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Effects of Hot Bath Immersion on Autonomic Activity and Hemodynamics

— Comparison of the Elderly Patient and the Healthy Young —

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Hot bathing has been associated with sudden death and so the present study investigated its effects on autonomic activity and hemodynamics in the elderly patient and the healthy young by analyzing heart rate variability (HRV). Subjects were 9 elderly men (mean age, 75 years) and 9 young men (mean age, 27 years), who were immersed up to shoulder level while in a sitting position for 10 min with the bath temperature at 40°C. Blood pressure (BP) and heart rate (HR) were monitored. BP in the young decreased during bathing ($p<0.01$), whereas in the elderly BP had a maximum value just at the start of immersion ($p<0.05$) with a slight decline at 4 min after the start of immersion. Although HR in the young increased ($p<0.01$), in the elderly there was an abrupt increase in HR just at the start of immersion ($p<0.05$), followed by a decrease in HR. With regard to HRV, the high-frequency (HF) component in the young men was suppressed during immersion ($p<0.01$), but was unaffected in the elderly. The LF (low frequency)/HF ratio in the elderly decreased at 4 min ($p<0.05$). In conclusion, hypotensive syncope may cause sudden death by drowning during hot bathing, and is a consequence of the decrease in sympathetic tone that develops approximately 4 min after immersion. (*Jpn Circ J* 2001; **65:** 587–592)

Key Words: Autonomic activity; Bathing; Elderly; Hemodynamics; Sudden death

It is a common Japanese custom to take a hot bath daily[1] and approximately 10% of the cases of sudden death investigated by the Tokyo Medical Examiner's Office from 1989 to 1993 occurred during bathing. Further, the risk of sudden death during bathing among the elderly was 10 times higher than death during sleep. Among deaths during bathing, approximately 10% were from drowning, followed by cardiovascular disease (eg, acute myocardial infarction, cerebral hemorrhage and transient ischemic attack).[2–4]

We considered that the some changes in hemodynamics and autonomic nervous activity may contribute to sudden death during bathing in the elderly. Hemodynamic changes produced by bathing in hot water have been studied mostly in patients with heart disease and in healthy young people.[1,5–7] Recently, heart rate variability (HRV) analysis has been developed to noninvasively evaluate autonomic activity,[8,9] and Kishino et al[10] and Miwa et al[11] have used this method to study the effects of hot bathing on autonomic activity in the young. However, no report has compared changes in hemodynamics and autonomic activity in the elderly and the young.

Although the Fast Fourier Transform (FFT) has been used to analyze cardiac autonomic activity as a frequency domain analysis, FFT needs a minimum interval of 2 min to perform the analysis. Because autonomic activity changes rapidly before or after some events, important data may be lost during that time delay. Thus the FFT method is inadequate to estimate the precise power spectral density from short time series data. The MemCalc method is a new technique for time series analysis, which reliably analyzes the low-frequency component (LF: 0.04–0.15 Hz) over an interval of 30 s.[9]

We used that method of analyzing HRV in the present study to compare the effects of taking a hot bath on autonomic activity and hemodynamics in the elderly patient and the healthy young.

Table 1 Characteristics of the Young and Elderly Subjects

	Young group (n=9)	Elderly group (n=9)
Age (years)	27.4±9.6	74.6±10.7
Body length (cm)	173.6±4.1	162.1±8.0
Bodyweight (kg)	69.7±9.1	52.7±7.3
Systolic blood pressure (mmHg)	114.1±18.2	107.7±21.5
Diastolic blood pressure (mmHg)	64.6±13.9*	52.8±11.0
Heart rate (beats/min)	69.3±10.0	68.3±10.8

*Values are mean±SD. *p<0.05 vs elderly group.*

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Table 2 Clinical Characteristics of Elderly Group

Case no.	*Age (years)*	*Body length (cm)*	*Bodyweight (kg)*	*Diagnosis*	*Medication*	*Blood pressure (mmHg)*	*Heart rate (beats/min)*
1	*55*	*173*	*68*	*HTN, lumbar vertebra hernia*	*Loxoprofen, tizanidine, etizolam, brotizolam*	*126/66*	*80*
2	*80*	*156*	*47*	*HTN, bronchial asthma, cerebral infarction, COPD*	*Theophylline, berizym, clostridium butyricum, emedastine difumarate, heparinoid from animal organs*	*139/72*	*72*
3	*85*	*153*	*45*	*HTN, prostatic carcinoma*	*Ticlopidine, nifedipine, flutamide, ibudilast, cefotiam hexetil*	*90/47*	*80*
4	*80*	*165*	*50*	*HTN, Paf, intermittent WPW syndrome*	*Amlodipine, lisinopril, tamsulosin, dipyridamole, pilsicainide*	*78/38*	*50*
5	*64*	*168*	*51*	*Paf*	*Cibenzoline*	*111/47*	*62*
6	*64*	*174*	*48*	*Anemia*	*Niflec, magnesium citrate*	*98/45*	*64*
7	*78*	*155*	*50*	*HTN, cerebral infarction*	*Amlodipine besilate, bisoprolol, rilmazafone*	*123/60*	*76*
8	*84*	*157*	*60*	*HTN*	*Clostridium butyricum, sulpiride*	*122/52*	*57*
9	*81*	*158*	*55*	*COPD, Paf*	*Digoxin, spironolactone, verapamil, cibenzoline*	*82/48*	*76*
Mean±SD	*74.6±10.7*	*162.1±8.0*	*52.7±7.3*			*107.7±21.5/ 52.8±11.0*	*68.3±10.8*

HTN, hypertention; Paf, paroxysmal atrial fibrillation; COPD, chronic obstructive pulmonary disease.

Methods

Subjects

The study subjects were 9 elderly men (mean age, 75±11 years) without severe heart disease and 9 young men (mean age, 27±10 years) (Table 1). All subjects in the elderly group were hospitalized with an underlying disease at the time of the study, but were permitted by their doctor to take a hot bath (Table 2). The study was performed without alterations to the current medications of the patients. When the study was performed, all subjects were in sinus rhythm. Written informed consent was obtained from all subjects before the study.

Hot Bath Immersion (Fig 1)

Hot bath immersions were conducted around 15.00 h. The bathroom temperature was kept above 24°C. After a rest of more than 15 min, the subjects were immersed in hot water up to shoulder level and rested for 10 min in a seated position with the bath temperature at 40°C (39.9±0.9). All subjects completed 10 min of immersion.

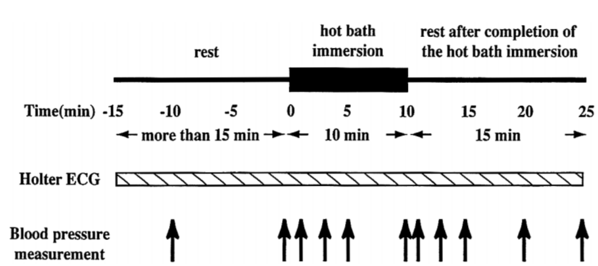

Fig 1. Protocol of the investigation. (Black box) Hot bath immersion. (Slash mark box) Holter ECG monitoring. (Arrows) blood pressure measurement.

Measurement of Hemodynamic Changes

Changes in blood pressure (BP) and pulse rate (PR) were monitored intermittently with an automatic digital sphygmomanometer (HEM-808F, OMRON Co, Tokyo, Japan), which measures digital arterial pressure indirectly from the left second finger.[12] (Prior to this investigation, we confirmed the reliability of the automatic digital sphygmomanometer and the digital BP measured with the automatic digital sphygmomanometer correlated well with left brachial BP measured with a mercury-based sphygmomanometer [n=9, systole; r=0.70, p<0.05, diastole; r=0.88, p<0.001]). The measurements were done at 5 and 15 min before the hot bath immersion, at 1, 3, 5, and 10 min during immersion, and at 1, 3, 5, 10, and 15 min after immersion. Double product, also called pressure–rate product, was calculated using the following formula: double product = [systolic BP]×[PR]. This is an indirect indicator of left ventricular oxygen consumption.

Electrocardiogram Monitoring

The ECG was recorded using a 2-channel Holter tape recorder (SM-60, Fukuda Denshi Co, Tokyo, Japan). We used a waterproof electrode (TE-18H-3, Fukuda Denshi Co) and lead NASA for only 1 channel. The tapes were analyzed with the Del Mar Avionics analyzer (model 563, Strata Scan, Los Angeles, CA, USA). No subjects had frequent arrhythmia during the investigation.

HRV Analysis

The ECG recordings were played back from the 2-channel tape recorder, and the signals were digitized using a 12-bit analogue-to-digital converter at a sampling rate of 1 kHz. From these signals, we obtained the RR interval (ms) as the time domain index of HRV. Spectral analysis of HRV using the MemCalc system (MemCalc, Suwa Trust

Co, Tokyo, Japan) was performed for each 30-s period at 30-s intervals, starting 15 min before hot bath immersion and continuing until 15 min after bathing had finished. Only normal to normal (NN) data was used to provide sufficiently reliable information for assessing both the LF component (0.04–0.15 Hz) and the high-frequency component (HF: 0.15–0.40 Hz) obtained from the power spectral analysis. The HF component has been used to infer parasympathetic nervous activity. In general, because the LF component involves both parasympathetic and sympathetic activity, many investigators infer sympathetic activity from the LF/HF ratio. The values of LF, HF, and LF/HF are reported as their natural logarithms (Ln).

Statistical Analysis

All values are expressed as mean ± standard deviation. Because the distribution of the frequency domain measurements of HRV was extremely skewed, a natural logarithm transformation (Ln) of each measure, which produces a nearly normal distribution, was applied before statistical analysis was performed.[13] The averaged HRV indices measured during the 15 min before hot bath immersion were considered to be the baseline. Comparisons of all measurements made at baseline with those made during or after hot bath immersion were made using the paired t test. The statistical significance of the differences between the elderly and the young group at corresponding times was determined by unpaired t test. Values were considered significantly different at a value of p<0.05.

Results

Effects of Hot Bath Immersion on BP

Systolic and diastolic BP at baseline, and during and after hot bath immersion are shown in Fig 2. There was no significant difference in baseline systolic BP between the elderly and the young groups. The systolic BP in the young group significantly decreased from baseline during hot bath immersion, reached the minimum of 84.6±8.1 mmHg at 10 min from the start of immersion (p<0.01) and returned to baseline by 10 min after completion of immersion.

In the elderly group, systolic BP reached a maximum of 129.4±27.7 mmHg at the start of hot bath immersion (p<0.05) and although the systolic BP during immersion

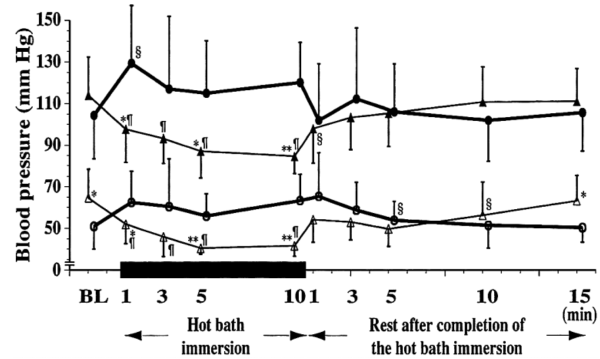

Fig 2. Changes in blood pressure during hot bath immersion. (Black box) Hot bath immersion. (●) Systolic blood pressure in elderly group. (▲) Systolic blood pressure in young group. (○) Diastolic blood pressure in elderly group. (△) Diastolic blood pressure in young group. BL, base line. Values are mean ± standard deviation. *p<0.05 compared with the elderly group, **p<0.01 compared with the elderly group, §p<0.05 compared with baseline, ¶p<0.01 compared with baseline.

was higher than at baseline, the difference was not significant. Systolic BP returned to baseline by 1 min after immersion ended. During immersion, systolic BP was higher in the elderly group than in the young group at 1, 5, and 10 min from the start of immersion (p<0.05, p<0.01, p<0.05, respectively).

At baseline, diastolic BP in the young group was higher than in the elderly group (p<0.05). The diastolic BP in the young group decreased during immersion, to a minimum of 40.3±2.8 mmHg (p<0.01) at 5 min from the start of immersion, and returned to baseline by 15 min after the end of immersion.

The diastolic BP during immersion was higher than at baseline in the elderly group, but not significantly. Diastolic BP returned to baseline by 5 min after the end of immersion. During immersion and by 5 min after immersion, the diastolic BP in the elderly group was higher than in the young group. The differences between the 2 groups at 1, 5, 10 min from the start of immersion were significant (p<0.05, p<0.01, p<0.01, respectively). Diastolic BP at 15 min after completion of immersion was higher in the young group than in the elderly group (p<0.05).

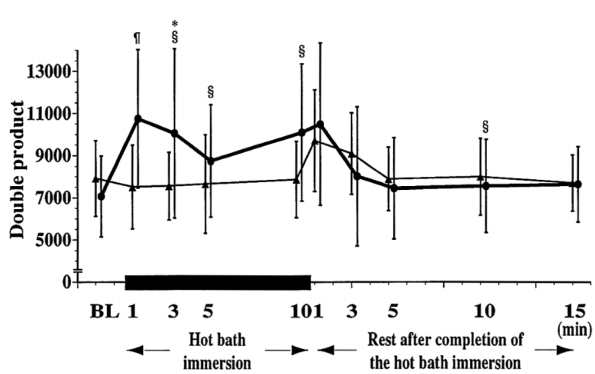

Fig 3. Changes in double product by hot bath immersion. (Black box) Hot bath immersion. (●) Elderly group. (▲) Young group. BL, base line. Values are mean ± standard deviation. *p<0.05 compared with elderly group, **p<0.01 compared with elderly group, §p<0.05 compared with baseline, ¶p<0.01 compared with baseline.

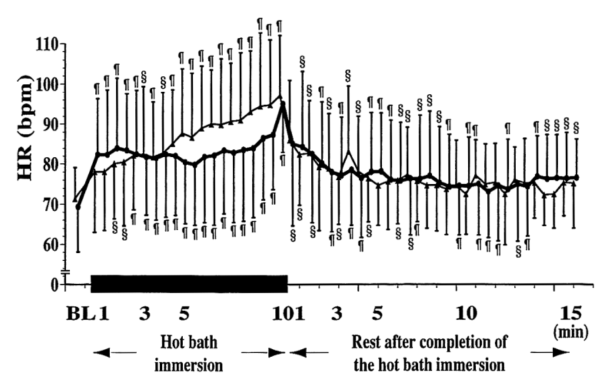

Fig 4. Changes in heart rate during hot bath immersion. (Black box) Hot bath immersion. (●) Elderly group. (▲) Young group. HR, heart rate; bpm, beats per minute; BL, base line. Values are mean ± standard deviation. *p<0.05 compared with elderly group, **p<0.01 compared with elderly group, §p<0.05 compared with baseline, ¶p<0.01 compared with baseline.

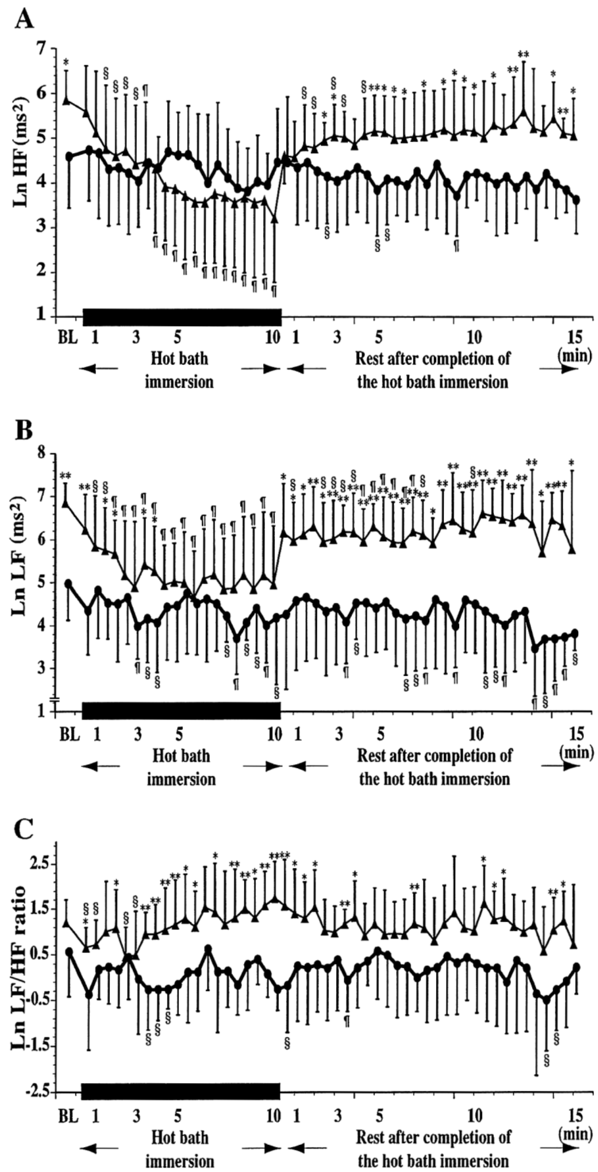

Fig 5. Changes in power spectral density by hot bath immersion. (A) Changes in HF. (B) Changes in LF. (C) Changes in LF/HF ratio. (Black box) Hot bath immersion. (●) Elderly group. (▲) Young group. Ln, natural logarithm; HF, high frequency; LF, low frequency; BL, base line. Values are mean ± standard deviation. *p<0.05 compared with elderly group, **p<0.01 compared with elderly group, §p<0.05 compared with baseline, ¶p<0.01 compared with baseline.

Effects of Hot Bath Immersion on Double Product (Fig 3)

The baseline double product was the same in both groups. The double product in the young group remained stable during and after immersion, whereas it was higher in the elderly group during immersion than at baseline, with a maximum value of 10,741±3,281.5 at the start of immersion ($p<0.01$). The double product returned to baseline 5 min after the end of immersion. In the elderly group the double product was higher than in the young group at 1 and 3 min after the start of immersion ($p<0.05$).

Effects of Hot Bath Immersion on HR (Fig 4)

The baseline HR was the same in both groups. The HR in the young group increased from baseline during immersion to a maximum of 97.1±14.9 beats/min at 10 min from the start of immersion ($p<0.01$) and returned to baseline by 8 min after the end of immersion.

In the elderly group, the HR increased to 82.3±14.0 beats/min at the start of immersion ($p<0.01$) and then stabilized until a decrease after about 5 min. Subsequently the HR increased again, and reached a maximum of 95±12.0 beats/min at 10 min after the start of immersion ($p<0.01$). There were no significant differences between the 2 groups.

Effects of Hot Bath Immersion on HRV

The changes in the HF, LF, and LF/HF ratios are shown in Fig 5. In the young group, the HF component was higher at baseline than in the elderly group ($p<0.05$), decreased to a minimum of 3.212±1.43 ms^2 at 10 min from the start of immersion ($p<0.01$) and then returned to baseline by about 11 min after the end of immersion.

The HF component did not change during immersion in the elderly group, although it was lower than the baseline at 2.5, 5, 5.5, and 9 min after the end of immersion ($p<0.05$, $p<0.05$, $p<0.05$, $p<0.01$, respectively). The HF component was higher in the young group than in the elderly group at the end of immersion ($p<0.01$).

The LF component was higher in the young group than in the elderly group at baseline ($p<0.01$), decreased during immersion to a minimum of 4.67±1.08 ms^2 at 6 min after the start of immersion ($p<0.01$) and returned to baseline by 10 min after the end of immersion. In the elderly group, it decreased abruptly at 3 min from the start of immersion ($p<0.01$) and decreased further at 8 min to a minimum of 3.709±0.84 ms^2 ($p<0.01$). After completion of immersion, the LF was lower than at baseline ($p<0.01$). The LF in the young group was higher than in the elderly group after the end of immersion ($p<0.01$).

At baseline, the LF/HF ratio was higher in the young group than in the elderly group, but not significantly. In the young group, the LF/HF ratio decreased at the start of immersion ($p<0.05$) and then increased, but not significantly. In the elderly group, the LF/HF ratio decreased at 4 min to a minimum of –0.265±0.48 ($p<0.05$). It reached a nadir at 30 s after completion of immersion, then fluctuated, but always remained lower than baseline. However, the changes were not significant. The LF/HF ratio after bathing was lower in the elderly group than in the young group ($p<0.01$).

Discussion

The present study demonstrated that the physiological response to immersion in a hot bath is different in the elderly and the young. Furthermore, it is difficult for the elderly to maintain homeostasis during immersion because the autonomic nervous system is unable to respond vigorously enough to the heat stress. The depressed parasympathetic activity is feeble, and sympathetic activity may actually decrease temporarily rather than increase when the vasoconstriction necessary to maintain BP is needed to compensate for surface vasodilation. Hypotension and bradycardia may result from this transient autonomic imbalance, leading to loss of consciousness and death by drowning.

Effect of Aging on the Regulation of Hemodynamics

The effect of aging on the regulation of hemodynamics and autonomic activity during hot bath immersion has received little attention. In the present study, clear differences in the response of the young and the elderly were observed. Of particular interest is that BP in the elderly increased during immersion, whereas it decreased gradually in the young group. Moreover, the double product in the elderly increased immediately, but remained constant in the young. These results show how difficult it is for the elderly to maintain homeostasis during hot bathing. The fact that the double product, which reflects the myocardial oxygen consumption, was increased immediately upon immersion, because of the increase of both BP and PR, suggests that ischemic heart attacks are likely to occur at that time.

Autonomic Activity During Hot Bath Immersion

Previous studies have measured BP, HR and serum catecholamine concentration,[13,14] but these parameters cannot evaluate sympathetic and parasympathetic activity simultaneously, which can be done with HRV analysis. Changes in autonomic activity during hot bath immersion have been studied with this method,[10,11,15] but the previous studies used a minimum interval of 2 or 5 min. As mentioned before, autonomic activity changes rapidly and important data may not be apparent duringsuch a long delay.[9] The MemCalc method analyzes the LF component with a minimum sampling interval of 30 s.

Previous studies have reported that the HF component in the young decreased and the LF/HF ratio increased during hot bath immersion followed by a temporal decrease at the start of immersion,[10,15] although why the LF/HF ratio decreased in the young at the start of immersion was not clear. It is necessary to evaluate the effects of hydrostatic pressure and water temperature independently. We also found that the HF component decreased in the young, but not in the elderly, which suggest that parasympathetic activity is suppressed during hot bath immersion in the young, but not in the elderly.

Relationship Between Sudden Death, Autonomic Activity and Hemodynamics During Hot Bath Immersion

One of the causes of drowning during immersion in hot water is syncope resulting from a rapid decrease in BP.[16] The BP initially increases upon immersion, but falls quickly in a patient with acute myocardial infarction.[6,17] At higher water temperatures (43°C), the same phenomenon can be produced in young subjects.[1] Our data established clearly that the decrease in BP and HR in young subjects is associated with suppression of parasympathetic activity and can be thought of as a compensatory mechanism. On the other hand, in the elderly, BP and HR initially rise immediately upon immersion in a hot bath then subsequently decrease after about 4 min. These changes are associated with a temporary decrease in sympathetic activity without the compensatory suppression of parasympathetic tone; hypotension and bradycardia are the result.

Although the time interval between when the victim enters the bathroom and when the family discovers the death has been reported,[18] the actual point at which death occurs has not been established, although the present study suggests that death may occur as soon as 4 min after immersion in hot water.

Study Limitations

First, the number of participants in this study was small, 9 subjects in each group. Additional investigation with a larger number of subjects is required. Second, because many of the elderly patient in this study were taking medication that influences hemodynamics, it is not possible to determine whether or to what extent pharmacology biased the results. Also, the study cohort was heterogenous from the standpoint of underlying disease. The effect of this factor is also not possible to establish. Third, the LF/HF ratio may not accurately measure sympathetic activity. The LF component reflects both sympathetic and parasympathetic activity, though the HF component reflects only parasympathetic activity.[8] For this reason, the LF/HF ratio is considered by some investigators to be an indirect measure of sympathetic activity.[9] Thus, a direct index of sympathetic activity is needed to enhance accuracy and reliability. Finally, BP measured by a digital sphygmomanometer differs from BP measured by a brachial sphygmomanometer. Because the digital sphygmomanometer records arterial pressure in the finger, a more distal site, the pressure recorded will be lower than pressure in the brachium. This confounding variable must be taken into account.

Conclusion

The present study suggests that hypotensive syncope is one cause of sudden death of elderly persons by drowning during hot bath immersion, and is a consequence of the decrease in sympathetic tone that develops approximately 4 min after immersion.

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