Temperature Dependent Physiological Changes by Footbath — Changes of EGG and hunger sensation —

Kazuo UEBABA, FengHao XU
International Research Center for Traditional Medicine of Toyama Prefecture

足浴による温度依存性の生理的変化
-胃電図と空腹感の変化について-

上馬場 和夫、許 鳳浩
富山県国際伝統医学センター

抄録
足浴は、伝統的に、プライマリケアや看護・介護、外科手術後のケアに利用されてきたが、足浴の仕組みを研究すれば、溺没などの危険性がない安全な理療療法として活用できると思われる。特に外科手術後の腸管マヒの予防などに活用できる可能性を検討するため、様々な温度の足浴による健常人での胃運動への影響を、胃電図と自覚的な空腹感の問診により調査した。被験者は、健常成人14名（全員男性：平均年齢32±6.0歳）として、文書による同意を得た後、4種の足浴実験（膝下10 cmまでの淡水浴：38°C、40°C、42°Cと対照座位）に参加させた。各実験は、各自において4日間以上無作為の順序で、一日の同じ時間帯（10:00-14:00）で昼食摂取前に行った。生理期間中は実験を行わず、終了後に空腹感に関する問診を行った。R-R変動のFFT解析によりLF (0.04-0.15 Hz) 、HF (0.15-0.4 Hz) のパワースペクトラルデンシティを計算し、自律神経バランスを推定した。EGG波形についても、フーリエ解析により周波数と振幅を求めた。その結果、EGGの周波数も振幅も温度依存性に変化を認めた。ただ、副交感神経指標とされているHFパワーとEGG振幅との間には負の相関性を認めた。また、足浴中空腹感では、38°Cと40°Cにおいて空腹感を訴える例が対照よりも有意に多かったが、42°Cでは、胃電図の振幅や周波数の有意な変化を認めながらも、空腹感を訴える例は少なかった。これは、42°Cで脳波の5波が増大していることを考慮すると、皮膚の発汗による電位のドリフトによりかけ上胃電図が増大したためと推定された。以上、健常人において38°C～40°C、30分間の足浴により、空腹感が増大し、胃電図の変化も起こることから、足浴が胃運動を促進する可能性が示唆された。

Key words: footbath, Electrogastrogram (EGG), autonomic nervous activity, temperature dependence, hunger sensation
I INTRODUCTION

Footbath has long been used for the relief of fatigue, common cold and other minor symptoms, and it is one of the nursing techniques in the modern medicine. However, footbath is not so popular in spite of its long history in the medicine, because few scientific researches have been conducted about its effects and their mechanism. We have studied the temperature dependent physiological and biochemical changes by footbath, and showed immunological and sleep change by the herbo-mineral footbath.

More systematic studies are needed to investigate the effect of footbath to make it a safe and easy post-operative care. After surgery, gastric paresis is one of the rate limiting symptoms for recovery. Gutierrez reported heat was effective for anorexia nervosa. We studied the effects of footbath on the gastric motility and subjective hunger sensation in healthy volunteers.

The electrogastrogram (EGG) is a new tool to detect the electric activity of the internal organs, especially of the stomach. It needs only putting some electrodes at the surface of the abdomen for measuring the gastric motility. Hot bathing of full body make it impossible to attach some electrodes on the surface of the abdomen, however it is easy to pick up the skin electrical activity of the abdomen during footbath. Although some problems exist for the speculating the gastric activity from EGG, it may be the best noninvasive way to detect the gastric motility. The temperature (38, 40 and 42°C) dependent changes of the EGG were monitored during footbath as well as changes of hunger sensation, and its mechanism of action were discussed in relation to the autonomic nervous activity.

II METHODS

Subjects

Fourteen healthy adult females (26 - 43 y.o.: 32 ± 6 years old) signed informed consents and participated in this study. They took footbaths after 10-min rest at sitting position. Each footbath was 30 min long, followed by 10-min rest. The same subject participated in the study four times at the same time of the day before taking lunch (10:00 - 14:00). They had footbaths of 38, 40, 42°C and control sitting position in a random order four days apart each other except menstruation periods.

Method of foot bathing (Fig. 1)

After 10-min rest, the subjects took the footbath by the footbath machine for 30 min, followed by 10-min rest at the same sitting position. The volume of the footbath machine was 32.4 little (27 cm in width, 30 cm in length, 40 cm in depth). The water level was 10 cm lower than the knee. Room temperature was 26 ± 1°C and room humidity was 40 ~ 60%. The footbath machine had the function to regulate and keep the bath temperature (± 0.2°C) by mixing water. The control study was conducted at sitting position on the same chair. The motor’s noise of the footbath machine was kept the same level even at the control study. Their breathings were paced at 0.25 Hz (15/min) by a metronome.
The examinations studied

Continuous blood pressure with ECG R-R intervals (ANS508 of Colin Co. Ltd.) was monitored for 50 min throughout the experiment. EGG (Termo Co. Ltd) was also measured continuously at the 4 points of the abdominal wall (Fig. 2). The time constant of EGG was set at 3 s. The subjects were asked about hunger sensation yes or no three times: before experiment, before finishing footbath and after finishing experiment. Simultaneously, EEG of P3, P4, F3, F4 (10/20 International method) leads were monitored. The experiment started after the permission of the Ethical Committee of International Research Center for Traditional Medicine.

Analysis

R-R variability of ECG was analysed to get the power spectrum by means of FFT analysis. High frequency component (HF: 0.15 - 0.4 Hz) and low frequency component (LF: 0.04 - 0.15 Hz) of the power spectrum density were calculated to get HF and LF/HF ratio in order to evaluate sympathetic and parasympathetic tonus, respectively\(^{14,15}\). Raw EGG waves were also analysed to get the amplitude and frequency by means of FFT. The average amplitude and frequency of the first and second peak were calculated, and the mean values of these amplitudes and frequencies from 4 leads on the abdomen were defined as EGG data.

The correlation between EGG data regarding amplitude and frequency, and HF power or LF/HF...
ratio from R-R variability were calculated. Then average results from 14 subjects were calculated every 5 min in the 4 kind of experiments. 10 couples of the values were obtained from one experiment, and regression coefficients of 40 couples of values in all 4 experiments were calculated by the Pearson's method.

Statistical analysis: One way or two way ANOVA were used for the analysis of the difference of the changes in 2 or more groups. Paired-t-test was used to compare the changes in one group. The correlation was calculated by Pearson's method. Chi square test was used to compare the incidence rate of the hunger sensation in the experiments with in the control study. The criterion of significance was set under 0.05.

III RESULTS

1) Changes of the R-R variability (Fig.3 and Fig.4)

LF/HF ratio before starting footbath was compared with other values in one group of the same temperature by paired-t-test. At 40 and 42 °C, the increase of LF/HF ratio was statistically significant from 15 min after starting footbath as shown in Fig.3 (*p<0.05, paired-t-test to pre1 and pre2 values). At 38 °C, the LF/HF ratio showed no significant changes. In this study the respiration rate was regulated at 0.25 Hz by the metronome, however, the room humidity was not kept the same level (room temperature was 26 ± 1°C and room humidity was 40 ~ 60% ). HF component power decreased significantly at 20 min after starting footbath at 42°C as shown in Fig.4 (*p<0.05, paired-t-test to pre1 and pre2 values).

The results of LF/HF ratio and HF component power showed so large variation that the comparison between pre1 or pre2 and points after starting footbath in each group was performed only by paired-t-test.

2) Changes of EGG (Fig.5, Fig.6 and Fig.7)

Fig.5 showed changes of the amplitude of EGG by footbath. Although at 38 °C and control study there were no significant changes, amplitude of EGG increased significantly at 40 and 42 °C as shown
Temperature dependent changes of EGG

Fig. 5 Changes of amplitude of EGG by footbath

Fig. 6 Changes of frequency of EGG by footbath

Fig. 7-1 Temperature dependent EGG change

Fig. 7-2 Temperature non-dependent EGG change

in Fig. 5 (*p<0.05 and **p<0.01 by paired-t-test).

Fig. 6 showed changes of the frequency of EGG by footbath. At 42 °C, frequency of EGG increased significantly during footbath (20 min after starting footbath) as shown in Fig. 6 (*p<0.05 by paired-t-test to the pre1 or pre2 value).

Fig. 7 showed two types of EGG changes depending on the temperature. In the case of Fig. 7-1, the amplitude increased depending on the temperature, while in Fig. 7-2 the amplitude decreased at 42 °C footbath. In the case of Fig. 7-1, the subject felt hungry at 40 and 42 °C footbath, while another case in Fig. 7-2 felt hungry at 38 and 40 °C, but she lost her appetite at 42 °C.

3) Changes of δ wave power of EEG (Fig. 8)

Fig. 8 showed the changes of average value of δ wave power from 4 leads of EEG (P3, P4, F3 and F4). The power of the δ wave increased significantly at 42 °C (one way ANOVA and *p<0.05 or **p<0.01 by paired-t-test). In other temperature, there was no significant change. The δ wave of EEG indicated electrical drifts due to artifact by sweating at 42 °C footbath.

4) Incidence rate of subjective hunger sensation (Table 1)

Table 1 showed the incidence rate of hunger sensation of the subjects. At 38 and 40 °C, the subjects had more incidence of hunger sensation (8/14) than control study (2/14), while at 42 °C the in-
Table. 1 Answers about hunger sensation in the experiments

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<tr>
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<th>38°C</th>
<th>40°C</th>
<th>42°C</th>
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<tr>
<td>Incidence of hunger</td>
<td></td>
<td></td>
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<tr>
<td>During FB</td>
<td>2/14</td>
<td>8/14*</td>
<td>5/14</td>
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<tr>
<td>After FB</td>
<td>4/14</td>
<td>9/14</td>
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*p<0.05 by Chi square test compared with the incidence rate of the control study.

The correlation coefficient was 0.44 (p<0.005, N=40).

Fig.9 The correlation between HF power of R-R variability and amplitude of EGG
The correlation coefficient was 0.44 (p<0.005, N=40).

4) Correlation between EGG and autonomic nervous activity (Fig.9)

The average data from 14 subjects were calculated every 5 min in the 4 kind of experiments. The regression coefficients of 40 couples of values in all were calculated by the Pearson’s method. After the survey of the correlation between autonomic nervous activity and EGG, low but significant correlation exists between HF power and the amplitude of the EGG (r=0.44, p<0.005, N=40). This correlation indicated that the lesser HF power was, the more the amplitude of the EGG during footbath was.

IV DISCUSSION

We have already reported temperature dependent physiological changes of systemic circulation and autonomic nervous balance during footbath.\textsuperscript{4,5} EGG changes especially amplitude of EGG were also dependent on the temperature as shown in Fig.5. However, the correlation between HF power of R-R variability and amplitude of EGG as shown in Fig.9 was not compatible with the previous reports.\textsuperscript{9,12} This study showed the larger the amplitude of the EGG during footbath was, the lesser HF power was (Fig.9). Considering increased δ waves of EEG at 42 °C footbath (Fig.8), the artifacts due to sweating may have interrupted the EGG at 42°C. Although some subjects showed the same tendency of hunger sensation with EGG amplitude (Fig.7-1,7-2), the total tendency showed opposite relationship (Fig.9). The amplitude of EGG was maximum at 42 °C, but the largest incidence rate of hunger sensation occurred at 38°C and 40°C. The low incidence rate of hunger sensation at 42°C was compatible with high LF/HF and low HF power of R-R variability at 42°C, because
Temperature dependent changes of EGG

Fig. 10 Suspected mechanism of action of footbath on EGG and autonomic nervous system

it is said that the sympathetic nerves suppress the gastric activity while parasympathetic nerves enhance it. The incidence rate of hunger sensation at 38°C and 40°C footbath was significantly larger than in the control study (Table 1), which suggested same changes of gastric motility. The discrepancy between EGG amplitude and hunger sensation or R-R variability analysis would be caused by the technical problems that the skin voltage (EGG) was interrupted by sweating due to hot bathing at 42°C. Although the nonspecific drifts of the EGG by the sweating at 42°C should be the taken into account, HF power have some relation with EGG during footbath. Anyway, it was indicated footbath induced the changes of gastric activity and autonomic nervous changes by the thermal action. The suspected mechanism was summarized in the Fig 10.

In Fig. 10, both tactile and thermal stimulation were said to be sensed by Aβ or Aδ fiber, and C fibers respectively. And they are transmitted to the thalamus via spino-thalamic tract or spino-reticular tract. Then the stimuli must be transported to the reticular formation as well as to the cerebral cortex. The latter stimuli must be transmitted to the autonomic nervous center in the hypothalamus, thereafter, to the autonomic nervous system, which innervated the stomach or internal organs.

V CONCLUSION

Although the more invasive methods are needed for the reliable conclusion about the action of the footbath on the gastric motility, the changes of hunger sensation and of R-R variability supported that the footbath may induce some changes of gastric activity and autonomic nervous activity. Foot-
bath of 38 - 40°C may promote gastric motility and induce hunger sensation in healthy volunteers.

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References
Summary

Footbath have long been used for primary health care or for nursing, however, few researches have been reported. We intended to make footbath a safe physiotherapy or care technique in the modern medicine by more profound researches on footbath. The effect of footbath on the gastric motility was studied because footbath may promote recovery from post-surgical gastric paresis. The effects of footbath on the gastric motility and subjective hunger sensation were monitored in 14 healthy adult females (32 ± 6 years old). They signed informed consents and took footbaths at 38, 40, 42°C and control footbath (by a footbath machine). The experiments started after permission of the Ethical Committee of International Research Center for Traditional Medicine.

They took footbath after 10-min rest in a sitting position. Each footbath was 30 min long, followed by 10-min rest. The same subject participated in the studies four times at the same time of the day before taking lunch (10:00 - 14:00). These experiments were in a random order four days apart each other except menstruation periods. Their blood pressure, ECG R-R variability and electro-gastrogram (EGG) were monitored. The subjective hunger sensation was asked before, during and after footbath. The autonomic nervous balance was estimated from FFT analysis of the R-R variability. LF (0.04 - 0.15 Hz) and HF (0.15 - 0.40 Hz) components of the R-R variability were calculated. EGG was also analysed by means of FFT to calculate amplitude and frequency. The results showed the amplitude and frequency of EGG increased depending on temperature. However, the correlation between HF power of R-R variability and amplitude of EGG showed negative correlation. Regarding hunger sensation, more cases felt hunger in 38, 40°C than in control. At 42°C, the amplitude and frequency were apparently higher than in other temperatures, while the hungry cases were less than in 38 or 40°C. These discrepancies may be caused by the artifact due to sweating on the abdominal EGG leads, considering high δ wave of EEG at 42°C.

In conclusion, it was indicated that footbath may promote gastric motility and induce hunger sensation at 38 - 40°C in healthy volunteers.