Sensitivity and specificity of clinical signs for assessment of dehydration in endurance athletes

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ABSTRACT

Objective To investigate the diagnostic accuracy of commonly used signs of dehydration in marathon runners.
Design The diagnostic accuracy of 5 clinical signs/symptoms thought to indicate dehydration (altered skin turgor, dry oral mucous membranes, sunken eyes, an inability to spit and the sensation of thirst) was assessed by comparing the presence of these markers with the criterion standard of body weight change over a marathon footrace.
Setting 2006 Auckland Marathon
Participants 606 competitors in the full marathon
Assessment Body weight was measured before and immediately after the marathon. The 5 clinical signs/symptoms were assessed immediately after the marathon.
Main outcome measures Diagnostic accuracy of clinical signs/symptoms to detect dehydration greater than 3% of body weight.
Results 606 complete data sets were obtained. 3 clinical signs were associated with greater percentage weight loss: sunken eyes (mean percentage weight loss with symptom 2.6% (standard deviation 1.5), without 2.3% (1.5)); decreased skin turgor (with 3.0% (1.4), without 2.3% (1.5)) and the sensation of thirst (with 2.5% (1.5), without 2.3% (1.5)). The ability to spit and dry oral mucous membranes were unrelated to percentage weight loss. No signs/symptoms showed acceptably high validity for detecting a weight loss equal to or greater than 3% of body weight.
Conclusions The 5 parameters (decreased skin turgor, sensation of thirst, sunken eyes, inability to spit and dry mucous membranes) tested in this study did not precisely identify runners with total weight loss >3% at the end of a marathon.

It is generally believed that an individual's fluid status can be accurately determined by the use of clinical examination. This often includes assessment of skin turgor, the appearance of the eye sockets and the state of the oral mucous membranes.[1] Athletes may finish prolonged exercise such as 42 km marathon races either dehydrated, euhydrated or overhydrated.[2] Since these conditions require contrasting treatments,[3 4] and the treatment of a semiconscious overhydrated athlete with intravenous fluids can produce a fatal outcome,[5] it is essential that the fluid status of collapsed athletes be accurately assessed so that correct treatment can be given.[3 4 6–10]

Current "gold standards" for accurately measuring hydration status include plasma osmolality and urine specific gravity.[11–13] These techniques are not easily adopted for the care of large numbers of collapsed athletes. Body weight change provides a simpler estimate of postrace hydration status, and has become a standard method to detect hydration state in athletes.[6 7 11 12 14] However, several confounders affect body mass over an athletic event, including substrate oxidation, water of oxidation, respiratory losses, water unavailable in the bladder and water released from glycogen.[14] Up to 2% loss of body mass may be expected from these variables.[14] This may help explain the fact that plasma osmolality does not begin to rise until body weight loss exceeds 4%.[4] "True" dehydration (loss of body water from the interstitial and intracellular compartments as reflected by hypertonicity) has been argued to begin only at this point.[4] Conversely, body weight loss less than 2% (or actual body weight gain) may cause a reduction in plasma osmolality.[4] Therefore body weight loss seems to overestimate "true" dehydration by 2–4%. In this paper we have defined the boundary between overhydration and underhydration as 3% body weight loss (rather than 0%), as this is the point above which subjects will tend towards dehydration and below which they are euhydrated or even overhydrated, depending on the amount of weight gain. This is the clinically relevant boundary line, particularly when using clinical signs to determine the need for, and risk of, rehydration.

A variety of clinical symptoms and signs are used to predict each athlete's hydration status at mass participation endurance events. These include reduced skin turgor, sunken eyes, mucous membrane dryness, dryness of the axilla and the inability to spit as well as measurements such as heart rate, blood pressure and respiratory rate. To our knowledge only one previous study has attempted to establish the validity of these variables as predictors of postexercise hydration status.

Thus Sharwood *et al*[6] were able to collect hydration data and incomplete examination data in a 226 km Ironman Triathlon. They presented this as a single table and brief comment, in addition to the main focus of their research, which was the relationship of hydration levels to medical complications. They concluded that the variables examined were unable to differentiate those who experienced weight losses of up to 10%.

All of the other original studies supporting clinical signs such as altered skin turgor, dry mucous membranes and sunken eyes are based in the hospital setting and in particular paediatric[15 16] and elderly[17–19] populations. Steiner *et al*[15] showed that in children under 5 years of age altered skin turgor, capillary refill and respiration rate were the most accurate signs to detect dehydration greater than 5%. Similarly, Gorelick *et al*[16] reported that dry mucous membranes, slow capillary refill, general appearance and the absence of tears were the best predictors of a body weight loss greater than 5% but sensitivity, in particular, remained modest.

In the adult population McGee *et al*[18] also concluded that dry mucous membranes, a furrowed tongue, sunken eyes and a dry axilla were the most accurate clinical signs, though their predictive value was modest. The accuracy of clinical assessment in general was questioned by Thomas *et al*,[19] who showed that, of 102 consecutive medical admissions over the age of 65 years with a clinical diagnosis of dehydration, 32% did not have intravascular volume depletion and 83% were not dehydrated according to the current gold standards.

It is difficult, however, to interpret the applicability of these results to the very different scenario of athletes engaged in endurance running. In view of the uncertainty of the accuracy of these measures when used in clinical populations and the absence of large-scale studies in endurance athletes, we designed this study to evaluate the validity of the popularly used clinical signs of dehydration in a group of 42 km marathon runners. The clinical signs of decreased skin turgor, dry mucous membranes and sunken eyes were chosen as they have shown the most promise in the detection of dehydration in clinical populations.[15–18] In addition, these signs are less likely than other variables, such as axillary dryness, heart rate, blood pressure and respiratory rate, to be influenced by the confounding effects of recent exercise.

The second aim of the study was to investigate whether a novel sign, the inability to spit, could be used as a simple clinical test of significant dehydration. This possibility is raised by a series of anecdotal reports[7] and laboratory studies.[20–22] We also measured each athlete's perception of thirst as another potential predictor of the level of hydration.

These five variables were compared with change in body weight over the marathon.

METHODS

Subjects

Subjects were recruited from participants in the 2006 Auckland marathon, held on 29 October in New Zealand. All participants in the full 42.2 km marathon were eligible. The nature and the risks of the experimental procedures were explained to the subjects and all gave their written informed consent to participate in the study, which was approved by the Northern Region Ethics Committee of New Zealand.

Prerace

Participants were weighed at race registration using a calibrated TI-BWB 600 Digital scale (Wedderburn, Australia) on a hard, level floor. Subjects were weighed in light shorts and t-shirts with their shoes off. Weights taken 2 days before the race have been shown to vary by a mean of between 0 and 0.1 kg from the athlete's weight on race day.[8]

Postrace

Immediately after the race and before drinking any fluids, participants were asked whether they felt thirsty (yes/no) and asked to spit into a cup (yes/no). Ability to spit was defined as the expectoration of visible saliva into individual receptacles, which were then disposed of sanitarily. Subjects were then examined for the presence of sunken eyes, dry mucous membranes (oral) and reduced skin turgor (back of the hand). These three clinical signs were assessed subjectively by one examiner (JM), who was blinded to the other results. Following this examination, subjects were reweighed on the same set of scales in their running clothes and again with their shoes removed. The five clinical variables assessed were then compared with body weight change over the race.

Both univariable analysis (analysis of each variable on its own) and multivariable analysis (whether each association was explained by the values of the other clinical signs) were carried out.

Statistical analysis

Analysis was carried out in SAS v9.1 for Windows and SPSS Answertree. Difference in percentage weight change in those with and without a measured variable was investigated using Student t tests (univariable analyses). To investigate the independent effect of the symptoms, having controlled for the other symptoms, a general linear model was fitted with percentage weight change as the outcome and skin turgor, sunken eyes, dry membranes, ability to spit and thirst as the explanatory variables (multivariable analysis). A decision tree analysis was also performed using the exhaustive CHAID algorithm[23] to explore whether some combination of risk factors could be used to predict body weight change.

Results

Seven hundred and one of the 1068 competitors were weighed prerace. Reasons for non-participation were not explored. Of these 701, 606 were examined and reweighed immediately postrace (149 women and 457 men) to provide complete sets of data. Thus 95 subjects were lost to follow-up. All age divisions from under 35 years through to over 75 years were represented, with a mean age of 31 years. Race times ranged from 2 h 37 min to 6 h 27 min (average 4 h 6 min).

Prerace weights ranged from 47.0 kg to 106.3 kg (mean 73.6 kg). Postrace weights ranged from 45.2 kg to 103.9 kg (mean 71.8 kg). Weight change ranged from −4.9 kg to +1.7 kg (mean −1. 8 kg), and from −6.1% to +2.5% (mean −2.4%) body weight. The prevalence of symptoms and signs investigated varied markedly. Only 2% of subjects (n = 10) were unable to spit after the race, 17% (n = 103) had decreased skin turgor, 40% (n = 242) had sunken eyes, 63% (n = 382) felt thirsty and 70% (n = 422) had dry mucous membranes.

Table 1 compares the percentage weight change in groups on the basis of whether or not they exhibited each of the five signs or symptoms considered to indicate dehydration in both clinical and athletic populations.

Table 1 Relationship of clinical signs of dehydration with percentage weight change

Clinical signs		%Weight change, mean (standard deviation)	Univariable p value	Multivariable p value*
Decreased skin turgor	Yes	−3.0 (1.4)	<0.001	<0.001
	No	−2.3 (1.5)		
Sensation of thirst	Yes	−2.5 (1.5)	0.01	0.02
	No	−2.2 (1.5)		
Sunken eyes	Yes	−2.6 (1.5)	0.02	0.02
	No	−2.3 (1.5)		
Unable to spit	Yes	−2.4 (1.5)	0.33	0.54
	No	−2.8 (1.5)		
Dry membranes	Yes	−2.4 (1.4)	0.96	0.86
	No	−2.4 (1.6)		

*including all the clinical signs

In univariable analysis skin turgor showed the strongest association with percentage weight loss: those with decreased turgor had a mean 3.0% weight loss compared with 2.3% in those without. The other signs which showed an association with percentage weight loss were sunken eyes and the sensation of thirst. Neither the inability to spit nor the presence of dry mucous membranes was related to weight loss during the race. Multivariable analysis showed that decreased skin turgor, sunken eyes and a sensation of thirst all had an independent association with percentage weight loss. Tree analysis showed that combining individual signs did not improve their ability to satisfactorily predict weight loss. The combination of those with reduced skin turgor and/or thirst, for example, correctly identified 81% of those with weight loss but it also incorrectly classified 65%.

The first four columns of table 2 show the numbers of athletes with and without the measured variables further divided by whether or not they exhibited a weight loss greater than 3% of body weight. These are presented as both raw numbers and percentages of the total number of subjects. The second four columns present the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) for each variable to detect a weight loss of 3% of body weight.

Sensitivity is the percentage of those with weight loss ⩾3% who also showed the clinical sign and reflects the ability of the test to correctly identify this target population. PPV reflects the percentage of those with the sign who also had weight loss ⩾3%. Specificity is the percentage of those who did not lose ⩾3% weight who did not show the sign, and reflects the test's ability to identify those who are not in the target population. NPV is the percentage of those without the sign who also did not lose ⩾3% weight.

The highest sensitivity was 71% for a sensation of thirst, but the specificity of this symptom was only 41%. The highest specificity was for the inability to spit (98%), but this was due to the low numbers who had this sign (10 subjects, 2% of total examined), and this was reflected in the very low sensitivity of only 2%. Decreased skin turgor had a reasonable specificity of 87% but a sensitivity of 25%. PPVs ranged from 33% (dry mucous membranes) to 51% (decreased skin turgor). NPVs were higher than PPVs and ranged from 63% (dry mucous membranes) to 73% (sensation of thirst).

DISCUSSION

This is the first study specifically to evaluate the predictive accuracy of clinical variables considered to indicate dehydration in endurance athletes.

The most important finding of our study is that these commonly used clinical signs and symptoms of dehydration do not reliably detect weight loss ⩾3% in runners who completed a 42 km marathon without collapse. Sensitivity, specificity, positive predictive values and negative predictive values for all variables were poor. Reduced skin turgor was the sign with the strongest correlation with percentage weight loss (table 1), but of those who exhibited this sign only 51% would actually have dehydration (PPV), only narrowly outperforming a coin toss.

The paper of Gorelick *et al*[16] suggested that combining signs of dehydration as a battery of tests improved diagnostic accuracy when compared with using the tests individually. However, a tree analysis showed that combining the clinical variables we studied did not strengthen their validity as a diagnostic tool.

The weakness of the three clinical signs examined may relate to their highly subjective nature, normal individual variability between patients and complication by other physiological variables. The examiner (an experienced sports medicine practitioner) assessed the signs as they are used in typical clinical practice, e.g. subjectively and without baselines. Skin turgor may be affected by age-related alterations in elastin levels and assessment is known to be unreliable between examiners in the elderly population.[24] Mucous membrane moistness in the mouth is affected by the same wide variation in individual saliva flow which affect ability to spit[20 21](see below). The degree of sunken eyes can vary with individual appearance and can also be affected by medical conditions. These factors will all tend to reduce the validity of these examination signs.

The second finding of our study is that the novel sign of an inability to spit is not useful in detecting weight loss ⩾3%. Only 10 cases (1.7%) were unable to spit after the race, and no relationship to weight loss was seen. These small numbers were reflected in the very high specificity of this variable. Laboratory studies investigating the relationship of saliva production to exercise-induced dehydration show that by 2–3% dehydration there is a significant reduction in rates of saliva flow.[20 21] However, the studies also note significant variation between individuals. This variability may be one factor in the poor performance of ability to spit in our study. Also, the introduction of other potential variables when moving from the laboratory to the field (such as pattern and timing of fluid intake) may affect the validity of this test. It is possible that inability to spit becomes more useful at higher levels of dehydration: further studies are needed to clarify this point.

In the current study the sensation of thirst had the highest NPV, and 73% of those not feeling thirsty would correctly have weight loss ⩾3% excluded by this variable alone, yet over a quarter of cases would still have a weight loss of >3%

Table 2 Presence or absence of measured variables in runners with and without weight loss ⩾3% (absolute number (percentage of total subjects)) and validity to detect this level of dehydration

		⩾3% weight loss (%)	<3% weight loss (%)	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
Decreased skin turgor	Yes	53 (9)	50 (8)	(25)	(87)	(51)	(69)
	No	155 (26)	348 (57)				
Sensation of thirst	Yes	147 (24)	235 (39)	(71)	(41)	(38)	(73)
	No	61 (10)	163 (27)				
Sunken eyes	Yes	94 (16)	148 (24)	(45)	(63)	(39)	(69)
	No	114 (19)	250 (41)				
Unable to spit	Yes	4 (1)	6 (1)	(2)	(98)	(40)	(66)
	No	204 (34)	392 (65)				
Dry membranes	Yes	139 (23)	283 (47)	(67)	(29)	(33)	(63)
	No	69 (11)	115 (19)				

What is already known on this topic

No previous studies have looked specifically at the validity of clinical signs of dehydration in athletes. Data included in one previous study[6] has suggested that they perform poorly.

What this study adds

This study suggests that these five clinical variables (altered skin turgor, dry oral mucous membranes, sunken eyes, an inability to spit and the sensation of thirst) do not have good validity for predicting 3% weight loss in endurance athletes.

incorrectly excluded. This study reinforces the fact that, although there is a relationship between thirst and body weight loss, it does not exhibit strong enough validity to be relied upon. As noted by other authors, there is considerable variability between individuals' fluid needs.[25]

Potential limitations of this study include the use of body weight as the gold standard for hydration change, as explained above. Although body weight change is a validated measure of hydration change at endurance events,[6 8 11 12] a small amount of variation in weight may be due to factors other than fluid loss or gain.[4 14] While we believe that understanding the relationship of body weight change to markers of "true" dehydration such as plasma osmolality allows it to be used as a useful surrogate in the field, further studies are needed to confirm or refute our results by directly relating the clinical variables to one of the gold standards themselves.

Only one examiner was used in this study due to logistical reasons and the time pressures involved in examining a large number of participants in a relatively short space of time. Future studies would ideally include multiple examiners and an analysis of interexaminer reliability if solutions to the pressures of time could be found.

This study did not include finishers who ended the race in the medical tent. Therefore the variables were assessed only in well runners, and this is a potential weakness of the study. The study also covers only the range of hydration seen at a 42 km marathon distance, rather than the much more extreme changes in hydration encountered at Ironman and "ultramarathon" distances.

The poor predictive value of popular clinical signs to evaluate weight loss $\geqslant$3% has important implications for all clinicians involved in the assessment and treatment of athletes at endurance athletic events, in particular when considering whether or not fluid replacement should be provided. The failure of these signs to exhibit clinical validity suggests that they should not be used to diagnose "dehydration" or to exclude overhydration in endurance athletes. Therefore other methods need to be used to make this distinction. While the plasma sodium concentration is the critical measurement for the diagnosis of exercise-associated hyponatraemia due to fluid overload,[26] body weight change provides a cheaper, quicker, and easier method. Speedy *et al*[7] have established that it is possible to insist that ultradistance triathletes can start a race only if their prerace body weight has been recorded. This study supports the need for compulsory prerace weighing in all endurance events since this is the only accurate, feasible and low-cost surrogate marker of postrace hydration status.

CONCLUSION

The five parameters (decreased skin turgor, sensation of thirst, sunken eyes, inability to spit and dry mucous membranes) tested in this study did not precisely identify runners with total weight loss >3% at the end of a marathon.

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Competing interests None.

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