J SPORTS MED PHYS FITNESS 2000;40:80-4

Markers of hydration status

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This paper reviews the literature, describes and discussess methods by which whole body hydration status can be determined in humans. A method of determining whether or not an individual is hypohydrated is of particular significance in an exercise situation as even moderate levels of hypohydration have a negative impact on exercise performance. Inspection of the published literature indicates that a number of methods have been used to determine hydration status. Body mass changes, urinary indices (volume, colour, protein content, specific gravity and osmolality), blood borne indices (haemoglobin concentration, haematocrit, plasma osmolality and sodium concentration, plasma testosterone, adrenaline, noradrenaline, cortisol and atrial natiuretic peptide), bioelectrical impedance analysis, and pulse rate and systolic blood pressure response to postural change are discussed. The urinary measures of colour, specific gravity and osmolality are more sensitive at indicating moderate levels of hypohydration than are blood measurements of heamatocrit and serum osmolality and sodium concentration. Currently no "gold standard" hydration status marker exists, particularly for the relatively moderate levels of hypohydration that frequently occur in an exercise situation. The choice of marker for any particular situation will be influenced by the sensitivity and accuracy with which hydration status needs to be established together with the technical and time requirements and expense involved.

Key words: Dehydration - Exercise - Body water.

Hypohydration generally has a negative effect on physical performance as well as on overall health. A reliable marker of hydration status may, therefore, be of benefit to many individuals in many situations. A body water deficit of as little as 2-3% of total body water impairs exercise performance, so any marker to be of use in this situation would have to be capable of indicating such a deficit.

Acute changes in body mass during exercise will generally be due to loss of body water in the form of sweat; respiratory water loss and substrate oxidation are relatively small. A 1 g change in mass represents a 1 ml change in water status. Over a bout of exercise, a reduction in body mass, measured nude and with skin towelled dry before and after exercise will indicate a state of hypohydration. However, food or fluid consumed during the exercise will confuse the picture.

Urinary indices, including the volume, colour, protein content, specific gravity and osmolality of the urine, have been investigated as hydration status markers. Urine colour, estimated from a colour chart has been demonstrated to provide a reasonable "in the field estimate" of hydration status in association with exercise.

Blood borne indices, including haemoglobin concentration and haematocrit, plasma osmolality and sodium concentration, plasma testosterone, adrenaline, noradrenaline, cortisol and atrial natriuretic pep-

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tide concentrations, have been investigated as hydration status markers. These blood borne indices have the disadvantage of being more invasive than many of the other measures described and in an exercise setting some respond not only to hydration stresses but to exercise stresses too.

Bioelectrical impedance analysis can give a rapid estimate of total body water, and its cellular divisions if a multifrequency device is utilised. Changes in hydration status may be detected if the procedure is carefully standardised in many ways but the precision and sensitivity of the method remain to be established.

Alterations in the response of pulse rate and systolic blood pressure to postural change, have been demonstrated in clinical settings of dehydration and rehydration. However, these measures may not be sensitive enough to be of value in an exercise situation.

A wide variety of indices have been investigated to establish their effectiveness as markers of hydration status in an exercise situation. An individuals choice of hydration status marker will be influenced by the sensitivity and accuracy with which they need to establish hydration status together with the technical and time requirements and expense involved.

Effects of a body water deficit

Following dehydration, individuals must recover from their hypohydrated state and return to a state of euhydration. In terms of sustaining life, there are certain limits below which the body water content must not fall. However, far from these limits, adverse effects of a body water deficit on exercise performance can be demonstrated. Nielsen *et al.*[1] showed that prolonged exercise, which resulted in a loss of fluid corresponding to 2.5% of body mass, resulted in a 45% fall in the capacity to perform high intensity exercise lasting about 7 min: with similar reductions in body mass induced by either sauna exposure or diuretic administration, reductions in performance undertaking the same type of exercise amounted to 35% and 18% respectively. Armstrong *et al.*[2] dehydrated subjects by about 1.5 to 2% of body mass with a diuretic drug (40 mg of furosemide) after which the subjects took part in track races over distances of 1500, 5000 and 10000 m. Relative to their performance time when euhydrated, there were increases in the time to cover the race distance of 0.13, 1.31 and 2.62 min respectively, corresponding to decreases in running velocity of 3.1, 6.7 and 6.3 %.

TABLE I.—*Daily body water input and output (9).*

Parameters	ml
Daily water loss	
Kidneys	1500
Respiratory tract	400
Gastrointestinal tract	200
Skin	500
Total	2600
Daily water intake	
Fluid	1300
Food	1000
Cellular oxidation	300
Total	2600

The plasma volume decrease associated with dehydration may be of particular importance in influencing work capacity; blood flow to the muscles must be maintained at a high level during exercise to supply oxygen and substrates, but a high blood flow to the skin is also necessary to convect heat to the body surface where it can be dissipated.[3] In a high ambient temperature, especially if the blood volume has been decreased by sweat loss during prolonged exercise or if exercise begins in a hypohydrated state, there may be difficulty in meeting the requirement for a high blood flow to both these tissues. In this situation, skin blood flow is more likely to be compromised, allowing central venous pressure and muscle blood flow to be maintained, but this reduces heat loss and can therefore cause body temperature to rise sharply.[4]

Mechanisms of dehydration

Daily regulation of body water

Total body water is normally maintained within a small window of fluctuation on a daily basis by intake of food and drink and excretion of urine.[5] Most of our water intake is related to habit rather than thirst, but after periods of deprivation, the thirst mechanism is effective at driving intake.[6-8] Hyperhydration is corrected by an increase in urine production and hypohydration by an increase in water intake via food or drink consumption initiated by thirst. There are also water losses via the respiratory tract, the gastrointestinal tract and the skin but these normally represent only a relatively small fraction of the total body water loss. The extent of these losses will vary from individual to individual, but a general example for a sedentary individual is outlined in Table I.

Body water regulation and heat stress

As outlined above, there is a daily loss of approximately 500 ml of water through the skin. However, when the body is exposed to a heat stress and behavioural and vasomotor mechanisms are insufficient to prevent a rise in temperature, the physiological responses generally include an increase in sweat production in an attempt to prevent hyperthermia; the evaporation of sweat from the skin removes with it latent heat. It is in this situation that a significant dehydration can develop: prolonged exercise, particularly when carried out in conditions of high ambient temperature and humidity, is associated with significant sweat losses, and daily water requirements of athletes living and training in the heat may reach 10-15 l d^{-1}.[10]

Body mass and hydration status

Acute changes in body mass during exercise will generally be due to loss of body water in the form of sweat; respiratory water loss and substrate oxidation are relatively small. In order to estimate the extent of hypohydration, the assumption is made that a 1 g change in mass represents a 1 ml change in water status, *i.e.* assuming that the specific gravity of sweat is 1.0.[11] Over a bout of exercise, a reduction in body mass, measured nude and with skin towelled dry before and after exercise, will indicate a state of hypohydration. However, food or fluid consumed during the exercise will confuse the picture and will have to be taken into account when measurements are made.

In the situation of unlimited access to large quantities of good quality food (as is frequently the case at athletic venues and training camps), the temptation to over-eat is high. Some athletes in this situation will restrict fluid intake to maintain a constant body mass and thus keep within weight limits set by the team management and coaching staff. Alternatively, a fall in body mass may occur because of the loss of appetite that is often observed to occur in hot climates. However, a progressive fall in body mass over a period of a few days may suggest a failure to increase fluid intake to match an increased loss when living and training in the heat.

Urinary indices of hydration status

Volume, osmolality and specific gravity

As well as acting to regulate body water levels by an increase or decrease in the amount of urine produced, the urine also acts as a vehicle for the elimination of waste products from the body. This, therefore, also has an influence on the volume of urine formed. A healthy individual on a normal diet excretes approximately 600 to 800 mosmol of solute per square metre of body surface area per day.[12] The kidneys can dilute urine to at least as low as 100 mosmol kg^{-1} and can concentrate it to approximately 1200 mosmol kg^{-1}. Therefore, the volume required to excrete the daily solute load ranges between approximately 500 ml and more than 13 l. As a result of the requirement for waste product excretion, an obligatory minimum amount of urine must always be excreted. The basal volume which must be excreted is generally in the region of 20 ml to 50 ml per hour.[13] However, in the majority of healthy individuals in most situations, the volume of urine produced and excreted is in excess of these basal levels.[14] The volume of urine produced in a healthy individual is largely determined by circulating hormone levels, and in particular by levels of vasopressin and aldosterone, whose release is regulated by the body's salt and water balance.

A hypohydrated individual, in an attempt to minimise further dehydration, will produce small volumes of urine. The solute load will, therefore, be within a small volume of urine with a high osmolality. It has recently been demonstrated that the osmolality of the first urine of the day to be excreted, collected before ingestion of food or drink, varies according to hydration status [15] such that hypohydrated individuals produce urine with a greater osmolality. Specific gravity and conductivity measures have been shown to give similar results.[16]

Monitoring the volume of urine excreted, together with observing the frequency of urination has been suggested to athletes as a useful tool for monitoring their own hydraion status. This is particularly useful around times of changes in lifestyle such as moving to warm weather venues for training camps etc. when comparisons can be made to the individuals normal pattern.

Colour

Athletes have also been advised to take note of their urine colour every day and use it as an indicator of their hydration status.[17] Urine colour can, however, be influenced by a number of factors unrelated to hydration status, including foods, medications and illness. Urine colour, estimated from a colour chart, has been demonstrated to provide a reasonable "in the field estimate" of hydration status in association with exercise [18] when compared to measures of urine osmolality and specific gravity. The use of monitoring urine colour has the attraction of giving an immediate answer with no need for sophisticated measuring devices.

Blood indices of hydration status

Haemoglobin concentration and haematocrit, serum osmolality and sodium concentration and the concentrations of blood borne protein and hormones including testosterone, adrenaline, noradrenaline, cortisol, ANP and been investigated in relation to hydration status.

Measurement of haematocrit or haemoglobin concentration is another possibility as an index of hydration status, provided that a reliable baseline is established. However, to ensure comparable results, a standardisation of posture for a short time (15-20 min) prior to blood collection is necessary to distinguish between the postural changes in blood volume, and therefore in haematological indices, which occur.[19] Also, acute exercise, such as endurance running, has been shown to cause an immediate fall in the calculated plasma volume followed by an expansion which is maintained for at least 72 hours.[20] This will cause problems in the interpretation of data from athletes training on a daily basis.

Francesconi *et al.*[21] investigated military personnel over a period of 44 days field training and reported that even when the subjects had lost more than 3% of their body mass and had a high urine specific gravity, there was no change in haematocrit or serum osmolality measurements. The authors concluded that plasma volume is defended by the body in an attempt to maintain cardiovascular stability, and therefore plasma variables are not affected by hypohydration until a certain degree of body water loss (which must be more than 3% of body mass loss) occurs. Similar findings were again reported by Armstrong *et al.*[18] who reached the same conclusion.

Hoffman *et al.*[22] reported that hypohydration to the extent of a body mass loss of up to 5.1% did not influence plasma testosterone, cortisol or adrenaline concentrations but plasma noradrenaline concentrations responded to the hydration changes. This, the authors suggest, makes plasma noradrenaline concentration a possible contender as a sensitive marker of exercise-heat stress.

Bioelectrical impedance analysis

Bioelectrical impedance analysis (BIA) can give a rapid estimate of total body water, and its cellular divisions if a multifrequency device is utilised. Changes in hydration status in an exercise situation may be detected if the procedure is carefully standardised, but the precision and sensitivity of the method remain to be established.[23] The posture of a subject when BIA measurements are made and the time for which they have been in that posture may influence the results obtained, as may food or drink consumption before making measurements. Further, the bout of exercise per se may also influence the results obtained.[24]

Pulse rate and blood pressure

Alterations in the response of pulse rate and systolic blood pressure to postural change have been demonstrated in clinical settings of dehydration and rehydration.[25] However, at present there seems to be no record of their use in an exercise situation and indeed it is probably that they may not be sensitive enough to be of value in association with exercise-induced dehydration.

Conclusions

A wide variety of indices have been investigated to establish their effectiveness as markers of hydration status in an exercise situation. The choice of marker will be influenced by the sensitivity and accuracy with which hydration status needs to be established, together with the technical and time requirements and expense involved. Further, many of the measures outlined above are influenced in the short term by exercise *per se*, and may only be successfully implemented for the identification of dehydration some time after the cessation of exercise.

It is apparent that urinary measures of colour, specific gravity and osmolality are more sensitive at indicating moderate levels of hypohydration than are blood measurements of haematocrit and serum osmolality and sodium concentration. Collection of urine has the further advantage of being a largely non-invasive, distress-free technique for all individuals whereas blood collection can prove stressful for some individuals. Further, to comply with the drug testing procedures implemented by governing bodies, the majority of athletes reaching even a moderate levels in their sport will at some time have to provide a urine sample for analysis. For many athletes this is a very familiar routine and they are very comfortable with it.

Urine osmolality rather than specific gravity should be the preferred index of urine concentration used as the measure of hydration status because unlike the specific gravity measure which is influenced by solutes such as urea, glucose and protein.[26] A urine osmolality greater than about 900 mosmol kg^{-1} could reasonably be taken as indication of a hypohydrated state.[15] However, it would be fair to say that at present there is no "gold standard" measure of hydration status and indeed debate still arises as to how a state of euhydration should be defined and determined.

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