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# Effects of alcohol on thermoregulation during mild heat exposure in humans

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**Abstract**

We investigated the effects of alcohol on thermoregulatory responses and thermal sensations during mild heat exposure in humans. Eight healthy men participated in this study. Experiments were conducted twice for each subject at a room temperature of 33 °C. After a 30-min resting period, the subject drank either 15% alcohol (alcohol session) at a dose of 0.36 g/kg body weight or equal volume of water (control session). Skin blood flow and chest sweat rate in the alcohol session significantly increased over those in controls 10 min after drinking. Deep body temperature in the alcohol session started to decrease 20 min after the onset of sweating and eventually fell 0.3 °C lower than in the controls. Whole body hot sensation transiently increased after alcohol drinking, whereas it changed little after water drinking. The increased ''hot'' sensation would presumably cause cool-seeking behavior, if permitted. Thus, alcohol influences thermoregulation so that body core temperature is lowered not only by automatic mechanisms (sweating and skin vasodilation) but also behaviorally. These results suggest that decreases in body temperature after alcohol drinking are not secondary to skin vasodilation, a well-known effect of alcohol, but rather result from a decrease in the regulated body temperature evidenced by the coordinated modulation of various effectors of thermoregulation and sensation. 

*Keywords:* Alcohol; Human; Body temperature; Sweating; Skin vasodilation; Sensation

## 1. Introduction

Alcohol affects various physiological systems. For example, acute alcohol administration elicits an increase in heart rate (HR) due to a baroreflex following initial arteriolar and venous dilation and a subsequent volume depletion as a consequence of alcohol-induced diuresis (Allison & Reger, 1992; Grassi et al., 1989; Howes and Reid, 1986; Iwase et al., 1995). Alcohol is often involved with cases of accidental hypothermia, which continues to result in many deaths (Teresinski et al., 2005). Although a large number of studies have been conducted, the means by which alcohol influences body temperature and thermoregulation in humans remain poorly understood (Allison & Reger, 1992; Desruelle et al., 1996; Johnston et al., 1996).

There are two general categories into which the effects of ethanol can be divided. The first category includes nonspecific and disruptive effects, and the second category contains regulatory and presumably adaptive effects. The work of Myers (1981) is characteristic of conditions that favor nonspecific and disruptive effects: In extremely hot or cold environments and with the administration of high doses, ethanol disrupts thermoregulation and thus facilitates the development of hyperthermia or hypothermia, depending on the external conditions. In humans, this category of effects is emphasized, and ethanol is typically viewed as an agent that disrupts thermoregulation. The vasodilation seen in peripheral blood vessels following ethanol administration is considered to be a direct effect on the vessels (Wasielewski & Holloway, 2001). The warm sensation that ethanol often produces is postulated to be due to the warm skin caused by dilated peripheral vessels (Fleming et al., 2001). To some extent, the lack of agreement regarding

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the effect of ethanol on human thermoregulation is due to a relatively small effect (Johnston et al., 1996) in comparison with other, smaller mammals.

In rodents tested at ambient temperatures below the thermoneutral zone, moderate doses of alcohol lead to a pronounced hypothermia (Huttunen et al., 1998; Lomax et al., 1980). Whereas at high doses disruptive effects inevitably predominate, alcohol freely crosses the blood brain barrier, and at moderate and low doses the main effects are on the thermoregulatory centers of the central nervous system (Crawshaw et al., 1997). Alcohol-treated rats select ''cooler'' ambient temperatures in the temperature gradient and become hypothermic (Gordon et al., 1988; Mohler & Gordon, 1990). Similarly, mice select very cool ambient temperatures following an ethanol injection even during the time when body temperature is falling rapidly (Gordon & Stead, 1986; O'Connor et al., 1989). The above studies are a very clear indication that ethanol decreases the regulated temperature in rodents. Likewise, goldfish, which are ectotherms and are only able to regulate body temperature behaviorally, select cooler water when ethanol is added to an aquatic temperature gradient (O'Connor et al., 1988). A lowered body temperature is beneficial for an animal with increased blood ethanol. In mice, a 7 °C decrease in body temperature increases the lethal concentration of blood ethanol by 21% (Malcolm & Alkana, 1983).

The inconclusive nature of the ethanol studies on thermoregulation in humans is partly because a majority of the experiments were performed in a cool environment, partly because relatively low doses must be used, and partly because the effects of ethanol seem to be less intense in humans. Given these difficulties, it has been very difficult to separate a decrease in the regulated temperature from the disruptive effects of ethanol. In the cold, both disruption and a decrease in the regulated temperature predict decreased shivering and a loss of vasomotor tone. The consequences of the alternative causes, i.e., augmented heat loss and a more rapid decrease in core temperature, are the same.

Studies performed in a warm environment also remain inconclusive. In one study, alcohol ingestion did not alter thermoregulatory responses to 40 °C water immersion (Allison & Reger, 1992), and in another study body core temperature in men exercising in a warm environment at 35 °C did not decrease in spite of increases in sweating and vasodilation (Desruelle et al., 1996). However, these extreme conditions (water immersion or exercise) might well mask any ethanol-induced modification of the regulated temperature.

In this study, we investigate the effects of alcohol on thermoregulatory responses and thermal sensations in resting humans during mild heat exposure. By continuously monitoring sweat rate (SR), mean skin temperature, skin blood flow (skBF), and core temperature, the possibility of detecting and differentiating the regulatory and disruptive effects of ethanol is optimized. Our working hypothesis is that alcohol lowers body temperature not only by a direct effect on blood vessels, if any, but rather by a central effect that decreases the regulated temperature and results in coordinated heat loss responses by all thermoregulatory effector mechanisms. We chose a room temperature of 33 °C, which is slightly higher than the upper critical temperature for a naked human (Gordon, 2005). At cooler temperatures, following ethanol administration sweating would be unlikely, and the cause of decreases in metabolic heat production would not yield conclusive results. At temperatures much warmer than 33 °C, the sweating rate would be much higher and further increases in the sweating rate would be difficult to elicit.

## 2. Methods

Eight healthy male Japanese subjects participated in the present study. All subjects were screened by history and medical examination. All were occasional drinkers, but no subjects had a current or past diagnosis of alcohol abuse or dependence. Some Japanese (5–10%) cannot drink alcohol at all, probably because of the lack of mitochondrial aldehyde dehydrogenase (ALDH2) activity (Harada et al., 1980; Shibuya et al., 1989). Such potential subjects were screened out of this experiment. The subjects gave informed consent for the experimental protocol, which was approved by the Human Research Ethics Committee in the School of Sport Sciences, Waseda University. Their mean age was 26.3 ± 4.2 (S.E.M.) year, body weight 69.3 ± 4.5 kg, and height 170.5 ± 4.8 cm.

Experiments were conducted twice for each subject at a room temperature of 33 °C. Subjects fasted from 8:00 p.m. on the day before the experiment. In the morning of the experiment they were allowed an isotonic drink. They came to the laboratory at 8:00 a.m. Dressed only in short pants, they entered the environmental chamber (33 °C with 50% rh, relative humidity). The subjects then rested in a sitting position for 1 h during which time all measuring devices were applied. They rested for another 30 min as baseline data were obtained. Then, the subjects drank either 15 vol % (ml/100 ml) alcohol at a dose of 0.36 g/kg body weight (alcohol session) or an equal volume of distilled water (control session), and remained in a sitting position for another 90 min. The order of the two sessions was randomly chosen with a 2-day interval between experiments. To avoid a direct effect on body core temperature, both alcohol and water were ingested at 37 °C. To avoid evaporation, the alcohol solution was prepared immediately before drinking.

Body core temperature (Tcore) was measured with a telemetry system (CoreTemp2000, HIT Technologies, Inc.). The transmitter pill was swallowed 90 min before the onset of each experiment. Recordings of $T_{core}$ were made each minute and presented as 10 min means. HR was also measured telemetrically (CoreTemp2000, HIT Technologies, Inc.). Skin temperatures at eight sites (forehead, chest,

back, arm, hand, thigh, calf, and toe) were measured with copper–constantan thermocouples. Mean skin temperature (mean $T_{sk}$) was calculated from temperatures of the eight skin sites according to the area weighting formula by Hardy and DuBois (1938). $T_{sk}$, SR, and skBF were recorded every 10 s and averaged over 10 min. SR on the chest was measured with a commercial hygrometer (Perspiro oss-100, Kenz). skBF changes in the chest were evaluated with laser Doppler flowmetry (ALF 21, Advance).

It is generally accepted that there are two kinds of temperature-related sensations: objective thermal sensations and subjective thermal comfort (Hensel, 1981). Behavioral thermoregulation is probably induced by both sensations, and therefore we measured both. Subjects were asked to report both subjective thermal sensation and thermal comfort by moving an indicator along a 10-cm line rating scale. A vertical line drawn at the center of the line indicated "neutral." The thermal sensation scale was labeled "cold" to the left of "neutral" and "hot" to the right. Similarly, the comfort scale was labeled "discomfort" to the left and "comfort" to the right of "neutral." Subjects were allowed to indicate sensation beyond the scales, which ended at +5 and −5. However, no one did so. The length from the neutral point to the point marked by the subject was measured as the rating score of thermal sensation or thermal comfort. The responses were recorded as negative values if subjects indicated that their sensations were cold or uncomfortable. These estimates of thermal sensation and comfort were made every 5 min during the resting and recovery period and every 2 min after drinking (from 0 to 40 min).

Differences in the measured values between the alcohol and control sessions were assessed by analysis of variance with repeated measures. A significant difference of means between the two sessions at a specific time point was subsequently identified by the Newman–Keuls procedure. Values except deep body temperature are expressed as changes from the means in the period prior to drinking (−20 to 0 min). All values are presented as means ± S.E.M.; the alpha level for statistical significance was set at 0.05.

## 3. Results

Tcore decreased 20 min after drinking in the alcohol session and 60 min after drinking fell to 37.1 ± 0.1 °C. On the other hand, Tcore remained unchanged throughout the control session (Fig. 1). Tcore in the alcohol session was significantly lower than in the control session for the period from 50 to 120 min ($P < .01$).

Fig. 2 shows changes in mean skin temperature (mean $\Delta T_{sk}$; Fig. 2A), skin blood flow (ΔskBF; Fig. 2B), sweat rate (ΔSR; Fig. 2C), and heart rate (ΔHR; Fig. 2D) expressed as the differences from the means in the period prior to drinking (−20 to 0 min). Mean $\Delta T_{sk}$ gradually decreased after drinking both alcohol and the control solution. Although there were no statistically significant

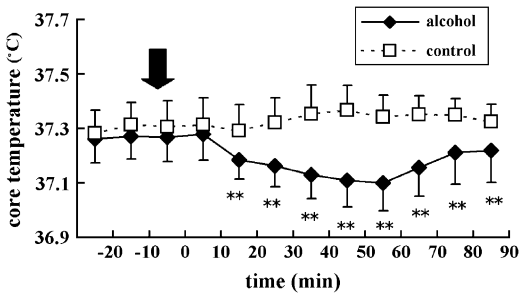


Fig. 1. Deep body temperature during the alcohol and control sessions. The arrows show the time of drinking alcohol or water. Values are means ± SEM ($n = 8$). **$P < .01$, alcohol versus control sessions.

differences between the alcohol and control sessions, for the 35 min period following ingestion mean $\Delta T_{sk}$ was always lower for the alcohol session (Fig. 2A). In the control session, ΔskBF showed little change throughout the 120-min measurement. In contrast, ΔskBF in the alcohol session showed a dramatic increase 20 min after drinking alcohol. There were significant differences ($P < .01$) between the two sessions during the period from 20 to 70 min (Fig. 2B). ΔSR in the alcohol session increased rapidly, and 10 min after drinking alcohol ΔSR was significantly higher than in the control session ($P < .01$). Sweating reached a peak 20 min after alcohol ingestion at 0.254 ± 0.05 mg $cm^{-2}$ $min^{-1}$, and remained above control values for the entire session. All but two points were significantly above control values (Fig. 2C). Whereas ΔHR remained unchanged in the control session, ΔHR in the alcohol session increased immediately after drinking alcohol. This increase remained significant throughout the session ($P < .01$).

Fig. 3 shows the rating scores of thermal sensation (Fig. 3A) and thermal comfort/discomfort (Fig. 3B). The rating scores of thermal sensation in both alcohol and control sessions were slightly "hot" (1.09 ± 0.05 and 1.19 ± 0.32) in the alcohol and control sessions at the initiation of measurement. Sensations in the alcohol session increased in the "hot" direction just after drinking alcohol, reached a peak at 10 min, and then gradually decreased and returned to the predrinking level. Scores in the control session remained unchanged throughout the period of measurement. Because the mean predrinking ratings of the alcohol group were lower than those of the control group, there were no statistically significant differences in absolute scores of thermal sensation between the alcohol and control sessions. But when changes were calculated from predrinking levels, the "hot" thermal sensation in the alcohol session was significantly greater than that of the controls (Fig. 3C). The rating score of thermal comfort/discomfort in the control session remained steady throughout the period of measurement (Fig. 3D). In the alcohol session, the magnitude of the "hot" sensations increased after drinking, plateaued at 15–25 minutes, and decreased thereafter.

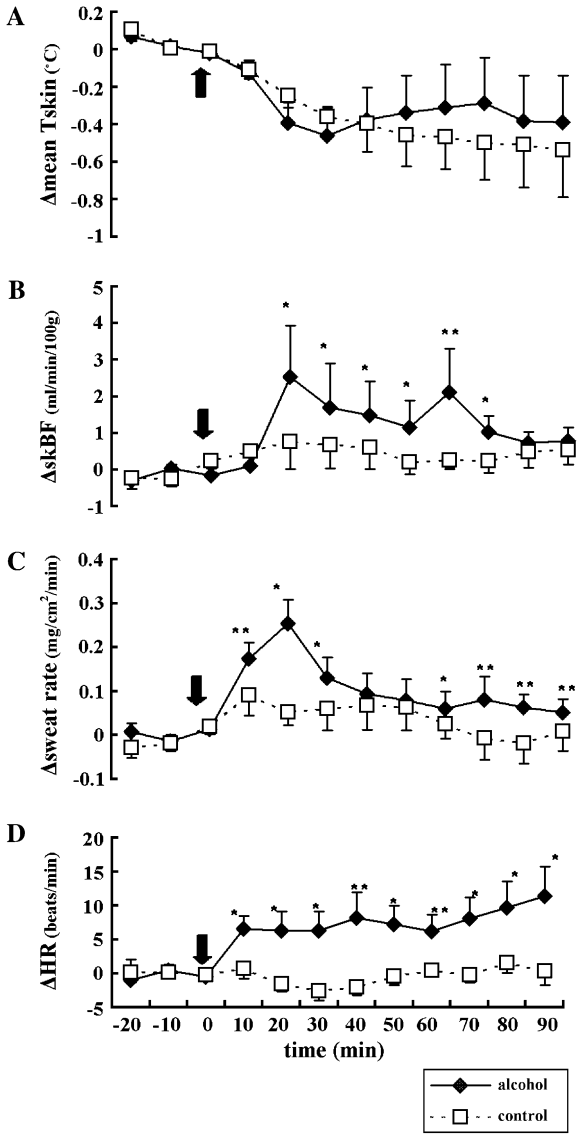


Fig. 2. Skin temperature, skin blood flow, sweat rate, and heart rate during the alcohol and control sessions. Values are changes from the averages in the period prior to drinking (−20 to 0 min). The arrows show the time of drinking alcohol or water. Values are means ± SEM ($n = 8$). $^{**}P < .01$, $^{*}P < .05$, alcohol versus control sessions.

## 4. Discussion

In the present study, we examined the effects of alcohol on body temperature regulation during mild heat exposure in humans. After drinking alcohol Tcore decreased. This decrease was facilitated by an increase in heat loss, because both sweating and skin vasodilation were augmented. Discrepancies between this study and those of Myers (1981) and others are due to the moderate ethanol dose and low level of heat stress we used. Myers administered a much higher dose of alcohol (4.0 g/kg body wt) which, for rats, is a strong anesthetic dose. Our dose for humans (0.36 g/kg body wt) could be described as a moderately intoxicating dose. Other observations corroborate the effects we observed. Both rats and mice when injected with a dose of ethanol of 1.5 g/kg at a thermoneutral $T_a$ showed a decrease in Tcore with no increase in metabolism (Lomax et al., 1980). In another experiment using the same dose, an increase in tail temperature accompanied the fall in Tcore (Crawshaw et al., 1997). Our results are in agreement with these findings, because for humans in a warm environment, a moderately intoxicating dose of alcohol produced a decrease in body temperature.

As reported by others (Wolf et al., 1999), skBF in our experiments increased after drinking alcohol. It is generally considered that alcohol acts directly on cutaneous blood vessels and causes them to dilate (Wasielewski & Holloway, 2001). However, Malpas et al. (1990) suggested that alcohol might induce skin vasodilation by acting centrally, because in quadriplegics, who lacked vasomotor efferent function, no significant changes in skin temperature or forearm blood flow were observed after alcohol administration.

In this study, in addition to vasodilation, sweating was accelerated by alcohol. Sweating usually occurs in response to overheating of the body. In our experiments, body temperature decreased. To our knowledge, there is no study showing the direct exertion of a local effect by alcohol to facilitate sweat gland activity. If anything, it is likely that ethanol would act to disrupt sweat gland function and thus decrease sweating. Sweat glands are innervated by sympathetic nerves, and it is probable that the increase in sweating we observed is the result of an effect of alcohol on the central nervous system.

Because the most likely site of action is the central nervous system, the affected locus should be a region common to both effectors. Warm-sensitive neurons in the preoptic area integrate temperature changes of the local brain as well as of other parts of the body including skin, and send efferent signals to various effector organs (Boulant, 1980; Nakayama, 1985). Although recent studies on rats suggest that different groups of warm-sensitive neurons send signals to different effectors, and they work independently (Kanosue, 1998, 2001), warm-sensitive neurons would be the elements common to the various effectors. We propose that alcohol acts directly on warm-sensitive neurons. Indeed, preliminary data obtained from a hypothalamic slice preparation indicated that warm-sensitive neurons in the preoptic area seemed to be more affected by ethanol than by thermally insensitive neurons (unpublished observation, J. A. Boulant, 2005). If so, all effectors would also be modulated in a direction so as to lower body temperature; at the whole animal level, this would be seen as a decrease in the regulated body temperature.

Thermoregulation is accomplished not only by the autonomic responses described above but also by behavioral processes. Behavioral thermoregulation is the most powerful mechanism for controlling body temperature. Indeed, the first response of an endotherm to a thermal challenge is behavior (Crawshaw et al., 1981). In this study, the subjects felt hotter after alcohol ingestion. This sensation

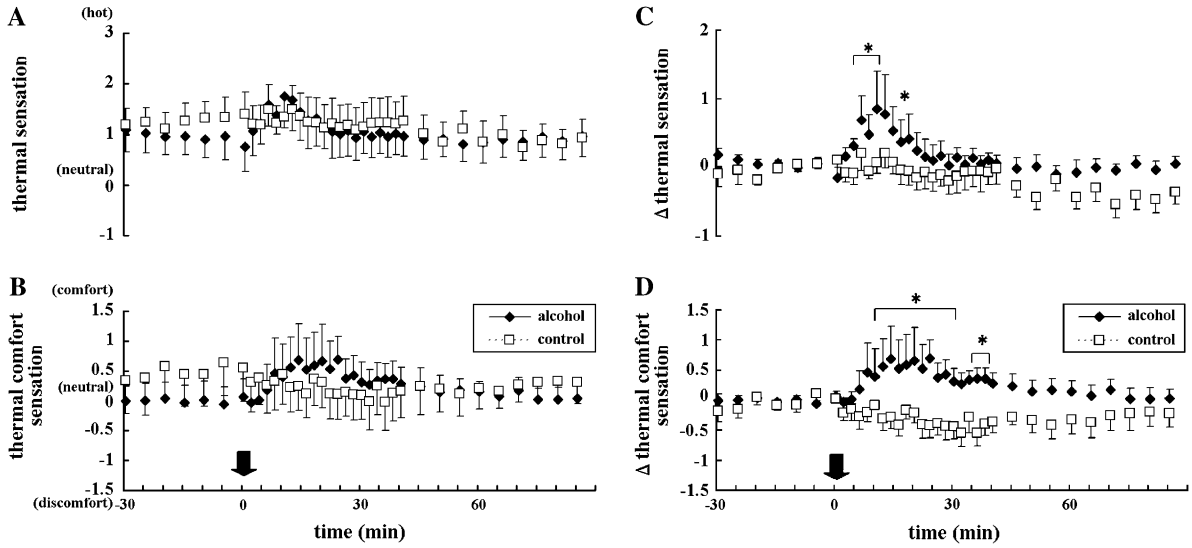


Fig. 3. Scores of subjective thermal sensation (A) and thermal comfort sensation (B) during the alcohol and control sessions. (A) Positive and negative values indicate hot and cold, respectively, and the score 0 indicates neutral. Maximum score is 5 and minimum score is −5. (B) Positive and negative values indicate comfortable and uncomfortable, respectively, and score 0 indicates neutral. (C, D) Values which are changes from the averages in the period prior to drinking (−20 to 0 min). The arrows show the time of drinking alcohol or water. Values are means ± SEM ($n = 8$). *$P < .05$, alcohol versus control sessions.

occurred when $T_{sk}$ was slightly lower, and Tcore was equal to or lower than preingestion values. This is a clear demonstration that the warm sensation felt after ethanol ingestion is due to a change in the regulated temperature and not to a locally induced increase in skin temperature.

A hot sensation provides a strong cue to search for cooler environment. Our subjects were not allowed to do so, but had the subjects been permitted to move, they would have searched for a cooler environment to lower body temperature. This assertion is corroborated by the results of animal experiments. For mice in a tubular temperature gradient, alcohol administration was followed by concurrent decreases in both selected $T_a$ and Tcore (O'Connor et al., 1989). In rats, administration of 3.0 g/kg alcohol significantly decreased Tcore as well as the temperature selected (Gordon et al., 1988). Mohler and Gordon (1990) measured the effects of methanol on behavioral thermoregulation in both Fisher and Long Evans rats, and both strains displayed a decreased Tcore and remained in the cool end of the thermal gradient. Moreover, O'Connor et al. (1988) studied the effects of alcohol on behavioral thermoregulation in goldfish. They used a horizontal aquatic temperature gradient with a range of 9–33 °C. Goldfish in 1% (vol/vol) ethanol selected a cooler water temperature than did controls in water. Although ectotherms do not have autonomic effectors to alter Tcore, the neuronal mechanisms that initiate thermoregulatory behavior and autonomic responses are similar throughout the vertebrate subphylum (Crawshaw et al., 1981). We have provided additional evidence that the response to ethanol is also similar across this subphylum, and we feel that the most likely site of action is the preoptic area. Therefore, in both humans and animals alcohol produces a similar effect; in humans, a hot sensation is experienced, and in animals, cold-seeking behavior is observed.

Both thermal sensation and behavior are mediated by the central nervous system. Although the neuronal mechanisms for thermal sensation and thermoregulatory behavior are not fully understood, the preoptic area of the hypothalamus is a primary site for sensing body temperature and for initiating behavioral as well as autonomic thermoregulatory responses. Local thermal stimulation of the preoptic area in animals produces appropriate operant behavior to obtain warm or cold air (Adair, 1969, 1970). The effects of alcohol on the thermoregulatory system are likely to be on the warm-sensitive neurons of the preoptic area, which has been shown to be involved with both autonomic and behavioral regulation.

In any case, we have demonstrated that low doses of alcohol modulate not only autonomic heat loss processes but also behavioral (sensation) processes for thermoregulation, which lower body temperature. These results suggest that both the hot sensation and the effector heat loss responses may be due to a direct effect of alcohol on the thermoregulatory centers of the brain such that body temperature is regulated at a lower level.

Our experimental protocol finished 90 min after alcohol drinking. At the end of the protocol, Tcore had still not returned to the level present before drinking. Gallaher and Egner (1987) reported a delayed elevation in Tcore following acute alcohol intoxication in rats. Further, alcohol has been observed to lead to delayed hyperthermic responses in humans (Danel et al., 2001). This phenomenon may reflect an overcompensating thermoregulatory response to the acute hypothermic effects of alcohol. Gordon (2005) suggested the possibility of viewing delayed hyperthermia as a fever. Our study might have detected such responses, if the experiment had continued for a longer time period. Periodic measurement of blood alcohol levels would also

have provided information about the time course of the effects. Unfortunately, blood ethanol levels were not monitored in this study.

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