Analysis of Hemihidrotic Phenomenon due to Skin Pressure

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Abstract: Skin pressure application on one side of the lateral chest of experimental subject led to a decrease of sweat production on the ipsilateral side of the skin. This is the so-called hemihidrotic phenomenon which was first described by Kuno. The purpose of the study was to reconfirm the hemihidrotic phenomenon by the application of skin pressure with a special newly designed apparatus. Local heat load or general heat load was applied to induce thermal sweating, detected by capacitance hygrometer-sweat capture capsule method on both sides of the forehead and chest in an environmental control chamber. Sweat-onset time was markedly prolonged on the ipsilateral side of skin pressure application. In addition, strong suppression of sweat production was observed close to the skin pressure application area. Skin temperatures were detected by means of thermistors and thermography, under the condition of no sweating. Chest skin temperature detected by thermistors at the ipsilateral side of pressure application was lower than that of the contralateral side. However, cheek skin temperature detected by thermography at the ipsilateral side of pressure application was higher than that of the contralateral side. Frequency reduction of synchronized sweating expulsions between the right and left chest as well as on the right and left forehead was induced either on the right or left side of skin pressure. This might indicate that the effect of skin pressure influences the spinal and the supraspinal function.

Key words: Skin pressure, Sweat rate, Skin temperature, Synchronization of sweat expulsions

INTRODUCTION

Considerable interest has recently been focused on the problem of non-specific inhibition of vegetative and extrapyramidal motor regulatory processes concerned with thermoregulation such as sweating and cold shivering. “Hemihidrotic phenomenon”, the inhibition of sweating in human beings as a consequence of postural changes (Kuno, 1956) has experimentally been studied and proved to be the effect of mechanical pressure applied on the skin (Takagi and Sakurai, 1950; Kawase, 1952; Ogawa et al., 1979; Ogawa et al., 1981; Tadaki et al., 1981). The central mechanism of the “skin pressure reflex” has not yet been
conclusively clarified because of the difficulty in the estimation of an autonomic function such as sweating in the unanaesthetized unrestrained animals. However, some reports indicate that cold shivering was markedly inhibited by mechanical pressure on the eye-ball or the skin (Kosaka, 1969; Kosaka et al., 1975). These reports have suggested there is a central mechanism concerned with the reflex inhibition of thermal sweating. The present study, therefore gave more evidence of hemihidrotic phenomenon due to skin pressure reflex which was reconfirmed by capacitance hygrometer-sweat capture capsule method (Fan, 1987).

**METHODS**

A total of 53 experiments were performed using 9 healthy male subjects aged between 19—44 years. Five out of 9 subjects were college students and 4 subjects were laboratory staff. Environmental control chamber (Kosaka et al., 1980) was used for the experiment on thermal sweating and skin pressure reflex.

Each subject clothed only in shorts sat quietly on a chair for at least 30 minutes in the environmental control chamber (25°C; 60% relative humidity; less than 1 m/sec air velocity) to equilibrate to the environmental condition. Two series of experiments were carried out as follows: 1) Local heat load was applied on the lower extremities by using hot water bath (43°C) and then applying pressure alternately on the right and left lateral chest (mammary level on the mid-axillar line) for 5—10 minutes. 2) Pressure was applied on the left lateral chest for 30 minutes. After 10 minutes of skin pressure, local heat load was additionally applied on the lower extremities for 40 minutes. On some occasions the experimental protocols were modified.

Skin pressure was quantitatively applied by means of an apparatus specially designed as shown in Fig. 1. The lateral portion of the chest was pressed by an adaptor (25 cm² in dimensions) covered with a soft rubber sponge. The adaptor applied on the contralateral chest was pulled down by 5kg steel weight by a pulley (Fig. 1). After preliminary experiments, the size of an adaptor (25cm²) and the weight load (5kg) were determined in reference to Kawase (1952), Ferres (1960), and Tadaki et al. (1981).

Local sweat rates on the bilateral forehead, chest and abdomen were essentially determined by capacitance hygrometer-sweat capture capsule method (Fan, 1987). Dry nitrogen gas flowed into a capsule (1.77cm³ in dimensions) attached on the skin with a constant flow rate of 0.75 l/min. Changes in relative humidity of effluent gas were detected by a hygrometer (H211 TAKARA) connected to a pen-recorder. A drop of sodium chloride solution (0.45%, 0.005ml) was introduced into the capsule through the small hole at the top of the capsule to calibrate the actual sweat volume. Oral (sublingual space) temperature and skin temperatures on the bilateral forehead and chest were continuously recorded by thermistors (K923 TAKARA) connected to the computer (PC—8801 NEC). Mean skin temperatures of a certain area each on bilateral forehead, cheek and chest were measured every minute and analyzed by a thermography (JTG—IBL JEOL) and computer system.
RESULTS

The responses of one subject due to the application of skin pressures are illustrated (Fig. 2). After the local heat load application on the lower extremities, a small rise in oral and skin temperatures occurred followed by thermal sweating. Sweat rates on both sides were almost the same on each of the determined region. The amount of sweat on the forehead was always larger than that on the chest, and sweating was markedly inhibited on the same sides of both the forehead and the chest due to continuous pressure application. After 20 minutes of heat load, pressure was applied on the left and right lateral chest each for 5 minutes at 2 minutes interval. During pressure application on the left lateral chest, sweat rates on the left ipsilateral sides of forehead and chest decreased. On the contrary, those on the right contralateral sides seemed to be increasing. After the first release of the left skin pressure, sweat rates on the right forehead and chest decreased contrary to those increasing on the left. Further increases on the left and decreases on the right forehead and chest were induced by pressure on the right lateral chest. In consequence to this hemihidrotic phenomenon, the right and left curves of sweat rates crossed at both forehead and chest. After the second release of the right skin pressure, sweat rates on both sides returned to the initial state. At the end of the experiment, the calibration of sweat rates was performed. A certain portion of Fig. 2 was used for the analysis of synchronization of sweat expulsions as shown in Fig. 6. During the analysis of the
Fig. 2. Effect of skin pressure on sweat rates during local heat load on the legs. Pressure was applied on the left and right lateral chest. The upper part of the figure shows oral and skin temperatures. The lower part of the figure shows sweat curves on each region. At the end of experiment, calibration of sweat rates was performed. To: oral temperature Ts: skin temperature.

Fig. 3. Effect of skin pressure on sweat rates during general heating. To: oral temperature Ts: skin temperature.
reflex inhibition of thermal sweating, no particular changes in oral, forehead and chest
skin temperatures occurred except for a small rise in oral and skin temperatures at initial
sweating.

As shown in Fig. 3, the subject was exposed to the general heat load (35°C; 60% relative humidity) throughout the experiment in order to keep constant sweat rates. This allowed the determination of both the increase and decrease of sweat rates during pressure application on the lateral chest. After the application of the first pressure on the left lateral chest for 5 minutes, and thereafter at 2 minutes interval, second successive pressure application on the right lateral chest, a marked reduction of sweat rates on the left forehead and chest were observed. However, pressure application on the right lateral chest decreased sweat rates on the ipsilateral forehead and chest but, those on the contralateral forehead and chest increased.

In order to investigate the effect of skin pressure on sweat-onset, in which skin pressure had been applied on the left lateral chest from 10 minutes before heat load, the experiment showed a marked and prolonged sweat-onset time at the left ipsilateral side of

![Graph](image-url)

Fig. 4. Effect of skin pressure on latent period of sweating by local heat load on the legs. To: oral temperature Ts: skin temperature.
pressure application. Sweat-onset time was 6 and 12.6 minutes for the right and left forehead respectively, and 8.2 and 20 minutes for the right and left chest, respectively as shown in Fig. 4. A marked prolonged sweat-onset time was observed on the ipsilateral side of skin pressure application. The onset time of the left chest was longer than that of the left forehead. This result may indicate that the inhibitory effect of skin pressure on sweat-onset time is bigger around the pressed region than that far away. It may also indicate that the hemihidrotic phenomenon seems to be a spinal reflex. On this assumption, it appears that complete inhibition of ipsilateral thermal sweating was induced by skin pressure on the left lateral chest as shown in Fig. 5.

Fig. 5 demonstrates the recording of thermal sweating of the same subject (Fig. 4) at a different time. Skin pressure was applied on the left lateral chest 10 minutes before local heat load. Skin pressure was released 10 minutes after the release of heat load (duration: 40 minutes). Thermal sweating especially on the ipsilateral chest was completely suppressed by skin pressure on the left chest.

To observe the synchronization of sweat expulsions (Fig. 6) which is efferently controlled by impulse of sweat-center in the preoptic area and anterior hypothalamus (PO/AH). The frequency of synchronized sweat expulsions between the right and left forehead during skin pressure application is shown by a portion of Fig. 2. A marked fre

Fig. 5. Effect of prolonged skin pressure and heat load application on sweat rates
To: oral temperature Ts: skin temperature.
quency reduction of (23 times/5min. to 7–12 times/5min) synchronization was observed during skin pressure application on both the right and left lateral chest.

The influence of skin pressure on displacement of skin temperatures measured by thermistors is in Fig. 7. The subject never sweated during the experiment (27°C; 60% relative humidity). Decrease in skin temperature on the ipsilateral chest was induced by

Fig. 6. Influence of skin pressure on the synchronization in sweat expulsion.

Fig. 7. Effect of skin pressure on skin temperatures with no sweat detected by thermistors.
To: oral temperature Ts: skin temperature.
skin pressure on the left lateral chest. A similar decrease in temperature on the ipsilateral chest was detected during skin pressure on the right lateral chest. Mean cheek skin temperature measured with a thermography was higher on the ipsilateral side of skin pressure application than on the contralateral side (Fig. 8a). Fig. 8b shows the difference in the mean cheek skin temperature between the right and left side in Fig. 8a.

![Fig. 8a. Changes in cheek skin temperatures during skin pressure application on lateral chest detected by thermography.](image)

![Fig. 8b. Difference between the right and left cheek skin temperatures during skin pressure application on lateral chest.](image)
DISCUSSION

The hemihidrotic reflex due to postural changes was first described by Kuno in 1934 (Kuno, 1956). This phenomenon observed by means of Minor's colorimetric method and the filter paper method, was called "pressure hemihidrosis" (Takagi and Sakurai, 1950; Kawase, 1952; Takagi, 1960). Watkins (1956) tested the effect of skin pressure on sweating and reached the conclusion denying the presence of the "hemihidrotic response to pressure" Watkins thought that any effect was due to chance variation. However, the hemihidrotic reflex was further confirmed by Ferres (1957, 1960). New methods for the observation and measurement of sweating such as an infrared gas analyzer (Albert et al., 1951), resistance hygrometry (Nakayama and Takagi, 1959; Custance, 1962; Van Beaumont et al., 1966) and capacitance hygrometry (Ogawa and Bullard, 1971, 1972; Sugeno and Ogawa, 1985) have been developed. Capacitance hygrometer-sweat capture capsule method (Fan, 1987) used in the investigation could record sweat rates continuously, hence very suitable for picking up fluctuations of sweat expulsion. There were reports on work about thermal sweating (Weiner, 1944; Randall, 1946; Fujishima and Kosaka, 1971; Hori et al., 1976).

Skin pressure was applied on the axillary portion in all the experiments because it has been found to be the most sensitive area for pressure stimulation (Takagi, 1950).

Special newly designed apparatus which allows the use of any pressure intensity was used, because a skin pressure of 5kg/25cm² did not cause any pain to the subjects (Kawase, 1952; Ferres, 1960; Ogawa et al., 1979; Tadaki et al., 1981). In some cases of this experiment, pressure application with the end of a pencil was sufficient to elicit the sweating reflex. Sweat rates on the same side decreased whenever pressure was applied. A most typical recording showing a clear hemihidrotic reflex is depicted in Fig. 2. The ipsilateral inhibition occurred almost immediately. The results obtained in many cases indicated the same tendency in experimental subjects. Then the question arose whether contralateral acceleration occurred or not. Similar experiments were carried out as shown in Fig. 3, where the subject was exposed to general heat load, and was slightly sweating throughout the experiment. When the subject broke out in sweat, the ipsilateral inhibition and contralateral acceleration of sweating were not clear all the time. That was why slight sweating was needed due to general heating. Other conditions than the application of heat load were equal to those in Fig. 2. These experiments failed to show the contralateral acceleration of sweating due to skin pressure as reported (Kawase, 1952; Nakayama and Takagi, 1959). The conclusion reached by Kawase (1952) on the sweating augmentation of the contralateral area due to skin pressure may not have been accurate. There is a similarity of acceleration of sweating to the previous work (Nakayama and Takagi, 1959).

The central pathways of the skin-pressure reflex have not been fully identified, although elaborate studies (Takagi, 1956; Kosaka, 1969; Kosaka et al., 1967; Kosaka et al.,
1975), have traced the afferent pathways up to the midbrain. On the other hand, Sato and Schmidt (1971) have reported that the somato-sympathetic reflex generally has dual pathways, spinal and supraspinal, the former exerts a more dermatomal effect while the latter a more generalized one. Recently Ito et al. (1978) have demonstrated in spinal cats that cutaneous stimulation produces excitatory and inhibitory electrodermal reflexes. Their observations in spinal cats resemble those of the pressure-sweating reflex in humans. Ogawa et al. (1979) have suggested that the sweat-inhibitory effect may be exerted primarily through the action of somatic afferent volleys on preganglionic sympathetic neurons at the segmental level. More recently Tadaki et al. (1981) have reported that the hemihidrotic effect is proportional to both the intensity of pressure per unit area and the surface area. These works have indicated that responses were by reflex induced in the supraspinal or spinal level by afferent nervous signals activated by pressure stimulation.

In order to characterize the central drive for sweating in relation to the thermal input to the thermoregulatory mechanism, synchronized sweat expulsions showed a linear function of ambient temperature, the sweat rate and even the frequency of sweat expulsions (Ogawa and Bullard, 1972). These observations and the fact that pulsatile sweat expulsions occur synchronously among skin areas, lead to the conclusion that the rate of sweat expulsions reflects the centrally-derived sudomotor neural activity. Furthermore, Ogawa et al. (1981) also observed that the extent of the hemihidrotic response is dermatomal such that skin pressure modifies the central drive for sweating at the spinal level. It was further observed that skin pressure affects the amplitude of expulsions and neither their frequency nor their synchronization (Ogawa and Bullard, 1972).

The so-called hidromeiosis shows the diminution of sweat output with skin wetting (Brown et al., 1965). This shows that the rate of sweat secretion can be modified by local factors. The frequency of sweat expulsions could not however be affected by such local factors (Ogawa and Bullard, 1972). This lead to the conclusion by Sugenooya and Ogawa (1985) that the mechanism for determining the rhythmicity of sweat expulsions might be located at a level above the spinal segment. The modification of sweat expulsions caused by skin pressure was observed in this investigation. The application of skin pressure on the left lateral chest showed a decrease in the frequency of synchronized sweat expulsions between the right and left forehead in almost all the cases (Fig. 6). These results may possibly differ from many reports by the limited accuracy of the experimental device. They might indicate that the hemihidrotic phenomenon is a reflex at the supraspinal level.

Skin pressure has significant effects on a wide range of body functions, such as all kinds of vegetative functions, muscle tone, involuntary movements, consciousness, and sweat production (Takagi, 1965; Kosaka, 1969; Ogawa et al., 1979).

The discordance of the results between the data measured by thermistors and those by thermography may be attributed to technical differences due to the function of the two devices (Fig. 8a, Fig. 8b). Thermography may be more accurate compared to thermistors on measuring skin temperatures because it has no mechanical effect like thermistors. The skin temperature on another region (forehead and chest) measured by thermography did
not always show the clear change due to skin pressure. This should be investigated further in future.

Ueki (1954) described that the activity of the regulatory center of the body temperature was depressed by skin pressure. Takagi (1960) postulated that skin pressure reduced central thermoregulatory activity and body temperature depending on the ambient temperature. On the other hand, Ogawa (1981, 1986) reported that skin pressure scarcely affected central thermoregulatory activity in association with its effects on sweating, and suggested that skin pressure may exert a sweat-inhibitory effect under the control of the central thermoregulatory mechanism. Ogawa's suggestion may be acceptable, even if another factor may play a role in relation to skin temperature.

A lot of sympathetic innervation in the skin, especially on the fingers cause constriction due to $\alpha$-adrenergic action and skin vasodilation in a hot environment as a result of a decrease in vasomotor tone (Nagasaka, 1990). New evidence on sympathetic vasodilator (peptidergic action) in the body trunk skin involving forearms was reported by Hökfelt et al. (1980), proposing that the increase in cutaneous blood flow when there was an increase of environmental temperature was enhanced by peptidergic nerve. The skin pressure may induce cutaneous vasodilation and vasoconstriction through the activation of these peptidergic nerves without displacement of ambient temperature.

In addition to thermal sweating mentioned, mental sweating must be referred to emotional stress. There are several reports (Kuno, 1956; Ogawa, 1975) indicating a positive correlation between thermal and mental sweating. Marked relation between them was scarcely observed in the present experiment. Further detailed investigations on the relationship between mental sweating and skin pressure will be carried out in future.

Similar effects of the autonomic nervous and the somatosensitive functions were induced by Aschner's phenomenon, the eye-ball pressure related to a test of autonomic nervous function even in an animal experiment (Kosaka, 1969). In this study, investigations on the effect of mechanical pressure on the eye-ball on sweat rates and skin temperatures on human subjects showed that the inhibitory effect of sweat rates and increase or decrease of skin temperatures was not clear. This study has therefore shown the effect of skin pressure on hemihidrotic phenomenon to the extent, however some of the questions raised by the results obtained and postulated require further investigations.

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