Introduction

Hypertension is a multifactorial disease and is a major independent risk factor for cardiovascular diseases. Numerous studies have reported that the prevalence of hypertension among heat-exposed workers is significantly higher than that of workers with exposure to normal temperatures. The difference is likely due to the fact that workers exposed to high temperatures must regulate their body temperatures through sweating. Heat-exposed work can lead to the production of large amounts of sweat, and water-soluble vitamins and minerals can be excreted in the sweat. These excretions affect micronutrient levels in vivo and increase the vitamin and mineral requirements for workers who may be exposed to high temperatures. Micronutrient levels are closely related to blood pressure.
(BP). Many papers have reported that dietary sodium intake is positively correlated with BP\(^{10,11}\) and dietary intakes of vitamin C, potassium, magnesium, and calcium are inversely correlated with BP\(^{11–19}\). Furthermore, serum vitamin C\(^{17–19}\), serum potassium\(^{19}\), and serum magnesium\(^{20}\) levels are inversely correlated with BP. The body cannot produce micronutrients on its own and, therefore, micronutrients must be supplied through dietary intake (Vitamin D is the only exception, since it can be produced by exposure to sunlight)\(^{21,22}\). Therefore, insufficient micronutrient consumption can lead to deficiencies, especially for heat-exposed workers. However, relationships between micronutrient losses in sweat and BP among heat-exposed steelworkers have not been reported. Vitamin C is an antioxidant that inhibits the inflammatory response, reduces oxidative stress\(^{23}\) and enhances endothelial function through effects on nitric oxide (NO) production\(^{24}\). Numerous oxidative and inflammatory mechanisms appear to be involved in the pathogenesis of high BP\(^{25,26}\). Inflammation, oxidative stress and endothelial function are all associated with hypertension\(^{27}\). A randomized trial showed that vitamin C supplementation significantly reduced levels of F2-isoprostane, an oxidative stress biomarker\(^{28}\). Potassium may lower BP through more than one mechanism: potassium can lead to vasodilatation\(^{29}\) and may decrease the need for antihypertensive medication\(^{30}\). Moreover, potassium lowers BP by regulating the dynamic balance between sodium and potassium, especially for salt-sensitive patients with hypertension\(^{31}\). Calcium may regulate hormones, electrolyte interactions, and the sympathetic nervous system to modify BP\(^{30}\), magnesium can affect cardiac electrical activity, myocardial contractility, and vascular tone. Epidemiologic and laboratory studies have also suggested that vitamin B\(_1\)\(^{32}\), B\(_2\)\(^{33}\), iron\(^{34}\), zinc\(^{35}\), copper\(^{35}\) and selenium\(^{36}\) may have beneficial effects on BP, but the mechanisms are not clear.

Heat-exposed steelworkers comprise a distinctive population and evaluation of the relationships between micronutrient losses in sweat and BP in this group are warranted. For this study, we measured the concentrations of water soluble vitamins (vitamins C, B\(_1\), and B\(_2\)) and minerals (potassium, sodium, calcium, magnesium, iron, zinc, copper, and selenium) in the sweat of heat-exposed steelworkers. We analyzed the associations between micronutrient losses in sweat and BP in order to support BP control and improve health promotion.

### Subjects and Methods

#### Subjects

Heat exposure limits for heat-exposed steelworkers are defined in GBZ 2.2-2007: “Occupational Exposure Limits for Hazardous Agents in the Workplace Part 2: Physical Agents,” which was implemented on November 1, 2007. For our study, we evaluated 243 heat-exposed male steelworkers aged 22 to 50 years old with lengths of service in the steel industry ranging from 1 to 30 years. The subjects were selected from the converter and rolling workshop of an ironworks facility in July 2012. We excluded participants who had taken micronutrient supplements or antihypertensive drugs within one month of the study and participants with incomplete data. A total of 224 participants were included in the final analysis. All participants voluntarily took part in this study and provided informed consent prior to its start. The study was approved by the Ethics Committee of Hebei United University (currently: North China University of Science and Technology).

#### General information

We used a questionnaire to collect general information about each worker, including age, length of service, type of work, smoking status (a non-smoker was classified as: someone who had never smoked or had smoked less than 100 cigarettes in a lifetime; an ex-smoker was someone who smoked more than 100 cigarettes in the past but was not smoking at the time of the questionnaire; a smoker was someone who had smoked more than 100 cigarettes and was still smoking at the time of the questionnaire); alcohol drinking habits, history of salt in the diet, exercise, family history and so on. To describe alcohol drinking habits, a non-drinker was defined as someone who drank less than once per month and a drinker was someone who had the habit at the time of interview or stopped the habit within one year before interview\(^{37}\). Dietary sodium intake was divided into three groups: low (< 2.3 g/day [< 5.85 g/day salt]), moderate (2.3–4.6 g/day [5.85–11.7 g/day salt]), and high (> 4.6 g/day [> 11.7 g/day salt])\(^{38,39}\). Dietary sodium intake was assessed by a combination of a 24-h dietary recall\(^{40}\) and weighing method\(^{41}\). The weighing method was used to evaluate working lunch in the factory canteen. We measured the weight and height of each participant and calculated the Body Mass Index (BMI).

#### Environmental conditions

According to the GB/T 4200-2008 Classified Standard of Working in the Hot Environment, a hot environment is...
defined as a workplace whose average Wet Bulb Globe Temperature (WBGT) is higher than 25°C during working hours. WBGT was directly measured three times on the same day in heat-exposed workplaces using a WBGT index measuring instrument (Questemp36, USA). We measured temperatures in various work environments according to different types of work, including steelmaking, sampling, measuring temperature, rolling mill, finishing, crown block, and heating furnace. We recorded WBGT readings for three days and calculated the Effective Time Weighted Average WBGT Index to define the hot environments. Workers were divided into groups of heat exposure according to the Effective Time Weighted Average WBGT Index: 30–35°C, 35–40°C, and 40–43°C.

Sample selection and determination

We collected sweat from the forehead, back, and chest of each participant by scraping the skin with a small beaker or 15-ml centrifuge tube during the rest time in the break room or at the work site immediately after exposure to high temperatures. Sweat was collected twice in the morning and twice again in the afternoon. We transferred the sweat samples into brown bottles and added oxalic acid. The samples were maintained in a bubble-wrapped fridge. And at least 5 ml of sweat was collected from each participant. All collection containers were soaked in 10% nitric acid solution overnight, washed with ultrapure water, and then dried. The total amount of perspiration excreted during an eight-hour work shift was calculated by the weight difference method (sweat excretion = weight before work – weight after work + liquids and food consumption – the weight of defecation and urine – respiratory water losses during work)\(^{(42)}\). We carefully measured the weight of each participant before and after work, and before and after drinking, eating, defecating, and urinating during the work shift. The precision of the scale was 10 g. We estimated respiratory water losses (500 to 600 g) of each participant according to labor intensity and heat-exposure time, which were approximated to be 5 h for heavy physical activity and 6.5 h for moderate to heavy physical activity. For comparison, studies have reported that respiratory water loss during exercise to be approximately 88 ± 10 g/h or 0.12 g/kcal\(^{(43,44)}\). We considered that micronutrient losses in sweat were equal to the product of the concentration of the micronutrient and the amount of sweat\(^{(42,43)}\).

In the field, vitamin C concentrations in sweat were estimated with 2, 6-dichlorophenol indophenol immediately after collection\(^{(45)}\). The sweat samples were then transported to the laboratory in a bubble-wrapped fridge. On the same day that the samples were obtained, vitamin B\(_1\) and B\(_2\) concentrations were estimated with fluorospectrophotometry (RF-5301PC, Shimadzu Corporation, Japan)\(^{(46)}\). The remaining samples were stored at −20°C until further analysis. After all samples were collected, the concentrations of potassium, sodium, calcium, magnesium, iron, zinc, copper, and selenium in sweat were determined by inductively-coupled plasma-atomic emission spectrometry (ICP-MS, Agilent-7500A, USA)\(^{(47)}\). The concentrations of the standard curves were 0.1 μg/L, 0.5 μg/L, 1 μg/L, 5 μg/L, 10 μg/L, 20 μg/L, 25 μg/L, and 50 μg/L. The sweat samples were diluted 10 times by 1% nitric acid (chromatographically pure). Water used in the experiments was deionized water, and glassware was soaked with 10% nitric acid (analytically pure). The relative standard deviations were all less than 5% and the precision of the method was acceptable.

BP measurements

We measured SBP and DBP after participants had been out of the high-temperature work environment for at least 12 hours. The participants rested for at least five minutes before BP measurements. A trained investigator used a mercury sphygmomanometer (Jiangsu Yuwell, China) to measure BP before workers began work in the morning. Three consecutive readings were recorded by measuring the same arm and the mean SBP and DBP values were calculated. Hypertension is defined as a SBP above 140 mm Hg or a DBP above 90 mm Hg\(^{(48)}\).

Statistical analysis

Data were double-entered by Epidata 3.0 and statistical analyses were performed using SPSS 17.0 for Windows. Continuous variables are expressed as means ± standard deviation and count data are expressed as percentages. The t-test was applied to compare the differences between the groups and a one-way analysis of variance was applied to compare multiple groups. Multiple stepwise regression analysis was performed to evaluate the effect of micronutrient losses in sweat on BP among heat-exposed steelworkers. A p-value < 0.05 was considered statistically significant.

Results

Descriptive statistics for the demographic information of participants are listed in Table 1. The subjects had an average age of 36.9 ± 5.9 years old and an average length of service 13.6 ± 6.4 years. All workers worked in three shifts.
Table 1. Demographic characteristics of heat-exposed steelworkers (n = 224)

| Characteristic                | n   | %    |
|------------------------------|-----|------|
| Age (years)                  |     |      |
| 22–29                        | 47  | 21.0 |
| 30–39                        | 133 | 59.4 |
| 40–50                        | 44  | 19.6 |
| Length of service (years)    |     |      |
| 1–9                          | 56  | 25.0 |
| 10–19                        | 122 | 54.5 |
| 20–30                        | 46  | 20.5 |
| Average WBGT value (°C)      |     |      |
| 30–35                        | 102 | 45.5 |
| 35–40                        | 85  | 38.0 |
| 40–43                        | 37  | 16.5 |
| BMI (kg/m²)                  |     |      |
| < 18.5                       | 3   | 1.3  |
| 18.5–23.9                    | 85  | 38.0 |
| 24.0–27.9                    | 74  | 33.0 |
| ≥ 28.0                       | 62  | 27.7 |
| Physical activity level      |     |      |
| Medium                       | 89  | 39.7 |
| Heavy                        | 135 | 60.3 |
| Education level              |     |      |
| Junior middle school or below| 23  | 10.3 |
| High school or technical secondary school | 132 | 58.9 |
| College degree or above      | 69  | 30.8 |
| Dietary salt intake          |     |      |
| Low                          | 32  | 14.3 |
| Moderate                     | 67  | 29.9 |
| High                         | 125 | 55.8 |
| Smoking status               |     |      |
| Current smokers              | 123 | 50.9 |
| Ex-smokers                   | 19  | 8.5  |
| Non-smokers                  | 82  | 36.6 |
| Alcohol intake               |     |      |
| Yes                          | 140 | 62.5 |
| No                           | 84  | 37.5 |
| Regular exercise             |     |      |
| Yes                          | 92  | 41.1 |
| No                           | 132 | 58.9 |

WBGT: Wet Bulb Globe Temperature

The average BMI of the participants was 25.4 ± 3.9 kg/m² (range 16.0–36.4 kg/m²). Most of the participants (n = 125; 55.8%) had a high dietary salt intake and 67 (29.9%) subjects had a moderate dietary salt intake.

The excretions of water soluble vitamins in sweat during an eight-hour work shift among heat-exposed steelworkers are outlined in Table 2. The average sweat excretion of 224 heat-exposed steelworkers was 3,181 ± 781 ml (range 1,513–7,695 ml). Sweat losses increased with increasing temperature of the work environment (all P < 0.01). The average concentrations of vitamin C, vitamin B₁, and vitamin B₂ in sweat were 4.84 ± 1.9 mg/L, 71.3 ± 20.1 μg/L, and 61.4 ± 22.3 μg/L, respectively (ranges 0.9–8.2 mg/L, 41–146 μg/L, and 46.8–114 μg/L, respectively). The excretions of vitamin C, vitamin B₁, and vitamin B₂ in sweat in the 35–40°C and 40–43°C groups were significantly higher than those in the 30–35°C group (all P < 0.01). The excretions of vitamin C, vitamin B₁, and vitamin B₂ in sweat in the 40–43°C group were significantly higher than those in the 35–40°C group (all P < 0.01).

The excretions of minerals in sweat during an eight-hour work shift among heat-exposed steelworkers are outlined in Table 3. The average concentrations of potassium, sodium, calcium, magnesium, iron, zinc, copper, or selenium in sweat among heat-exposed steelworkers were 161.2 mg/L, 1,173.1 mg/L, 32.1 mg/L, 5.7 mg/L, 290.3 μg/L, 274.9 μg/L, 28.5 μg/L, and 5.9 μg/L, respectively (ranges 76.4–193.2 mg/L, 976–3,210 mg/L, 16.4–44.5 mg/L, 5.4–6.4 μg/L, 243.1–390.4 μg/L, 231.5–510.3 μg/L, 21.6–34.8 μg/L, and 3.9–8.2 μg/L, respectively). The losses of all eight minerals in sweat in the 35–40°C and 40–43°C groups were significantly higher than those in the 30–35°C group (all P < 0.01). The mineral losses in the 40–43°C group were significantly higher than those in the 30–35°C and 35–40°C groups (all P < 0.01).

BP levels of heat-exposed steelworkers are listed in Table 4. The average SBP was 128.5 ± 15.0 mm Hg (range 100–175 mm Hg) and the average DBP was 80.8 ± 10.4 mm Hg (range 60–112 mm Hg). The prevalence of hypertension was 29.5% (n = 66). We observed significant differences among the three groups in terms of SBP (F = 3.193, P < 0.05). DBP in the 40–43°C group was significantly higher than that in the 30–35°C group (P < 0.05). No significant differences in DBP were observed among the three groups (F = 1.665, P = 0.192).

The relationships between micronutrient losses in sweat during an eight-hour work shift and BP among heat-exposed steelworkers are outlined in Table 5. A linear correlation analysis revealed that vitamin C, potassium, and calcium losses in sweat were positively correlated with SBP (r = 0.268, r = 0.299, and r = 0.303, respectively; P < 0.01) and DBP (r = 0.216, r = 0.233, and r = 0.303, respectively; P < 0.05). No correlations were noted between losses of vitamin B₁, vitamin B₂, sodium, magnesium, iron, zinc, copper, or selenium in sweat and BP.

The effects of micronutrient losses in sweat during an eight-hour work shift on BP among heat-exposed steelworkers are shown in Tables 6 and 7. We performed separate linear stepwise regression analyses with SBP or DBP as the dependent variable and age; length of work; BMI;
micronutrient losses in sweat and BP

Table 2. Excretions of water soluble vitamins in sweat during an eight-hour work shift

| WBGT (°C) | N  | Sweat losses (ml) | Water soluble vitamin losses in sweat |
|-----------|----|------------------|--------------------------------------|
|           |    |                  | Vitamin C (mg) | Vitamin B₁ (μg) | Vitamin B₂ (μg) |
| 30 – 35   | 102| 2,742.2 ± 411.4  | 10.7 ± 3.9     | 183.5 ± 60.4    | 160.6 ± 53.8    |
| 35 – 40   | 85 | 3,272.5 ± 407.2** | 18.7 ± 6.8*** | 247.7 ± 66.2**  | 209.3 ± 58.5**  |
| 40 – 43   | 37 | 4,180.6 ± 360.1***| 22.5 ± 8.4**** | 305.6 ± 80.4****| 263.2 ± 87.8****|
| Total     | 224| 3,181.4 ± 781.1  | 15.7 ± 7.8     | 228.0 ± 81.9    | 196.0 ± 78.3    |

Results are presented as means ± SD for continuous variables; N = number of workers.

Table 3. Excretions of minerals in sweat during an eight-hour work shift

| WBGT (°C) | N  | Sweat losses (ml) | Mineral losses in sweat |
|-----------|----|------------------|-------------------------|
|           |    |                  | Potassium (mg) | Sodium (mg) | Calcium (mg) | Magnesium (mg) |
| 30 – 35   | 102| 2,742.2 ± 411.4  | 439.9 ± 174.0    | 2,971.5 ± 289.8 | 82.8 ± 24.4 | 13.8 ± 2.0   |
| 35 – 40   | 85 | 3,272.5 ± 407.2**| 523.9 ± 225.8*** | 4,255.9 ± 749.6** | 113.5 ± 25.3** | 21.5 ± 2.2** |
| 40 – 43   | 37 | 4,180.6 ± 360.1***| 693.5 ± 225.9*** | 5,708.8 ± 525.0*** | 131.3 ± 18.6*** | 23.7 ± 3.2***|
| Total     | 224| 3,181.4 ± 781.1  | 513.6 ± 227.4    | 3,725 ± 845.0   | 102.4 ± 24.1   | 18.4 ± 4.2   |

Results are presented as means ± SD for continuous variables; N = number of workers.

Table 4. BP of heat-exposed steelworkers

| WBGT (°C) | n   | SBP (mm Hg) | DBP (mm Hg) |
|-----------|-----|-------------|-------------|
| 30 – 35   | 102 | 126.2 ± 14.3| 79.9 ± 9.7  |
| 35 – 40   | 85  | 129.5 ± 16.5| 80.6 ± 10.0|
| 40 – 43   | 37  | 133.1 ± 12.1| 83.6 ± 11.9|

Results are presented as means ± SD for the continuous variables; N = number of workers.

Table 5. Relationships between micronutrient losses in sweat during an eight-hour work shift and BP among heat-exposed steelworkers

| Micronutrient losses in sweat | SBP | DBP |
|------------------------------|-----|-----|
| Vitamin C                    | 0.268| 0.003| 0.216| 0.019|
| Vitamin B₁                   | −0.022| 0.599| 0.096| 0.338|
| Vitamin B₂                   | −0.053| 0.599| −0.052| 0.605|
| Potassium                    | 0.299| 0.001| 0.233| 0.012|
| Sodium                       | 0.077| 0.483| −0.032| 0.772|
| Calcium                      | 0.303| 0.005| 0.347| 0.001|
| Magnesium                    | 0.030| 0.786| 0.031| 0.776|
| Iron                         | 0.150| 0.170| 0.042| 0.701|
| Zinc                         | 0.102| 0.359| −0.071| 0.521|
| Copper                       | 0.180| 0.099| 0.075| 0.495|
| Selenium                     | 0.075| 0.592| 0.085| 0.540|

WBGT; vitamin C, potassium, and calcium losses in sweat; smoking habits; drinking habits; and physical activity level as independent variables. The analyses revealed that, potassium and calcium losses in sweat adversely affected SBP and DBP. BMI was positively correlated with SBP, and alcohol intake was positively correlated with DBP (Table 6).

An analysis of covariance revealed that SBP was significantly higher in workers with potassium losses of ≥ 900 mg than in workers with potassium losses of < 300 and 300 – 600 mg (all P < 0.05). DBP was significantly higher in workers with potassium losses of 600 – 900 mg and ≥ 900 mg than in workers with potassium losses of < 300 mg (all P < 0.05). SBP was significantly higher in workers with calcium losses of 100 – 130 mg and ≥ 130 mg than in workers with calcium losses of < 70 mg and 70 – 100 mg (all P < 0.05). DBP was significantly higher in workers with calcium losses of ≥ 130 mg than in workers with calcium losses of < 70 mg and 70 – 100 mg (all P < 0.01). SBP was
higher with vitamin C, potassium, or calcium losses of > 12 mg, > 900 mg, or > 100 mg, respectively. DBP was higher with potassium or calcium losses in sweat of > 600 mg and > 130 mg, respectively (Table 7).

Discussion

High BP is a major public health concern and it is an important risk factor for cardiovascular disease\(^1,2\). Many studies have revealed that the prevalence of high BP among heat-exposed workers is significantly higher than among workers with exposure to normal temperatures\(^3,49\). In our study, the average BP among heat-exposed steelworkers was 128.5/80.8 mm Hg and the prevalence of hypertension was 29.5%, which is slightly higher than that reported by Rui-Fang Li\(^{49}\). BP increased with increasing levels of heat stress, which was in accordance with results reported by Hong-Yan Yang\(^{50}\). Control and prevention strategies for elevated BP are needed in order to improve workers’ health.

Heat-exposed steelworkers lose large amounts of water-soluble vitamins and minerals through sweat. In our study, the average losses of vitamin C, vitamin B\(_1\), vitamin B\(_2\), potassium, and calcium in sweat were 16.3 mg, 240 μg, 201 μg, 513.6 mg, 102.4 mg, respectively, which were higher than previous reports; the average losses of sodium, magnesium, iron, zinc, copper, and selenium in sweat were 3,725 mg, 18.4 mg, 925.1 μg, 883.6 μg, 91.6 μg, and 19.1 μg, respectively, which were similar to previous reports\(^{51}\). Further, we did not find accurate reference ranges or standards of vitamin and mineral concentrations in sweat. Clarkson et al. reported that concentrations of vitamins C, B\(_1\) and B\(_2\) lost in sweat were 0 – 50 μg, 0 – 15 μg, 0.5 – 12 μg respectively, per 100 ml\(^2\). Consolazio et al. reported that concentrations of potassium, sodium, magnesium, and iron lost in sweat were 25 – 28 mg, 113 – 420 mg, 0.61 – 0.64 mg, 25 – 39 μg respectively, per 100 ml\(^3\). Other studies reported that concentrations of calcium\(^54\), zinc\(^35\), and copper\(^56\) lost in sweat were 54 – 501 mg, 0.56 – 0.90 mg, 30 – 1,440 μg, respectively, per 1 L. Consolazio et al. reported an average loss of 340 μg of selenium in sweat over an eight-hour period in men exposed to a temperature of 37.8°C, which was higher than our study\(^57\). The differences may be due to the variations in instruments or measuring methods and work environments.

Many studies have reported that serum vitamin C, potassium, and magnesium levels are negatively correlated with BP\(^17-19\). Micronutrient deficiencies in long-term heat-exposed steelworkers are likely due to the large amounts of micronutrients that are lost with sweating, as well as decreased micronutrient consumption associated with a reduced appetite. Most analyses of thermoregulationphasize that eating is the major contributing factor for maintenance of body heat\(^59\). However, food intake should decrease and, therefore, nutrient intake will be restricted at high temperatures, when heat loss is difficult, so that the body does not acquire more heat than it can. Prolonged strenuous exercise and heat-exposed work can result in marked changes in chromium, copper, iron, magnesium, zinc and ascorbic acid metabolism\(^59,60\). Possibly, the transient loss of micronutrients results in hypertension without changes in blood levels of the micronutrients because of hemocoagulation. Our findings are based on long-term occupational exposure to

---

**Table 6. Effects of vitamin C, potassium, and calcium losses in sweat during an eight-hour work shift on BP**

| Factors                        | B    | SE  | β   | t    | P    |
|-------------------------------|------|-----|-----|------|------|
| SBP                           |      |     |     |      |      |
| Constant                      | 56.571 | 8.996 | 6.288 | <0.001 |      |
| Age                           | 0.392  | 0.212 | 0.154 | 1.849 | 0.066 |
| BMI                           | 1.300  | 0.262 | 0.330 | 4.971 | <0.001 |
| Vitamin C loss in sweat       | 0.184  | 0.179 | 0.088 | 1.288 | 0.305 |
| Potassium loss in sweat       | 0.015  | 0.005 | 0.219 | 3.264 | 0.001 |
| Calcium loss in sweat         | 0.141  | 0.045 | 0.282 | 3.119 | 0.002 |
| DBP                           |      |     |     |      |      |
| Constant                      | 33.883 | 6.161 | 5.500 | <0.001 |      |
| BMI                           | 0.549  | 0.179 | 0.207 | 3.067 | 0.003 |
| Age                           | 0.435  | 0.145 | 0.253 | 2.999 | 0.003 |
| Alcohol intake                | 3.223  | 1.348 | 0.151 | 2.390 | 0.018 |
| Potassium loss in sweat       | 0.007  | 0.003 | 0.144 | 2.114 | 0.026 |
| Calcium loss in sweat         | 0.094  | 0.022 | 0.318 | 5.054 | <0.001 |

R\(^2\)=0.402 (Model SBP); R\(^2\)=0.415 (Model DBP).

B indicates the unstandardized coefficients and β indicates the standardized coefficients.

**Table 7. Analysis of covariance of the effects of vitamin C, potassium, and calcium losses in sweat on BP**

| Micronutrient losses in sweat | N | SBP (mm Hg) (M±SE) | DBP (mm Hg) (M±SE) |
|-------------------------------|---|--------------------|--------------------|
| Potassium (mg)                |  |                    |                    |
| <300                          | 61 | 126.82±1.62        | 79.20±1.19        |
| 300–600                       | 100| 126.90±1.25        | 80.14±0.93        |
| 600–900                       | 40 | 130.88±1.99        | 81.62±1.49**      |
| ≥900                          | 23 | 136.28±2.65***     | 86.25±1.96**      |
| Calcium (mg)                  |  |                    |                    |
| <70                           | 33 | 123.43±2.51        | 77.93±1.71        |
| 70–100                        | 83 | 126.26±1.61        | 79.31±1.09        |
| 100–130                       | 64 | 131.65±1.79***     | 81.33±1.23        |
| ≥130                          | 44 | 132.23±2.24***     | 84.99±1.52***     |

M±SE=Standard Error; N=number of workers.

\(^*\)P<0.05, \(^**\)P<0.01; \(^a\) compared to the first group, \(^b\) compared to the second group.
high temperatures.

A linear stepwise regression analysis revealed that is adversely affected by potassium, and calcium losses in sweat, BMI, age, and alcohol intake. Correction of micronutrient deficiencies with targeted nutrition supplementation according to excretion conditions of micronutrients in sweat may be indicated for BP control. Further, it is necessary to control weight and reduce alcohol consumption to maintain healthy BP.

An analysis of covariance revealed that SBP increased when potassium, or calcium losses in sweat were > 900 mg, or > 100 mg, respectively. Similarly, DBP increased when potassium or calcium losses in sweat were > 600 mg or > 130 mg, respectively. Therefore, to control BP, heat-exposed workers may consider increasing potassium intake at least 900 mg of potassium and 130 mg of calcium intake to compensate for the losses of potassium and calcium in sweat. There are several possible mechanisms for the effects of potassium and calcium on BP. Potassium can lead to vasodilatation\(^{(29)}\) and decrease the need for antihypertensive medication\(^{(29)}\). Moreover, potassium lowers BP by regulating the dynamic balance between sodium and potassium, especially for salt-sensitive patients with hypertension\(^{(29, 30)}\). In our study, we found that most workers (55.8%) had a high dietary salt intake and the mean sodium loss in sweat among heat-exposed steelworkers was 3,725 mg (equivalent to 9.5 g salt), which indicates that a high dietary salt intake is necessary. Calcium may regulate hormones, electrolyte interactions, and the sympathetic nervous system to modify BP\(^{(61)}\). Therefore, special attention should be given to the effects of potassium, and calcium losses in sweat on BP among heat-exposed steelworkers. More research is necessary to confirm our findings.

Conclusions

In conclusion, the losses of potassium, and calcium in sweat among heat-exposed steelworkers during an eight-hour work shift adversely affected BP. To control BP, workshops with high temperature environments should try to lower environmental temperatures to reduce potassium, and calcium losses in sweat. Heat-exposed steelworkers may also need to increase their dietary intakes of vitamin C, potassium, and calcium.

Acknowledgements

This work was supported by the Research Fund from Hebei Province Science and Technology Support Program (NO.11276906D). The authors thank the workers from Tangshan Iron and Steel Group Corporation who participated in the studies for their cooperation. We are also grateful for the guidance of Professor Yong-Mei Tang and the assistance of Chang Shu, Meng Yang, Xin-Hua Chen, and Rui-Xue Kang in the field survey.

References

1) Lloyd-Sherlock P, Beard J, Minicuci N, Ebrahim S, Chatterji S (2014) Hypertension among older adults in low- and middle-income countries: prevalence, awareness and control. Int J Epidemiol 43, 116 – 28. [Medline] [CrossRef]
2) Commodore-Mensah Y, Samuel LJ, Dennison-Himmelfarb CR, Agyemang C (2014) Hypertension and overweight/obesity in Ghanaians and Nigerians living in West Africa and industrialized countries: a systematic review. J Hypertens 32, 464 – 72. [Medline] [CrossRef]
3) Wang HY, Wei H, Li CF (2010) Analysis on influencing factors of blood pressure of workers with high temperatures exposure in iron and steel enterprises. Occup Health (Lond) 26, 2171 – 3.
4) Inter Encyclopedia national Labor Organization (2011) Effect of Heat Stress and Work in the Heat. In: Occupational Health and Safety, Geneva.
5) Bates GP, Miller VS (2008) Sweat rate and sodium loss during work in the heat. J Occup Med Toxicol 3, 4. [Medline] [CrossRef]
6) Chinevere TD, Kenefick RW, Cheuvront SN, Lukaski HC, Sawka MN (2008) Effect of heat acclimation on sweat minerals. Med Sci Sports Exerc 40, 886 – 91. [Medline] [CrossRef]
7) Bergeron MF (2003) Heat cramps: fluid and electrolyte challenges during tennis in the heat. J Sci Med Sport 6, 19 – 27. [Medline] [CrossRef]
8) Sawka MN, Montain SJ (2000) Fluid and electrolyte supplementation for exercise heat stress. Am J Clin Nutr 72 Suppl, 564S – 72S. [Medline]
9) Liu YG, Zhu QH, Ni X (1982) A preliminary report about vitamin B1, B2, C requirements among workers at high temperature. Ying Yang Xue Bao 4, 71 – 4.
10) Chateau-Degat ML, Ferland A, Déry S, Dewailly E (2012) Dietary sodium intake deleteriously affects blood pressure in a normotensive population. Eur J Clin Nutr 66, 533 – 5. [Medline] [CrossRef]
11) Geleijnse JM, Kok FJ, Grobbee DE (2003) Blood pressure response to changes in sodium and potassium intake: a metaregression analysis of randomised trials. J Hum Hypertens 17, 471 – 80. [Medline] [CrossRef]
12) Juraschek SP, Guallar E, Appel LJ, Miller ER, 3rd (2012) Effects of vitamin C supplementation on blood pressure: a meta-analysis of randomized controlled trials. Am J Clin Nutr 95, 1079 – 88. [Medline] [CrossRef]
13) He FJ, MacGregor GA (2001) Fortnightly review: Benefi-
cial effects of potassium. BMJ 323, 497–501.[Medline] [CrossRef]

14) Demigné C, Sabbah H, Rémésy C, Meneton P (2004) Protective effects of high dietary potassium: nutritional and metabolic aspects. J Nutr 134, 2903–6. [Medline]

15) Sacks FM, Willett WC, Smith A, Brown LE, Rosner B, Moore TJ (1998) Effect on blood pressure of potassium, calcium, and magnesium in women with low habitual intake. Hypertension 31, 131–8. [Medline] [CrossRef]

16) Bucher HC, Cook RJ, Guyatt GH, Lang JD, Cook DJ, Hatala R, Hunt DL (1996) Effects of dietary calcium supplementation on blood pressure. A meta-analysis of randomized controlled trials. JAMA 275, 1016–22. [Medline] [CrossRef]

17) Ness AR, Khaw KT, Bingham S, Day NE (1996) Vitamin C status and blood pressure. J Hypertens 14, 503–8. [Medline] [CrossRef]

18) Chen J, He J, Hamm L, Batuman V, Whelton PK (2002) Serum antioxidant vitamins and blood pressure in the United States population. Hypertension 40, 810–6. [Medline] [CrossRef]

19) Haddy FJ, Vanhoutte PM, Feletou M (2006) Role of potassium in regulating blood flow and blood pressure. Am J Physiol Regul Integr Comp Physiol 290, R546–52. [Medline] [CrossRef]

20) Sontia B, Touyz RM (2007) Role of magnesium in hypertension. Arch Biochem Biophys 458, 33–9. [Medline] [CrossRef]

21) Rai K N, Kumari NS, Gowda Km D, Kr S (2013) The Evaluation of Micronutrients and Oxidative Stress and their Relationship with the Lipid Profile in Healthy adults. J Clin Diagn Res 7, 1314–8. [Medline]

22) Tukvdzse S, Kverenchkhiladze R (2011) Nutrition for children of puberty age in boarding houses in Tbilisi. Georgian Med News 190, 61–5. [Medline]

23) Mortensen A, Lykkesfeldt J (2014) Does vitamin C enhance nitric oxide bioavailability in a tetrahydrobiopterin-dependent manner? In vitro, in vivo and clinical studies. Nitric oxide : biology and chemistry / official journal of the Nitric Oxide Society 36, 51-7. [CrossRef]

24) Jackson TS, Xu A, Vita JA, Keamey JF Jr (1998) Ascorbate prevents the interaction of superoxide and nitric oxide only at very high physiological concentrations. Circ Res 83, 916–22. [Medline] [CrossRef]

25) Block G, Jensen CD, Norkus EP, Hudes M, Crawford PB (2008) Vitamin C in plasma is inversely related to blood pressure and change in blood pressure during the previous year in young Black and White women. Nutr J 7, 35. [Medline] [CrossRef]

26) Yokoyama H, Kuroiwa H, Yano R, Araki T (2008) Targeting reactive oxygen species, reactive nitrogen species and inflammation in MPTP neurotoxicity and Parkinson’s disease. Neurological sciences : official journal of the Italian Neurological Society and of the Italian Society of Clinical Neurophysiology 29, 293-301. [CrossRef]

27) Bautista LE (2003) Inflammation, endothelial dysfunction, and the risk of high blood pressure: epidemiologic and biological evidence. J Hum Hypertens 17, 223–30. [Medline] [CrossRef]

28) Block G, Jensen CD, Morrow JD, Holland N, Norkus EP, Milne GL, Hudes M, Dalvi TB, Crawford PB, Fung EB, Schumacher L, Harmatz P (2008) The effect of vitamins C and E on biomarkers of oxidative stress depends on baseline level. Free Radic Biol Med 45, 377–84. [Medline] [CrossRef]

29) Coruzzi P, Brambilla L, Brambilla V, Gualerzi M, Rossi M, Parati G, Di Rienzo M, Tadonio J, Novarini A (2001) Potassium depletion and salt sensitivity in essential hypertension. J Clin Endocrinol Metab 86, 2857–62. [Medline] [CrossRef]

30) Zhao Q, Gu D, Chen J, Li J, Cao J, Lu F, Guo D, Wang R, Shen J, Chen J, Chen CS, Mills KT, Schwander K, Rao DC, He J (2014) Blood pressure responses to dietary sodium and potassium interventions and the cold pressor test: the Gen-Salt replication study in rural North China. Am J Hypertens 27, 72–80. [Medline] [CrossRef]

31) Vasdev S, Ford CA, Parai S, Longerich L, Gadag V (2001) Dietary vitamin C supplementation lowers blood pressure in spontaneously hypertensive rats. Mol Cell Biochem 218, 97–103. [Medline] [CrossRef]

32) Horigan G, McNulty H, Ward M, Strain JJ, Purvis J, Scott JM (2010) Riboflavin lowers blood pressure in cardiovascular disease patients homozygous for the 677C→T polymorphism in MTHFR. J Hypertens 28, 478–86. [Medline] [CrossRef]

33) Alaci-Shahmiri F, Soares MJ, Zhao Y, Sherriff J (2015) The impact of thiamine supplementation on blood pressure, serum lipids and C-reactive protein in individuals with hyperglycemia: a randomised, double-blind cross-over trial. Diabetes Metab Syndr 9, 213–7. [Medline] [CrossRef]

34) Stranges S, Guallar E (2008) Dietary iron and blood pressure. BMJ 337, a547. [Medline] [CrossRef]

35) Carpenter WE, Lam D, Toney GM, Weintraub NL, Qin Z (2013) Zinc, copper, and blood pressure: Human population studies. Med Sci Monit 19, 1–8. [Medline] [CrossRef]

36) Nawrot TS, Staessen JA, Roels HA, Den Hond E, Thijs L, Fagard RH, Dominiczak AF, Struijker-Boudier HA (2007) Blood pressure and blood selenium: a cross-sectional and longitudinal population study. Eur Heart J 28, 628–33. [Medline] [CrossRef]

37) Wu M, Zhao JK, Zhang ZF, Han RQ, Yang J, Zhou JY, Wang XS, Zhang XF, Liu AM, van’t Veer P, Kok FJ, Kampman E (2011) Smoking and alcohol drinking increased the risk of esophageal cancer among Chinese men but not women in a high-risk population. Cancer Causes Control 22, 649–57. [Medline] [CrossRef]

38) Batcagan-Abueg AP, Lee JJ, Chan P, Rebello SA, Ammar MS (2013) Salt intakes and salt reduction initiatives in Southeast Asia: a review. Asia Pac J Clin Nutr 22, 490–504. [Medline]

39) Brown JJ, Tzoulaki I, Candeias V, Elliott P (2009) Salt
intakes around the world: implications for public health. Int J Epidemiol 38, 791 – 813. [Medline] [CrossRef]
40) Frances ET, Amy FS (2008) Dietary Assessment Methodology. In: Nutrition in the prevention and treatment of disease. Sed Ed., 1-14 Elsevier, London.
41) Iwaoka H, Yoshiike N, Date C, Shimada T, Tanaka H (2001) A validation study on a method to estimate nutrient intake by family members through a household-based food-weighing survey. J Nutr Sci Vitaminol (Tokyo) 47, 222 – 7. [Medline] [CrossRef]
42) Brune M, Magnusson B, Persson H, Hallberg L (1986) Iron losses in sweat. Am J Clin Nutr 43, 438 – 43. [Medline]
43) Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS; American College of Sports Medicine (2007) American College of Sports Medicine position stand. Exercise and fluid replacement. Med Sci Sports Exerc 39, 377 – 90. [Medline]
44) Rogers G, Goodman C, Rosen C (1997) Water budget during ultra-endurance exercise. Med Sci Sports Exerc 29, 1477 – 81. [Medline] [CrossRef]
45) Sargent F, Robinson P, Johnson RE (1944) Water-soluble vitamins in sweat. J Biol Chem 153, 285 – 94.
46) Lin CH, Guo LW, Lai JQ (1985) Vitamin B1, B2, C urine test among workers at high temperature. Occup Med (Chic Ill) 12, 6 – 7.
47) Zhang XD, Wang H, Huang PL, Yan Z, Zhang SH, Liu YH (2010) Determination of serum 7 trace elements in the crowd with dyslipidemia by ICP-AES. Chinese Journal of Health Laboratory Technology 20, 2294 – 5.
48) Kappus RM, Curry CD, McAnulty S, Welsh J, Morris D, Nieman DC, et al. (2011) The effects of a multiflavonoid supplement on vascular and hemodynamic parameters following acute exercise. Oxidative medicine and cellular longevity 2011, 210798.
49) Li RF, Sun JY, Zhang P, Zheng JP (2009) Influencing factors of hypertension in steel workers exposed to heat stress. Chin J Publ Health 25, 818 – 20.
50) Yang HY, Ji WJ, Zeng S, Hu HY, Zhou X, Li YM (2008) Survey of hypertension in a heat-exposed population. Acta Academiae Medicinae CPAPF 17, 609 – 10.
51) Li YJ, Zu GD, Yang J, Jia LH (1998) Study of vitamin B1,B2,C and minerals among workers at high temperature. China Pub Health 14, 468 – 70.
52) Clarkson PM. The Effect of Exercise and Heat on Vitamin Requirements (1993) Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations. Washington, DC: The National Academies Press
53) Consolazio CF, Matoush LO, Nelson RA, Harding RS, Canham JE (1963) Excretion of sodium, potassium, magnesium and iron in human sweat and the relation of each to balance and requirements. J Nutr 79, 407 – 15. [Medline]
54) Consolazio CF, Matoush LO, Nelson RA, Hackler LR, Preston EE (1962) Relationship between calcium in sweat, calcium balance, and calcium requirements. J Nutr 78, 78 – 88. [Medline]
55) DeRuisseau KC, Cheuvront SN, Haymes EM, Sharp RG (2002) Sweat iron and zinc losses during prolonged exercise. Int J Sport Nutr Exerc Metab 12, 428 – 37. [Medline]
56) Hohnadel DC, Sunderman FW Jr, Nechay MW, McNeeley MD (1973) Atomic absorption spectrometry of nickel, copper, zinc, and lead in sweat collected from healthy subjects during sauna bathing. Clin Chem 19, 1288 – 92. [Medline]
57) Consolazio CF, Nelson RA, Matoush LO, Hughes RC, Uron P (1964) The Trace Mineral Losses in Sweat. Rep No. 284. Report US Army Medical Research and Nutrition Laboratory, 1 – 14.
58) Allison AY (1993) Food Intake, Appetite, and Work in Hot Environments. Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations. The National Academies Press, 298 – 303.
59) Priscilla MC (1993) The Effect of Exercise and Heat on Vitamin Requirements. Nutritional Needs in Hot Environments: Applications for Military Personnel in Field Operations. The National Academies Press, 137 – 171.
60) Litchi EL, Turner M, Deweese MS, Henzel JH (1970) Zinc concentration in venous plasma before and after exercise in dogs. Mo Med 67, 303 – 4. [Medline]
61) Augstein P, Heinke P, Salzsieder E, Grimm R, Giebel J, Salzsieder C, et al (2008) Dominance of cytokine-over FasL-induced impairment of the mitochondrial transmembrane potential (Deltapsim) in the pancreatic beta-cell line NIT-1. Diabetes & vascular disease research 5, 198 – 204.