirmed (significance level: 0.01).

From the above, all the data of 195 people showed a statistically significant increase in cholesterol level after bathing. By age group, though for the data of people in 50's and under, statistically significant changes in cholesterol level after bathing were not confirmed partly due to the lack of data, for the data of people in 60's and older, a statistically significant increase in cholesterol level after bathing were confirmed.

This was the opposite result of the above-mentioned experiment at Yuno Onsen conducted in 2021.

*3.2 Discussion*

The results of the experiment at Yuno Onsen conducted in 2021 are shown below.

It was investigated whether the values of "ester valley" or "ester peak" was increased or decreased after bathing in the hot springs for the valid data of 208 people and the results shown in Table 5 were obtained.

Table 5. Changes in cholesterol ester levels after bathing in hot springs (all ages (Yuno Onsen))

| | "ester valley" | "ester peak" |
|---|---|---|
| descent | 169 | 169 |
| rise | 39 | 39 |
| descent rate | 0.813 | 0.813 |
| rise rate | 0.188 | 0.188 |

Concerning this result, from the chi-square value of "ester valley" or "ester mountain" is 81.3 or 81.3, respectively and $\chi^2_{0.01} = 6.64$ statistically significant decrease of the cholesterol level after bathing is confirmed (significance level: 0.01).

In addition, for all age groups, the results that statistically significant decrease of cholesterol levels after bathing were obtained.

These results indicate that among the above three characteristics that may reduce cholesterol levels after bathing, radioactive springs are eliminated as candidates and alkaline and sulfur springs remain as candidates.

In the future, a survey with only one characteristic of alkaline or sulfur springs should be conducted and the characteristics that may reduce cholesterol levels before and after bathing should be narrowed down.

## 4. Conclusion

In order to narrow down the characteristics of hot springs that have efficacies on arteriosclerosis, changes in skin cholesterol levels after bathing at the Yobizuru Onsen, which is classified as a simple weakly radioactive cold mineral spring, were measured. As a result, a statistically significant increase in skin cholesterol levels after bathing was confirmed.

As a result, based on the results from the mathematical model of arteriosclerosis onset, it was indirectly shown that the nature of a radioactive spring may not have an efficacy on arteriosclerosis.

In the future, in order to clarify which of the two characteristics (alkaline, sulfur spring) has the efficacy on arteriosclerosis, it is necessary to investigate hot springs that have only one characteristic, alkaline or sulfur spring.

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