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THE ELECTROLYTE BALANCE AT AN ONE-HOUR EXERCISE

In a previous paper it was reported that the changes in the sodium, potassium and calcium content in the blood serum at muscular exercise depend on the character of the exercise and that the changes in their concentration do not always correspond to the changes in their total amount (Imelik, 1983). To get a clue to the causes of the changes in the present investigation, the concentration and the total amount of the above-mentioned electrolytes were determined in various body fluids simultaneously.

Methods

The investigations were carried out on twelve male students from 19 to 23 years of age at one-hour cross-country run of about 10 kms. Two hours before the experiment the urinary bladder was depleted, after which the subjects did not eat or drink. Before the experiment the consumption of food and water was free. The start, half-time and finish of the run took place in the laboratory. In order to determine the electrolytes value at rest, 10 ml blood was taken from the cubital vein approximately 15 min before the exercise. Through the same needle 5 ml of 1% Evans blue (T-1824) were injected for determining the plasma volume. Before the exercise, at the 30th and 60th min of exercise and 30 min after it 10 ml of blood were taken from the cubital vein of the other arm, the excreted urine and 5 ml of saliva were collected. The sweat secreted during the exercise was collected by means of ash-free discs of filter paper fixed hermetically by polyethylene membrane in the lumbal region of the spine. The filter paper discs, soaked with sweat and placed in a closed vessel, were weighed by an analytic balance and after calculating the amount of the collected sweat, the latter was washed out with aqua bidistillata to the dilution of 1:5. The total amount of the secreted sweat was calculated on the basis of the weight loss of nude subjects.

All samples were centrifuged, separated from the sediment, preserved in air-tightly closed test-tubes at +4 °C and analysed during the next day.

The concentration of electrolytes was determined by flame emission spectrophotometry (Carl Zeiss, Jena). To get the reading in the optimal region of sensitiveness of the apparatus the samples were diluted with aqua bidistillata as follows: for determining sodium — blood serum 1:100, urine 1:20, saliva and sweat 1:10, for determining potassium — blood serum 1:20, urine 1:400, saliva 1:100 and sweat 1:20; for determining calcium — blood serum, urine and saliva 1:20, sweat 1:5. The total amount of the electrolytes was calculated by multiplying their concentration (mg in 100 ml) with the plasma volume in litres ×10.

Results

The mean data of the changes in the concentration and total amount of the electrolytes are presented in the Table.

During the exercise the blood serum electrolytes concentration did not change significantly. The blood plasma volume diminished in most of the subjects already at the 10th min of exercise, and so did the total amount of the electrolytes on the basis of the mark test. During the experiment the total amounts of sodium, potassium and calcium were correlated in the blood serum: Na tot and K tot before the exercise $r=0.91$, at the 30th min of exercise $r=0.79$, at the 60th min of exercise $r=0.66$ and 30 min after the exercise $r=0.88$; Na tot and Ca tot correspondingly 0.83, 0.85, 0.81, 0.84; and K tot and Ca tot 0.89, 0.85, 0.71, 0.86.

The concentration of sodium and potassium in urine did not change during the exercise. After the exercise, on the basis of mark test, a decrease in the sodium concentration could be stated. The concentration of calcium decreased already during the first half of the exercise. The amount of the excreted urine increased in the first half and diminished in the second half of the exercise. Correspondingly the total amount of

Electrolyte content in the body fluids and the volume of blood plasma, urine and

Electrolyte content	before exercise
Concentration in the blood serum, mmol/l	
sodium	151.8±4.3
potassium	4.63±0.14
calcium	3.19±0.13
Total amount in the blood serum, mg	
sodium	9102±489
potassium	482±30
calcium	168±12
Blood plasma volume, ml	2545±109
Concentration in urine, mmol/l	
sodium	178.1±8.7
potassium	37.3±4.6
calcium	2.98±0.41
Total amount in urine, mg	
sodium	147±41
potassium	55±22
calcium	4.0±1.2
Urine volume, ml	38.2±10.8
Concentration in sweat, mmol/l	
sodium	–
potassium	–
calcium	–
Total amount in sweat, mg	
sodium	–
potassium	–
calcium	–
Sweat volume, ml	–
Concentration in saliva, mmol/l	
sodium	11.7–1.6
potassium	16.0–1.1
calcium	1.05–0.04

the excreted electrolytes also increased in the first half and decreased in the second half of the exercise, but still remained higher than during the rest.

The concentration of electrolytes in the sweat excreted during the exercise was considerably lower than in urine, but because of the comparatively great amount of the secreted sweat — on the average more than a kilogram — the total amount of sodium and potassium lost by sweat during the exercise, was twice as great, and that of calcium five times as great as that lost by kidneys during the exercise. The concentrations of potassium in sweat and urine were correlated, $r=0.82$, and also its total amount excreted during the exercise by sweat and urine $r=0.90$. The decrease of the blood serum electrolytes content was considerably lower than the electrolyte loss by sweat and urine taken together. The amount of secreted sweat was correlated with the blood volume ($r=0.65$) and with the volume of excreted urine ($r=0.66$).

The concentration of sodium in saliva increased during the exercise, while the concentration of potassium remained unchanged, but that of calcium remained decreased even half an hour after the exercise. The changes in the electrolytes content in saliva, blood plasma and urine were not correlated.

sweat at an one-hour exercise

30th min of exercise	P, %	60th min of exercise	P, %	30 min after exercise	P, %
152.2±3.4	—	155.2±5.0	—	154.8±4.2	—
4.61±0.15	—	4.66±0.15	—	4.53±0.11	—
3.23±0.10	—	3.33±0.14	—	3.17±0.12	—
8515±599	—	8510±576	>97.5	8344±558	>97.5
436±28	>97.5	427±19	>97.5	411±25	>99.5
155±10	—	155±11	>97.5	144±10	>99.5
2304±147	>99.5	2297±96	>97.5	2347±72	>97.5
166.7±9.8	—	156.7±9.6	—	166.8±8.2	>97.5
48.9±6.9	—	45.3±5.4	—	45.5±6.9	—
2.42±0.39	>97.5	1.39±0.25	>99.5	2.64±1.18	>97.5
215±50	>97.5	98±17	—	110±23	—
101±28	>97.5	49±8	—	47±10	—
4.8±0.9	>97.5	2.5±0.6	—	3.1±1.1	—
54.3±11.3	>97.5	27.3±4.0	—	27.8±5.5	—
—	—	26.2±1.9	—	—	—
—	—	6.9±0.7	—	—	—
—	—	0.8±0.2	—	—	—
—	—	664±57	—	—	—
—	—	313±58	—	—	—
—	—	35±7	—	—	—
—	—	1130±1.10	—	—	—
19.5−2.8	>99.5	18.1±2.7	>99.5	12.4±1.7	—
15.7−2.8	—	16.1±1.2	—	15.1±1.8	—
0.91−0.05	>97.5	0.96±0.05	>97.5	0.97±0.07	>99.5

Discussion

The relative constancy of the electrolytes concentration in the blood serum during various muscular exercise, stated by many authors (Refsum et al., 1973; Ефименко et al., 1981; Imelik, 1983; et al) is understandable because the regulating systems of electrolyte metabolism are primarily directed towards maintenance of their concentration in the blood serum. Our results confirm that these systems are able to guarantee the constancy at a rather strenuous prolongated effort. The fluctuations observed in the individual patterns of blood serum electrolytes concentration during the observation, are characteristic of every self-regulating system. The constancy of blood serum electrolytes, however, is not a criterion of their constancy in the tissue cells because the equilibrium between the intravasal and intracellular electrolytes concentration is maintained only in the state of homeostasis that does not exist at muscular exercise, and is particularly influenced by the changes in the blood serum pH (Böhmer, 1981). The decrease in the total amount of the blood serum electrolytes can be explained by the decrease in the blood plasma volume. That is also indicated by the unchanged ratio of the observed electrolytes during the exercise. The decrease in the plasma volume at the initial stage of the exercise is chiefly caused by the filtration of fluid from the capillaries into the interstitial space (Jacobson, Kjellmer, 1964). During a prolongated exercise it is followed by an influx of the fluid back into the vessels, and the plasma volume can be restored in spite of the loss of fluid by kidneys and sweat glands (Åstrand, Saltin, 1964; Imelik, 1978; et al.). The blood volume essential for the circulation is partly restored by the production of oxidation water (Olsson, Saltin, 1969), and partly by dehydration of the tissues. By this flow of the fluid there arises a difference between the concentration of potassium in the interstitial fluid and in the blood serum, the cause of which is not yet explained (Hirsche, 1980). It might be supposed that this difference is essential for preventing an excessive loss of potassium, while at an increased influx at muscular exercise its required concentration in the blood serum is maintained by excretion.

The amount of the electrolytes excreted by urine increased on account of the increased volume of urine in the first half of the exercise. The decrease of the urine volume in the second half-time of the exercise was presumably due to the considerable loss of water via sweat glands. In spite of the diminution of the volume no significant increase in the concentration of excreted urine took place. That also can be explained by an increased elimination of electrolytes via sweat glands. The different behaviour of calcium (its concentration in urine diminished during the exercise) as compared with sodium and potassium is explained by its different and extremely complicated balance regulatory system (Thurner, Amado, 1977).

The fact that the increased sweat secretion essential for thermoregulation is accompanied by a considerable increase in the sweat electrolyte concentration shows that the sweat glands acquire an important role as organs of excretion during the exercise. The loss of sodium, potassium and particularly calcium by sweat during the exercise exceeded the excretion by kidneys many times over. Contrary to the finding that the main increase takes place in the sweat sodium concentration at muscular exercise and the ratio Na/K rises almost to 20 (Ikai et al, 1969), our investigations showed remarkable increase also in the potassium concentration, the ratio Na/K being on the average approximately 4. The concentration of potassium in sweat exceeded even its concentration in the blood serum. The correlation between the potassium amount excreted by sweat glands and by kidneys indicates an identical regulation system for potassium excretion by both glands. As regards calcium, its excretion by sweat glands and kidneys changes reciprocally at exercise. The correlation between the blood volume and the volume of sweat and urine excreted during the exercise shows that the loss of water, and with it also the loss of electrolytes, depends on the plasma volume.

During the one-hour cross-country run about 1 g of sodium, 0.5 g of potassium and 0.03 g of calcium on the average were lost by sweat and urine. Thus the loss of sodium corresponded to 1/10, that of calcium to 1/4 of its total amount in the blood serum, but the loss of potassium was equal to its total amount in the blood serum. Compared with the electrolyte content in the whole body, the loss cannot be regarded as great. In addition, a certain resorption of electrolytes from the alimentary canal must be taken into consideration. It is true that at muscular exercise the loss of electrolytes does not increase equally from all tissues. In case of potassium, the increased efflux takes place only from the active muscles (Costill et al., 1981) and is individually various and lower in well-trained persons (Пайкин, 1981). It is probably so with other electrolytes as well. However, compared with the electrolyte content in the large muscle mass used at the run, the lost quantity of electrolytes is still negligible. So, in accordance with many investigators (Coastill et al, 1981; Hirsche, 1980; Kirsch et al., 1982), it is not likely that the loss of electrolytes could be the cause of fatigue and that the administration of electrolytes could increase the working capacity at muscular exercises of that nature.

Attention has been turned to the possibility that the easily available secretion saliva might contain information about the changes in the composition of body fluids. It has been found that the electrolyte content of saliva changes at muscular exercise and that the increase in potassium concentration exceedes the increase in sodium concentration (Танеева, 1980), and that its concentration at rest and changes at exercise can be even used for the estimation of fitness (Plauchitiu et al., 1976). Although our data about the electrolyte concentration value in saliva at rest coincided with the data presented in literature (Танеева, 1980; Роосалу, 1981), in well-trained subjects an increase only in the sodium concentration, but not in the concentration of potassium could be stated during the exercise. Our data demonstrate the fact that the changes in saliva electrolyte concentration at muscular exercise do not correlate with the changes in the electrolytes concentration or in their total amount in the blood serum, urine or sweat, and therefore they cannot be used as indices for changes that take place in other body fluids. While the changes in the saliva composition of various glands are different at muscular exercise, may be the saliva collected from one gland only, could contain more information.

Conclusions

1. In the blood serum electrolytes concentration no significant changes were stated at an one-hour cross-country run.
2. Due to the diminution of the blood plasma volume, the total amount of serum electrolytes were decreased during the run.
3. The amount of electrolytes excreted during the run exceeded their decrease in the blood serum, which points to a decrease of the electrolyte content in the active muscle tissue.
4. The renal excretion of electrolytes increased during the run due to the increased urine production in the first half of the run.
5. The extra-renal electrolyte loss exceeded the renal electrolyte loss during the run.

6. The blood volume correlated with the volume of sweat and urine excreted during the exercise.

7. The concentration of potassium-excreted by kidneys and sweat glands correlated, and so did the total amount.

8. The changes in the saliva electrolytes concentration were not in correlation with the changes in the electrolytes concentration or with the changes in the total amount in the blood serum, urine and sweat.

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ELEKTROLÜÜTIDE BILANSS TUNNIAJALISE TÖÖ PUHUL

Enne tunniajalist murdmaajooksu (ca 10 km), jooksu 30. ja 60. minutil ning 30 minutit pärast jooksu määrati 12 meesüliõpilasel leekfotomeetri abil naatriumi, kaaliumi ja kaltsiumi kontsentratsioon vereseerumis, uriinis, süljes ning jooksu ajal eritatud higis. Nimetatud kehavedelikes elektrolüütide üldhulkade väljaarvutamiseks määrati Evansisinise abil plasma maht ja mõõdeti eritatud uriini ja higi mahud. Saadud andmete alusel oli võimalik teha järgmised järeldused.
1. Vereseerumi elektrolüütide kontsentratsioon tunniajalise murdmaajooksu puhul usutavalt ei muutunud. 2. Vereseerumi elektrolüütide koguhulk oli jooksu ajal vähenenud vereplasma mahu vähenemise tõttu. 3. Jooksu ajal ületas elektrolüütide ekskretsioon nende hulga vähenemise vereseerumis, mis viitab elektrolüütide sisalduse langusele aktiivses lihaskoes. 4. Elektrolüütide renaalne ekskretsioon oli jooksu kestel suurenenud tingituna uriini hulga suurenemisest jooksu esimesel poolel. 5. Jooksu ajal ületas ekstrarenaalne elektrolüütide kadu renaalse kao. 6. Jooksu ajal eritatud higi maht ja uriini maht korreleerusid vere mahuga. 7. Neerude ja higi kaudu eritatud kaaliumi kontsentratsioonid kui ka üldhulgad korreleerusid. 8. Sülje elektrolüütide kontsentratsiooni tööaegsed muutused ei korreleerunud ei elektrolüütide kontsentratsiooni ega koguhulga muutustega vereseerumis, uriinis ega higis.

Олаф ИМЕЛИК, Рейн КОЛЬК, Калле КИЗАНД

БАЛАНС ЭЛЕКТРОЛИТОВ ПРИ ОДНОЧАСОВОЙ РАБОТЕ

При помощи пламенной фотометрии определяли содержание натрия, калия и кальция в сыворотке крови, моче, поте и слюне у 12 студентов перед началом одночасового бега (около 10 км), на 30-й и 60-й минуте и спустя 30 мин после бега. Для вычисления общего количества электролитов при помощи синьки Эванса определяли объем плазмы и количество выделенной мочи и пота.

Достоверных изменений в концентрации электролитов в сыворотке крови не наблюдалось, но их общее количество уменьшилось вместе с уменьшением объема плазмы. Выделение электролитов мочой и пóтом было больше, чем уменьшение их количества в крови, что указывает на их вытекание из активных мышц. В первой половине бега ренальная экскреция электролитов была увеличена за счет увеличения количества мочи. Во время бега выделенное пóтом количество электролитов превышало их ренальную экскрецию. Выделенное мочой количество калия имело корреляцию с количеством выделенного пота. Изменения концентрации электролитов в слюне не были связаны с изменениями их концентрации и общего количества в сыворотке крови, моче и поте.