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Short communication

Tear evaporation rates: What does the literature tell us?

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ABSTRACT

Purpose: A previous literature review reported tear evaporation rates (TERs) from studies conducted on rabbits and humans between 1941 and 2003. Closer examination of the presented data revealed inaccuracies in the reporting of some values. This paper presents updated tables of TERs using values from the original papers cited in the review, in addition to incorporating new studies published between 2003 and 2016.

Methods: A copy of each paper cited in the literature review was obtained and checked against the evaporation rate reported in the review. If the expected value could not be found in the cited paper, other papers by the same author were consulted to see if the value had been reported elsewhere. A PubMed and Scopus database search was conducted to find papers published on tear evaporimetry since 2003.

Results: Two new tables of TERs were created, based on the values reported by the original author. To aid in interpretation, the majority of results are expressed in units of x 10^{-7} g/cm^2/sec. Where it was not possible to convert these values, some values are expressed as x 10^{-7} g/sec, x 10^{-7} g/sec/eye or W/min.

Conclusions: Two new tables of TERs have been compiled to provide an accurate representation of the values reported in the original papers. These tables can be used as a point of reference for other researchers to compare their results.

1. Introduction

Dry eye disease is estimated to affect between 5 and 35% of the population [1]. The 2017 report of the Tear Film and Ocular Surface Society (TFOS) International Dry Eye WorkShop (DEWS) II classified dry eye into three main types: aqueous deficient (ADDE), evaporative (EDE), and mixed [2]. Meibomian gland dysfunction (MGD) is the leading cause of EDE, and is commonly encountered in clinical practice. Humans with an absent lipid layer, or an abnormal coloured fringe tear lipid pattern when viewed with specular reflection, have a four-fold increased rate of evaporation [3].

Evaporimetry is used to indirectly measure the rate of evaporation of the aqueous component from the tear film. The rate of water loss from the exposed ocular surface is typically investigated using temperature and humidity sensors incorporated within a goggle, of which there are two main designs − closed-chamber and open-chamber. Closed-chamber devices [4–9] are fully enclosed and are usually housed within a swimming goggle. This prevents the ocular surface from interacting with the external environment. Open-chamber devices [10,11] have a hole within the instrument which exposes the sensor to the ambient surroundings throughout the measurement. Many evaporimeters have also incorporated ventilation so that air of a known relative humidity (RH) and/or air flow can be added to the chamber [4–6,8,12].

The most common closed-chamber device reported in the literature [8,13–26] was designed by Mathers [8] and includes a dry air ventilation system (Fig. 1). The majority of published literature available on an open-chamber, unventilated evaporimeter was conducted with the ServoMed EP1 or EP3 (ServoMed, Sweden), which was a dermatological device that was modified for use on the eye [3,10,27–43]. More recently, spectral interferometry [44–46] and infrared thermography [47–49] have been used to estimate the rate of tear film evaporation. Currently, the only commercially available evaporimeter is an unventilated, closed-chamber device, the Eye-VapoMeter (Delfin Technologies, Finland), which was recently validated for ocular use [9].

Since a standardised and accepted method of measuring and reporting evaporimetry does not yet exist, researchers have found a variety of ways of expressing the human tear evaporation rate (TER) (Fig. 2). Evaporation rates have most frequently been expressed in units of x 10^{-7} g/cm^2/s or g/m^2/h. Modified dermatological devices that were originally designed to measure water loss from the skin, such as the Eye-VapoMeter [9,50–52], the ServoMed EP1 or EP3 [10,32], and

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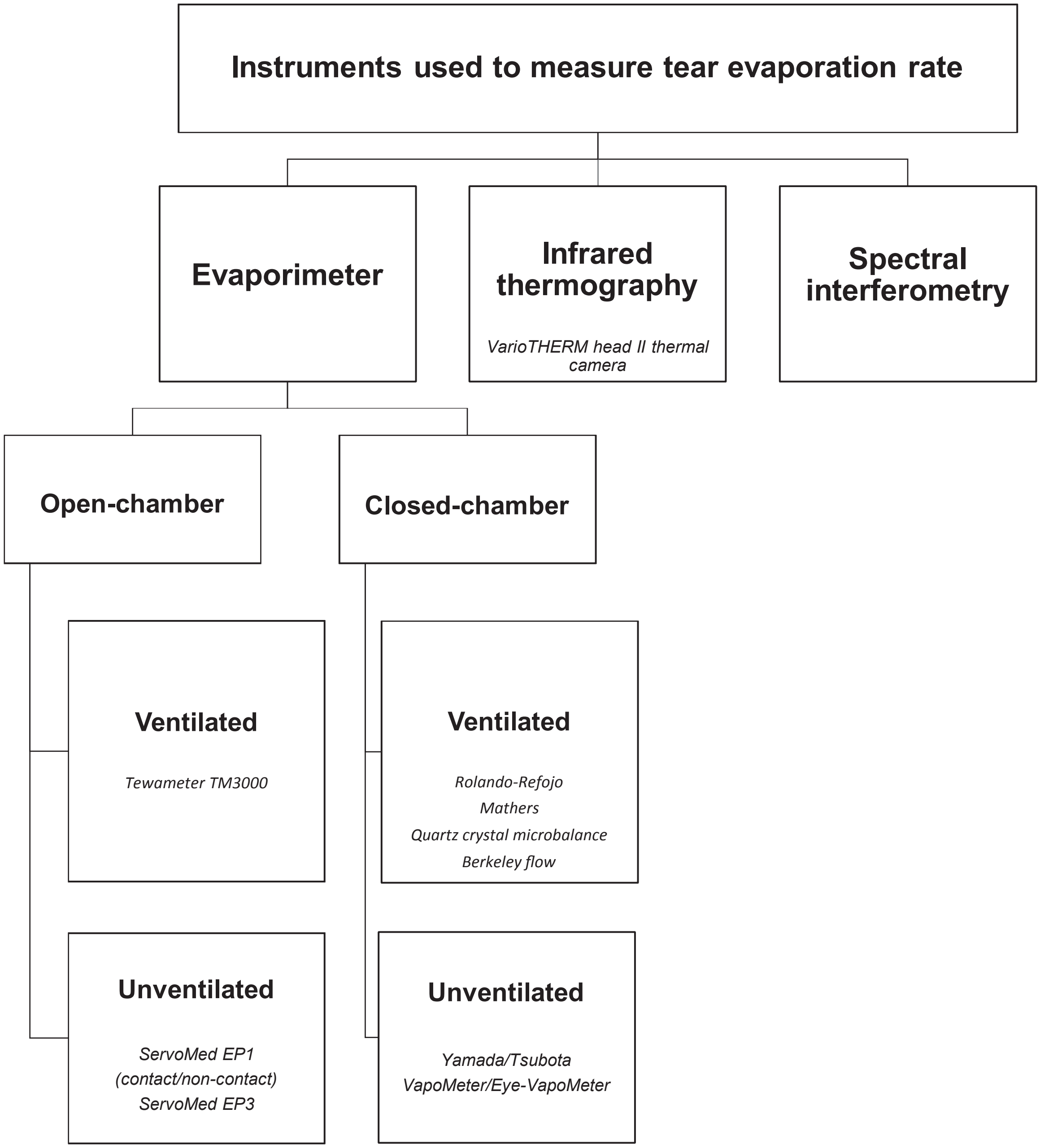

Fig. 1. Schematic diagram of the types of instruments that have been used to measure evaporimetry.

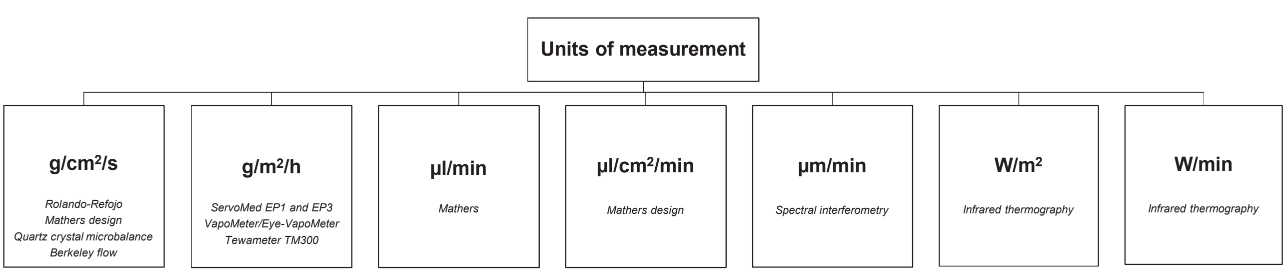

Fig. 2. Diagram of different units of measurement and the type of instrument that have been used to report tear evaporation rates.

the Tewameter [11], calculate rates of evaporation in units of g/m^2/h. Other researchers have reported TER in units of µl/min [8,13–15,42–44,53], µl/cm^2/min [16–23], µm/min [44–46,54], W/m^2 [47,48], and W/min [49]. Since there are a number of different ways of reporting TER, this leads to difficulty when comparing and interpreting the values reported between devices and varying ocular conditions or environments.

Mathers [55] published a literature review in 2004 that discussed the reported values of TER from the ocular surface available at that time. The first table of the review summarised the evaporation rate of 18 studies conducted on rabbits and humans between 1941 and 2003. The table included TER for humans with healthy, normal eyes and