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Review

Water channels and their roles in some ocular tissues

Jorge Fischbarg *

Institute for Cardiological Investigations "A.C. Taquini", University of Buenos Aires and CONICET, Marcelo T. de Alvear 2270, Buenos Aires, Argentina

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ABSTRACT

Water is a major component of the eye, and water channels (aquaporins) are ubiquitous in ocular tissues, and quite abundant at their different locations. AQP1 is expressed in corneal endothelium, lens epithelium, ciliary epithelium, and retinal pigment epithelium. AQP3 is expressed in corneal epithelium, and in conjunctival epithelium. AQP4 is expressed in ciliary epithelium and retinal Muller cells. AQP5 is expressed in corneal epithelium, and conjunctival epithelium. AQP0 is expressed in lens fiber cells.

It is known that five ocular tissues transport fluid, namely: (1) Corneal endothelium; (2) Conjunctival epithelium; (3) Lens epithelium; (4) Ciliary epithelium; (5) Retinal pigment epithelium. For the corneal endothelium, aquaporins are not the main route for trans-tissue water movement, which is paracellular. Instead, we propose that aquaporins allow fast osmotic equilibration of the cell, which is necessary to maintain optimal rates of fluid movement since the cyclic paracellular water transfer mechanism operates separately and tends to create periodic osmotic imbalances ($\tau \sim 5$ s).

Contents

1. Introduction

Water is a major component of the eye, and water channels (aquaporins) are ubiquitous in ocular tissues, and quite abundant at their different locations. Some of their main apparent functions will be highlighted here.

AQP1 is expressed in corneal endothelium (Hasegawa et al., 1993), lens epithelium (Nielsen et al., 1993), ciliary epithelium (Nielsen et al., 1993), and retinal pigment epithelium (Ruiz and Bok, 1996).
AQP3 is expressed in corneal epithelium, and in conjunctival epithelium (Hamann et al., 1998).
AQP4 is expressed in ciliary epithelium and retinal Müller cells (Hamann et al., 1998).
AQP5 is expressed in corneal epithelium (Raina et al., 1995), and conjunctival epithelium (Hamann et al., 1998).
AQP0 is expressed in lens fiber cells (Zampighi et al., 2002).

* Tel/Fax: +5411 4508 3888.
E-mail address: jf20@columbia.edu

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Of the tissues above, it is known that five of them transport fluid, namely:

(1) Corneal endothelium (Dikstein and Maurice, 1972);
(2) Conjunctival epithelium (Li et al., 2001; Shiue et al., 2000);
(3) Lens epithelium (Fischbarg et al., 1999);
(4) Ciliary epithelium (Bill, 1973).
(5) Retinal pigment epithelium (Frambach and Marmor, 1982).

The corneal epithelium does not spontaneously transport fluid, although it has all the transporters in place, can be mobilized to transport fluid at a low rate (Klyce, 1977), and does transport fluid when its intercellular junctions are inmature and permeable (Yang et al., 2000).

The aquaporins in the lens mass (AQP0) have only a very moderate water permeability (Oliva et al., 2010; Zampighi et al., 1995). They could instead have other undetermined function/s (gas channel, ascorbic acid carrier, etc.) (Nakazawa et al., 2011). Their importance is highlighted by the fact that a mutation in it produces a congenital cataract (Hu et al., 2012).

2. The route of fluid transport

It may seem odd to come forward with the notion that water channels (aquaporins) may not be the main route for transtissue water movements, but we do not really know as yet what is the role of aquaporins in the ocular tissues referred to. There are two recent reviews that examine this point and may serve as introduction to these concepts for disoriented readers (Hamann, 2002; Hill et al., 2004). Still, water channels are ubiquitous in many tissues, and as far as we know they are expressed in every fluid-transporting tissue, hence they must be connected with some important role for overall water movements. We advance here our idea for such a role.

To evaluate the existing evidence, we choose to focus on the coupling between the solute and solvent transports mechanisms. In this regard, where the evidence is most clear is in the corneal endothelium. In there, a mechanism based on fluid transport by electro-osmosis across the intercellular junctions has been advanced (for experimental evidence, see (Sanchez et al., 2002); for a summary of the discussion, see (Fischbarg, 2010)). This notion is further supported by a theory of how the endothelium works (Fischbarg and Diecke, 2005), by how can its junctions be selective as the basis for electro-osmosis (Rubashkin et al., 2005), and by how the permeabilities of the cellular and paracellular pathways are consistent with paracellular water flow (Diecke et al., 2011). Of particular relevance to the aquaporins (AQP1) in its plasma membranes, about half of the electro-osmotic transport is driven by the cyclic turning-on (Cacace et al., 2011) of the endothelial sodium-bicarbonate cotransporters (Montalbetti and Fischbarg, 2009). Their period is roughly 4.6 s, a time long enough that the water in the cells could conceivably fall out of phase with the ionic transport; in such case, an ionic build-up would lead to a progressive imbalance. That is where the water channels intervene; in those few seconds, they ensure that the volume and the ionic transports are in register (Kuang et al., 2006). Hence the evidence gathered for the corneal endothelium is quite respectable, and points to an electrogenic coupling mechanism being responsible for water being driven across the paracellular pathway. In turn, water channels would play their own part in allowing the cellular volume to stay in synchrony with the bulk of the water movement taking place via the paracelular pathway.

As for the other epithelia, there is some evidence that a similar type of phenomenon may be taking place in ciliary epithelium, where distinct oscillations in the volume of the cells have been observed with a period of some 3 s (Walker et al., 1999).

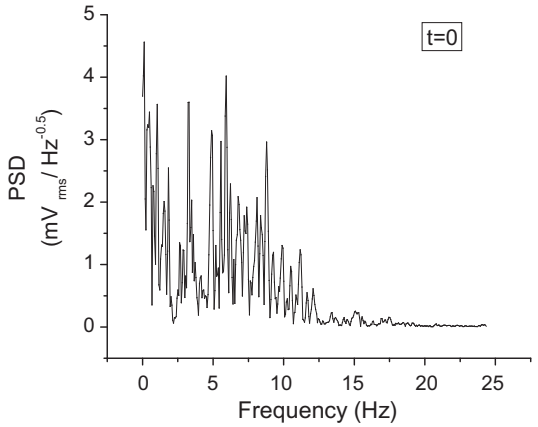

Fig. 1. Power spectrum of rabbit retinal pigment epithelium, just after mounting a preparation in vitro ($t = 0$). $T = 37$ °C. Other technical details as in Montalbetti and Fischbarg, 2009.