Journal of Thermal Biology 37 (2012) 111–117

Contents lists available at SciVerse ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

Review

Assessment of thermal dehydration using the human eye: What is the potential?

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ARTICLE INFO

Article history:
Received 28 October 2011
Accepted 21 December 2011
Available online 29 December 2011

Keywords:
Tear osmolarity
Tear break-up time
Intraocular pressure
Thermal dehydration
Sweat loss
Heat stress

ABSTRACT

Human hydration assessment is a key component for the prevention and proper treatment of heat-related fluid and electrolyte imbalances within military, sports and clinical medicine communities. Despite the availability of many different methods for assessing hydration status, the need for a valid method or technology that is simple, rapid, non-invasive, universal (detects both hypertonic and isotonic hypovolaemia) and is applicable for static (single point in time) and dynamic (change across time) hydration assessment is widely acknowledged. The eye is one candidate body region that might afford such a measure given the intricate balance between ocular dynamics (tear and aqueous humor formation) and blood (plasma osmolality and volume), which is considered the criterion measure for hydration assessment. The aim of this review is to introduce and discuss the potential for using ocular measurements for non-invasive hydration assessment, including tear fluid osmolarity (Tosm), non-invasive tear break-up time (NITBUT) and intraocular pressure (IOP). There is a relevant physiological basis for testing the merit of ocular measures for human hydration assessment and recent data indicate that Tosm and IOP may have utility. Further investigations are warranted to determine the degree to which ocular measures can act as accurate and reliable non-invasive hydration status markers.

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1. Introduction

Human hydration assessment is a key component for the prevention and proper treatment of fluid and electrolyte imbalances (Cheuvront and Sawka, 2005; Institute of Medicine, 2005; Mange et al., 1997; Sawka et al., 2007). The most common body water deficit (hypohydration) occurring in clinical, athletic and most military situations results from a net loss of hypotonic body fluids stemming from heat stress (sweating) and fluid restriction or fluid unavailability (Cheuvront et al., 2010; Institute of Medicine, 2005; Mange et al., 1997; Sawka et al., 2007). A rise in plasma osmolality is the hallmark of this hypertonic-hypovolaemia (Cheuvront et al., 2010; Feig and McCurdy, 1977), and the hypothalamus responds to these alterations by increasing arginine vasopressin hormone (AVP), which reduces urinary water loss and results in the production of more concentrated urine (Andreoli et al., 2000; Robertson et al., 1973). These physiological changes provide the framework for using blood and urine for

Abbreviations: Tosm, Tear fluid osmolarity; TBUT, Tear break-up time; NITBUT, Noninvasive tear break-up time; IOP, Intraocular pressure

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0306-4565/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.jtherbio.2011.12.006

hydration assessment. However, when substantial solute is lost, such as during cold or high altitude exposure and in many medically relevant scenarios (e.g., gastroenteritis, hyperemesis), less 'free water' (i.e. water lacking solute) is cleared (Mudge and Weiner, 1970; Nose et al., 1988) and the resulting isotonic or hypotonic-hypovolaemia can go undetected using the same measures (Cheuvront and Sawka, 2005; Institute of Medicine, 2005; Mange et al., 1997; Sawka et al., 2007). Although no method can yet be universally applied to all types of hypohydration (hypertonic, isotonic and hypotonic hypovolaemia), many methods for assessing hydration state have been used. The optimal choice will depend on the nature of the fluid losses, measurement circumstances (field versus laboratory), the potential for confounding influences and the degree of acceptable invasiveness (risk/benefit) (See Cheuvront and Sawka, 2005 for a review of these methods).

Currently, the most accurate methods to assess hydration status in clinical, athletic, and military settings utilizes dynamic hydration assessment from blood, urine, or cardiovascular (orthostatic) markers (Cheuvront et al., 2010; Cheuvront et al., 2011; Cheuvront and Sawka, 2005, Duvekot et al., 1994; Knopp et al., 1980; Levitt et al., 1992; Mange et al., 1997; McGee et al., 1999). Although change can provide good diagnostic accuracy it requires a valid baseline, control over confounding variables, and often multiple invasive blood or urine measures (Carvajal, 1980; Cheuvront et al., 2010). Large population heterogeneity explains, in part, why few hydration status markers demonstrate nosological sensitivity from a more practical, static (single point in time) measure (Cheuvront et al., 2010; Levitt et al., 1992). There is currently no method or technology that is simple, rapid, non-invasive (Armstrong, 2005; Institute of Medicine, 2005), universal (detects both hypertonic and isotonic hypovolaemia), and is applicable for static and dynamic hydration status assessment (Cheuvront et al., 2010). For these reasons, the Institute of Medicine (2005) encourages more research to improve upon hydration assessment methods for the judicious diagnosis and treatment of hypohydration.

Measurements of the eye (e.g. tear quality, pressure) can be influenced by both volume and osmolality changes in blood (Ashkenazi et al., 1992; Gaasterland et al., 1979; Patel and Blades, 2003; Visscher and Carr, 1944), the latter of which is the current criterion measure for static hydration assessment of hypertonic-hypovolaemia (Cheuvront et al., 2010; Feig and McCurdy, 1977); as such, one or both hypovolaemia subtypes may be diagnosed with non-invasive human eye measures (Fortes et al., 2011; Kayikcioglu et al., 1998; Martin et al., 1999). A paucity of research exists that examines the potential for using ocular measures for hydration assessment (Fortes et al., 2011; Hunt et al., in press; Kayikcioglu et al., 1998) Therefore, the aim of this review is to discuss three ocular measurements that may have the potential for use as non-invasive hydration assessment markers, including tear fluid osmolarity (Tosm), non-invasive tear break-up time (NITBUT) and intraocular pressure (IOP).

2. Aspects of ocular anatomy and physiology applied to hydration status assessment

A simplified schematic of human eye anatomy is drawn in Fig. 1A. The tear film and aqueous humor are detailed hereafter for a better understanding of how their measurement may be used and interpreted for hydration assessment. The tear film is composed of mucous, aqueous and lipid layers that act to lubricate and protect the eyeball (Oyster, 1999). The lacrimal gland (Fig. 1C) secretes electrolytes, water, protein and mucin into the tear film under tight neural control (Dartt, 2009) (Fig. 2). This occurs in two stages, firstly in the acinar cells and secondly in the ductal cells. Acinar cells comprise about 80% of the lacrimal gland and secrete primary lacrimal gland fluid that is isotonic and reflects an ultra-filtrate of plasma (Mircheff, 1989). In support of this contention, tear fluid has been reported to be isotonic with plasma (Rolando and Zierhut, 2001); and, as such, it could be hypothesized that a progressive increase in plasma osmolality during hypertonic-hypovolaemia would be reflected in Tosm. Ductal cells comprise about 10–12% of the lacrimal gland, are estimated to contribute about 30% of lacrimal gland fluid, and

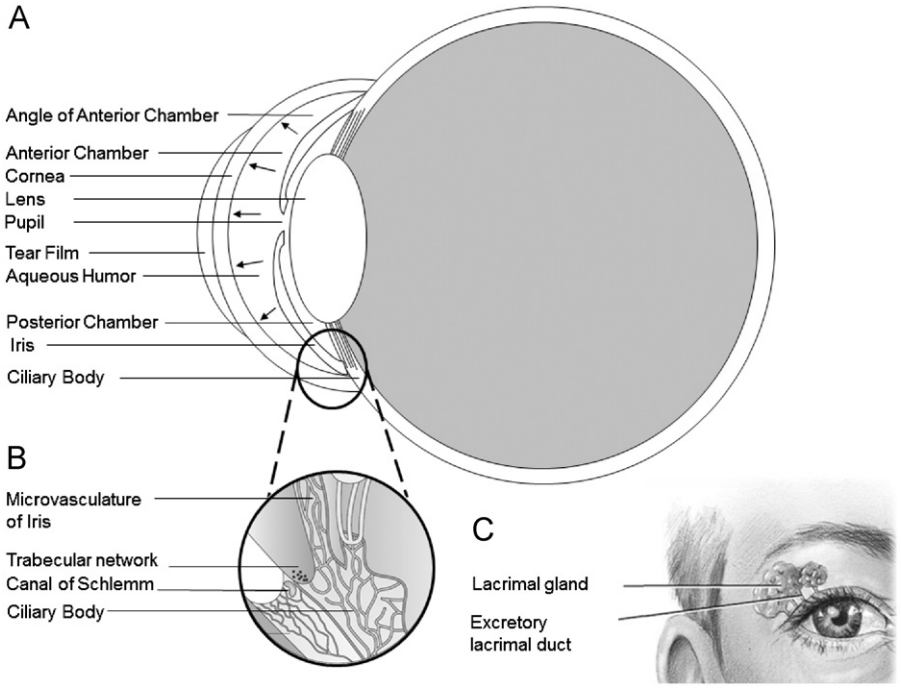

Fig. 1. (A) A simple cross-sectional eye schematic illustrating key parts of ocular anatomy. Intraocular pressure (IOP) is indicated by outward facing arrows in the anterior chamber. (B) Close-up of the aqueous humor drainage system. Aqueous humor drains through the trabecular network into the canal of Schlemm. (C) Depiction of the lacrimal gland.