Abstract. The effect of vasopressin released during Finnish sauna on blood pressure, heart rate and skin blood flow was investigated in 12 healthy volunteers. Exposure to the hot air decrease body weight by 0.6 to 1.25 kg (mean = 0.8 kg, P < 0.001). One hour after the end of the sauna sessions, plasma vasopressin was higher (1.7 ± 0.2 pg/ml, P < 0.01 mean ± SEM) than before the sauna (1.0 ± 0.1 pg/ml). No simultaneous change in plasma osmolality, plasma renin activity, plasma norepinephrine, epinephrine, cortisol, aldosterone, beta-endorphin and metenkephalin levels was observed. Despite the slight sauna-induced elevation in circulating vasopressin, intravenous injection of the specific vascular vasopressin antagonist d(CH2)5Tyr-(Me)AVP (5 μg/kg) 1 h after the sauna had no effect on blood pressure, heart rate or skin blood flow. These data suggest that vasopressin released into the circulation during a sauna session reaches concentrations which are not high enough to interfere directly with vascular tone.

During exposure to heat in a relatively dry atmosphere as in a Finnish sauna, sweating becomes a crucial variable in thermoregulation (Hasan et al. 1966, 1967; Luurila 1980). In these conditions, the percutaneous loss of water and salt is associated with a decrease in urine output which is most likely due to an enhanced secretion of antidiuretic hormone (Hellman et al. 1953; Karvonen et al. 1955). This latter hormone, also called vasopressin, represents a potent constrictor substance in in vitro preparations while, in the intact organism, its pressor effect seems to be effectively buffered in most circumstances by the baroreceptor reflex (Lohmeier et al. 1981). There exists, however, strong evidence that vasopressin not only acts as a circulating hormone at the renal and vascular level, but also as a central neurotransmitter. For instance, this polypeptide appears to be involved in the release of pituitary peptides such as corticotropin (ACTH) and beta-endorphin (Gillies et al. 1980, 1982; Rivier et al. 1983; De Bold et al. 1984; Milsom et al. 1985) which both originate from a common precursor named pro-opiocortin (Mains et al. 1977; Nakanishi et al. 1979).

The present investigation was planned to assess in healthy volunteers whether circulating vasopressin plays a role in cardiovascular homeostasis following a Finnish sauna. For this purpose the acute blood pressure, heart rate and skin blood flow response to a specific vascular antagonist of vasopressin was studied (Manning et al. 1982). In addition, we evaluated the effect of the sauna-induced reduction of total body fluid on a series of humoral parameters including vasopressin and opioid peptides.

Subjects and Methods

Twelve healthy normotensive volunteers aged 21–31 years (mean = 25), weighing between 61 and 81 kg (mean = 73), were included in the study. These subjects were not used to practice Finnish sauna. The protocol
was approved by the Hospital Ethics Committee. The nature and the purpose of the study was fully explained, and only consenting subjects were included. Each had a medical history taken and underwent a complete physical examination. For safety evaluation, routine laboratory tests and an electrocardiogram were carried out before the experimental day.

The volunteers were required to abstain from alcohol and smoking overnight. On the morning of the study, they were allowed to eat a light breakfast at 07.00 a.m. consisting of 2 dl milk and a yoghurt. The subjects were asked to come to our outpatient clinic at 11.00 a.m. On arrival, they were installed in a comfortable armchair, and a catheter was inserted in an antecubital vein. Half an hour later, blood pressure and heart rate were measured, and a blood sample was obtained. Blood pressure was determined by the conventional auscultatory method using a mercury sphygmomanometer. The volunteers then left the hospital by car to join a fitness club where a Finnish sauna was available. In the sauna, the temperature was maintained between 85° and 90°C with an air humidity of 10 to 15%. The volunteers remained in this atmosphere for 10 min, then took a cold shower before resting for 10 min outside the sauna in an air conditioned area. Thereafter, the same procedure was repeated twice.

At the end of the sauna session, the volunteers were driven back to the hospital and installed again as described above. In 8 of the subjects, a probe for continuous measurement of skin blood flow was applied on the left forearm. The skin blood flow was determined with a laser Doppler flowmeter (Periflux, Perimed, Stockholm, Sweden). This device was used according to the recommendations established previously (Nilsson et al. 1980). During this part of the study, blood pressure was monitored in all subjects using a semi-automatic blood pressure recorder (Remler M2000, Remler Corp., San Francisco, CA) fitted on the right arm and activated by a nurse (Jacot des Combes et al. 1984).

After a 30 min stabilization period and exactly 60 min after the last sauna session, a blood sample was drawn and an intravenous bolus dose of a specific antagonist of the vascular effect of arginine vasopressin (AVP) was administered. The monitoring of the haemodynamic parameters was terminated 30 min later. Blood pressure levels were read from the magnetic tape at the end of the experiment by means of a decoding unit (Remler M3000).

On the morning of the study, the AVP antagonist (1-ß-mercaptop-ß,ß-cyclopentamethylenpropionic acid) 2-(O-methyl)tyrosine arginine vasopressin or d(CH2)s-Tyr(Me)AVP, Ciba-Geigy AG, Basel, Switzerland) was dissolved in 0.9% saline to achieve a final concentration of 100 μg/ml and injected at a dose of 5 μg/kg. This dose of the antagonist has previously been shown to block the vascular effect of exogenous vasopressin for at least 2 h. Prior to administration, the solution containing the AVP-antagonist was passed through a Milex CS filter (Milipore, Molsheim, France). The body weight of the volunteers was measured at the clinic after voiding both before and following the sauna session. The same balance was used throughout the course of the study. In each of the blood samples (30 ml) haematocrit, protein concentration, plasma osmolality (Osmometer Vogel, Giessen, FRG), plasma renin activity (Sealy et al. 1972) as well as plasma levels of vasopressin (Brunner et al. 1983), catecholamines (Peuler et al. 1977), cortisol, beta-endorphin (Jeffcoate et al. 1978) and metenkephalin (Clement-Jones et al. 1980) were measured.

Statistical evaluation of the results was performed by one-way analysis of variance and Student’s t-test where appropriate. Data are reported as mean ± se of the mean (± SEM).

Table 1.
Humoral measurements before and after Finnish sauna bathing.

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
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<tbody>
<tr>
<td>Protein (g/l)</td>
<td>72.6 ± 1.0</td>
<td>74.2 ± 0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Haematocrit (%)</td>
<td>43.6 ± 0.8</td>
<td>43.3 ± 0.8</td>
<td>NS</td>
</tr>
<tr>
<td>Osmolality (mosm/kg H2O)</td>
<td>281 ± 1</td>
<td>281 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma vasopressin (pg/ml)</td>
<td>1.0 ± 0.1</td>
<td>1.7 ± 0.2</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>Plasma renin activity (ng/ml/h)</td>
<td>0.9 ± 0.2</td>
<td>1.2 ± 0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma epinephrine (ng/ml)</td>
<td>0.021 ± 0.006</td>
<td>0.014 ± 0.005</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma norepinephrine (ng/ml)</td>
<td>0.190 ± 0.010</td>
<td>0.220 ± 0.020</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma cortisol (μg/100 ml)</td>
<td>9.2 ± 0.9</td>
<td>7.4 ± 0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma beta-endorphin (pg/ml)</td>
<td>35.0 ± 5.3</td>
<td>38.9 ± 6.2</td>
<td>NS</td>
</tr>
<tr>
<td>Plasma metenkephalin (pg/ml)</td>
<td>68.3 ± 6.3</td>
<td>83.6 ± 10.1</td>
<td>NS</td>
</tr>
</tbody>
</table>

Mean ± SEM. n = 12.
### Results

Sauna was well tolerated by all participants. During the 3 consecutive 10 min exposures to heat, the volunteers lost from 0.6 to 1.25 kg (mean = 0.8 kg), which represents 0.8 to 1.6% (mean = 1.1%) of their body weight. They experienced no sensation of increased thirst.

Table 1 summarizes the results of humoral measurements carried out before as well as after the sauna session. Plasma vasopressin increased from 1.0 ± 0.1 to 1.7 ± 0.2 pg/ml (P < 0.01) in the absence of a change in plasma osmolality. All other parameters studied were not modified by the sauna.

In all subjects taken together, blood pressure and heart rate before sauna averaged 121/76 ± 5/3 mmHg and 72 ± 3 beats/min, respectively. The same parameters were at 110/65 ± 4/3 mmHg and 69 ± 3 beats/min immediately before injection of the AVP-antagonist. It was not attempted to test whether the blood pressure fall induced by sauna achieved a significant level because blood pressure measurements were obtained with different devices before and after the sauna session.

In the 12 volunteers, the AVP-antagonist had no effect on blood pressure and heart rate and no adverse reaction was reported after its administration. Fig. 1 illustrates the haemodynamic response to the AVP-antagonist of the 8 subjects who had the skin blood flow monitored in addition to blood pressure and heart rate. During the 30 min observation period, the AVP-antagonist did not modify the 3 haemodynamic parameters.

### Discussion

In response to the loss of water and salt from the body by sweating during a Finnish sauna, urine flow has been shown to decrease for more than 1 h (Karvonen et al. 1955). This effect of the sauna on renal fluid handling has been attributed to the release from the posterior pituitary into the circulation of the antidiuretic hormone, a polypeptide also called vasopressin because of its potent vasoconstrictor properties (Hellman et al. 1953).

The main purpose of the present study was to assess whether vasopressin acutely released due to the exposure to hot air in a sauna has any haemodynamic effect. To unmask a possible contribu-
tion of vasopressin to cardiovascular homeostasis, a specific antagonist of the vascular effect of this hormone was used (Manning et al. 1982). Due to the pronounced buffering effect of the baroreceptor reflex on the pressor action of vasopressin, at least theoretically changes in regional blood flow distribution could be expected to occur even in the absence of a blood pressure change (Lohmeier et al. 1981). Of note is the recent finding that blood supply to the cutaneous vascular bed decreased in humans as a consequence of a rise in circulating vasopressin levels triggered off by cigarette smoking (Waeb er et al. 1984). This urged us to monitor in our volunteers skin blood flow together with blood pressure.

Because facilities to carry out accurate measurements and to quickly process blood samples were not available at the fitness club, humoral and haemodynamic studies were performed at the clinic 1 h later. For this reason it has to be stressed that the results presented here might not be representative of the immediate response to sauna. It is indeed conceivable that sauna-induced modifications of some parameters were again spontaneously corrected during the 1 h interval between the end of the sauna session and the moment when the experiment was started.

Plasma electrolytes of the volunteers were not affected by the sauna-induced sweating. This observation is not surprising in view of the controversial results reported so far (Hasan et al. 1967). More interesting is the feature that vasopressin secretion was significantly stimulated by the sauna. The increment of circulating vasopressin levels was only modest and appeared not to be primarily mediated by an increase in plasma osmolality. Nevertheless, due to the design of the study, one cannot rule out that some degree of hyperosmolality was present shortly after the end of the sauna session. Such a hyperosmolality could have triggered off the release of vasopressin and might have been progressively corrected by the antidiuresis provoked by this hormone. Nonosmotic stimuli of vasopressin secretion have of course also to be considered. For instance, it is possible that the stimulus for vasopressin release originated from baroreceptors localized in the cardio-pulmonary circulation (Wang et al. 1984). Such a mechanism would go along with a diminished intrathoracic blood volume observed after a sauna session (Eisalo 1956).

The antagonist of the vascular effect of vaso-
pressin had no influence on blood pressure, heart rate or skin blood flow. This lack of a haemodynamic response does not really come as a surprise if one takes into account that the plasma vasopressin concentration was only slightly enhanced by sauna. In our experience, circulating vasopressin has to achieve higher levels in humans before it exerts detectable haemodynamic effects (Waeb er et al. 1984). Nevertheless, it does not rule out that vasopressin could influence blood pressure by a central mechanism (Berecek et al. 1983).

One group of investigators has observed an activation of the renin-angiotensin system during exposure to heat in a sauna (Dumoulin et al. 1980). In the present experimental settings such an effect was not apparent. This was also true with respect to the sympathetic nervous system. Both plasma norepinephrine and epinephrine concentrations remained unchanged, whereas urinary excretion of these catecholamines has been previously reported to increase after exposure to a hot and dry atmosphere (Taggart et al. 1972). Plasma concentrations of aldosterone and cortisol did not increase in response to the sauna. This observation contrasts with the findings of other investigators who reported an increase in urinary (Streeten et al. 1955; Hellman et al. 1956) and plasma aldosterone (Dumoulin et al. 1980) as well as in plasma cortisol (Adlercreutz et al. 1976).

The fact that in our volunteers circulating vasopressin was significantly increased in the absence of parallel rises in plasma cortisol and beta-endorphin levels is of particular interest. Indeed, vasopressin has been shown in vitro and in vivo to stimulate the release of ACTH and beta-endorphin from human pituitary tumours (Gillies et al. 1980, 1982; Rivier et al. 1983; Ratter et al. 1983; De Bold et al. 1984; Milsom et al. 1985). On the other hand, there is some evidence suggesting that opioid peptides play a role in the regulation of vasopressin release from the neurohypophysis (Ishikawa et al. 1982). It is therefore of note that both metenkephalin and beta-endorphin were not elevated in the plasma after the sauna session. Of course, vasopressin and opioid peptides have physiologically important central effects which may not be reflected by plasma measurements.

In conclusion, the present data suggest that sauna can stimulate the secretion of vasopressin without activating simultaneously the renin-angiotensin and the sympathetic nervous system.
They also seem to demonstrate that the levels of circulating vasopressin achieved after a sauna session are insufficient to contribute directly to cardiovascular homeostasis by a vasoconstrictor.

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References


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