

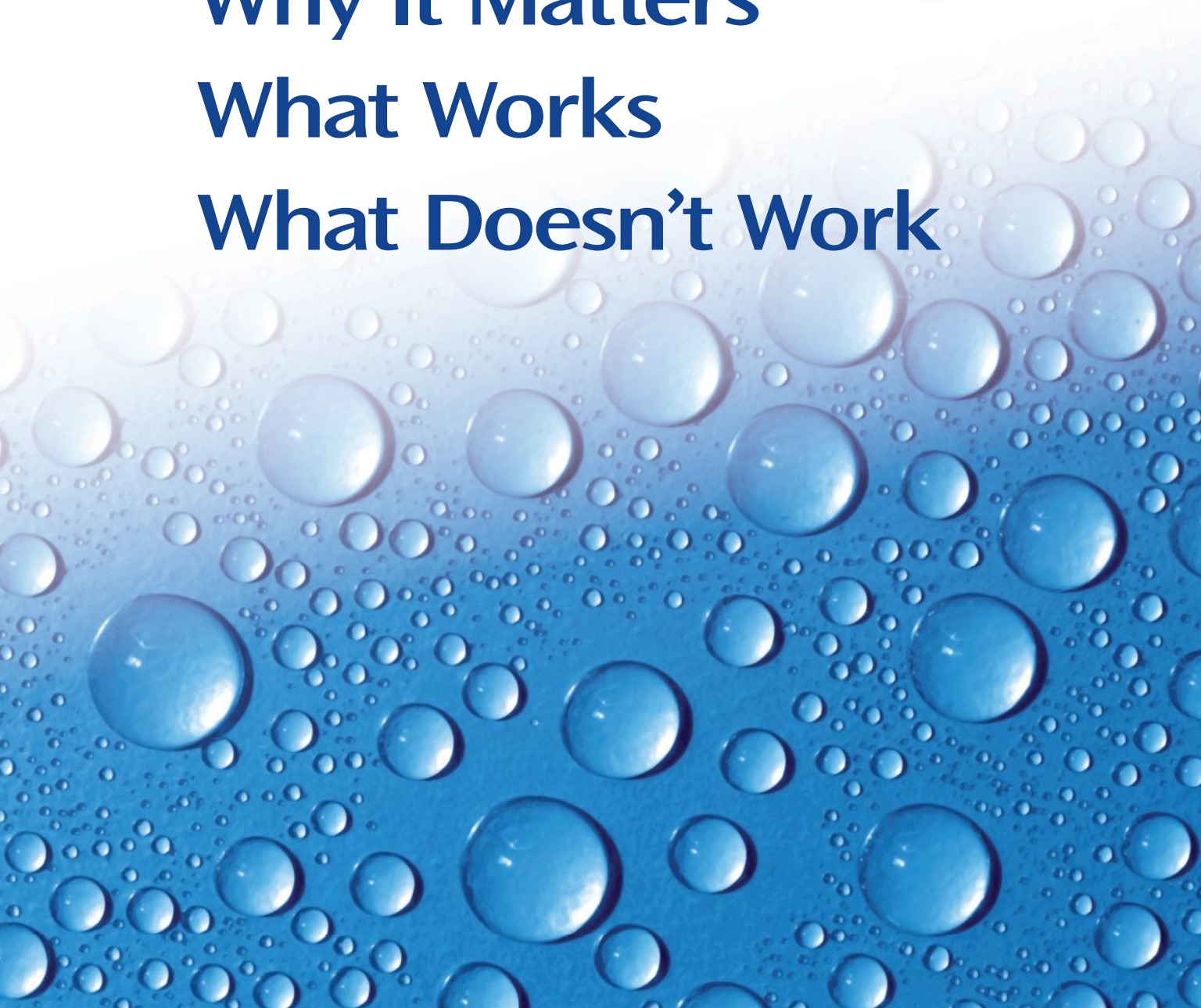
Contact Lens

Wetting

Why It Matters

What Works

What Doesn't Work





WHY IS CONTACT LENS WETTABILITY IMPORTANT?

Tears perform many functions: they lubricate and protect the ocular surface, they distribute nutrients, they maintain optical clarity, and they collect and eliminate wastes. The eye has a complex—and very effective—wetting mechanism that keeps normal tears on the eye so that they can perform these vital functions.

Blinking is a critical part of keeping tears functional. Blinking pumps vital tear lipids from glands in the lids; it mixes, distributes, and drains tear fluid; and it re-spreads the tear film to restore it in areas where it may have started to thin.

Blink is a frequent event in the normal eye, oc-

curing 6 or so times per minute, 8,000 to 9,000 times per day, 3 million-plus times per year.¹ Even if the touch of the lid on the cornea during blink is feather-light, that level of repetition requires good lubrication to prevent damage and discomfort with each blink. In normal eyes, that is accomplished by having the wet, lubricant surface that a healthy tear film provides.

THE BOTTOM LINE: Wetting performs many vital functions, one of which is lubrication for comfort during blink.

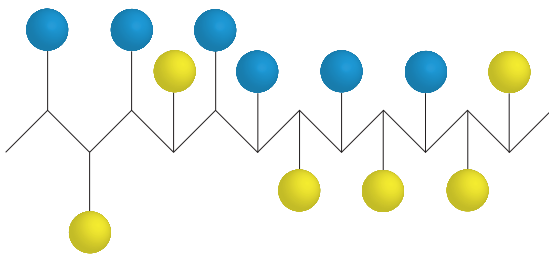


WHY IS THERE A PROBLEM WITH WETTABILITY IN CONTACT LENSES?

First, the surface chemistry of a contact lens is very different from the chemistry of the ocular surface. The ocular surface produces a mucin blanket that, when it's intact, completely hides the hydrophobic cell membrane, allowing a rich layer of water and soluble mucins to adhere to the ocular surface.

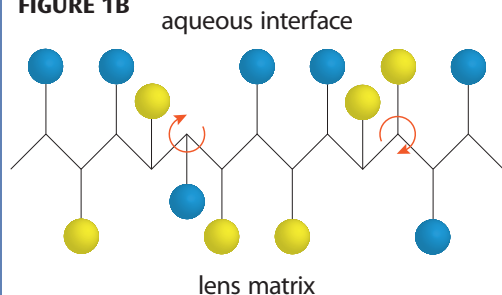
Contact lenses have nothing like the mucin blanket, and they have to be wet by entirely different means. All soft lenses contain hydrogel, which, as its name implies, is partly water and therefore at least partly hydrophilic. However, the long-chain

FIGURE 1A



The hydrophilic (blue) and hydrophobic (yellow) moieties of a polymer molecule can rotate about single bonds in the polymer backbone. If the environment of the lens surface is hydrophobic (eg, air), it will favor the presence of hydrophobic functional units at the interface; and an aqueous environment at the interface will favor the presence of hydrophilic units.

FIGURE 1B

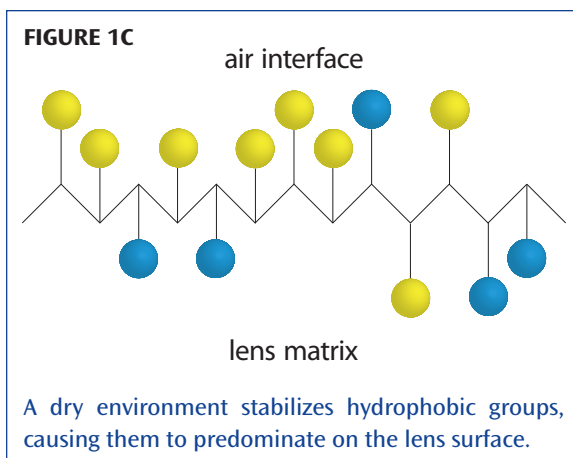


A moist environment attracts hydrophilic groups.

organic polymers that are also in the gel matrix have both hydrophobic and hydrophilic groups. If the hydrophobic groups cluster on the lens surface, there can be a region of relative dryness.

But how can that be—how can hydrophobic groups “cluster on the surface?” To picture this, we have to realize that the lens plastic isn’t static: at the lens surface, the configuration of the molecules is changing constantly.² Remembering a bit of organic chemistry, the sigma (single) bonds that are common in organic molecules allow rotation. So different chains or parts of chains can rotate. And if they are near the surface, they can rotate up to the surface. Similarly, if they are at the surface they can rotate away (Figure 1A).

If a hydrophilic group rotates to the surface and finds water there, it will tend to stay because it is sta-



ble (Figure 1B). Similarly, if it finds air (which is hydrophobic) it will tend to rotate away (Figure 1C). The situation is complex and dynamic, but over time the most stable situation will likely prevail. That means that a dry microenvironment at the lens surface favors hydrophobic groups, while a wet microenvironment will favor hydrophilic groups.

THE BOTTOM LINE: The surface of a contact lens is dynamic, with portions of the lens molecules continuously rotating to and away from the surface. Because of this, nonwetable portions of the polymer molecule can move to the surface, creating areas of relative dryness.

SILICONE HYDROGELS ARE TREATED TO MAKE THEM WETTABLE. DON'T THEY SOLVE THIS PROBLEM?

To create this relatively new lens class, silicone has been added to hydrogel to yield new materials with the properties of both substances. As a result, contact lenses can be made with the extraordinary oxygen permeability of silicone; unfortu-

No silicone hydrogel lens has been able to completely stop the powerfully hydrophobic silicone from coming to the surface and affecting wettability. This, in turn, makes these lenses inherently more difficult to keep wet than traditional hydrogels.

nately, along with its excellent gas permeability, silicone comes with some unwanted baggage: it is highly hydrophobic, which is a significant problem for a material that must stay wet on the eye.

Every silicone hydrogel manufacturer has gone to great lengths to make their material wettable. And while all have succeeded to the point where the lenses are wearable, no silicone hydrogel lens is perfect from a wettability standpoint. Two general approaches have been taken to make

these lenses wet on the eye: silicone is sequestered away from the surface of the lens, or a wetting agent is added to the lens to counteract the effects of the silicone. For example, Bausch + Lomb's PureVision* lens uses a plasma surface treatment to make the lens surface less hydrophobic; CIBA Vision's lotrafilcon A and lotrafilcon B lenses apply a plasma coating to act as a barrier between the silicone and the ocular surface and tear layer.^{3,4,5} CooperVision manufactures Biofinity* lenses in such a way as to sequester the silicone inside the matrix of the lens. Finally, Johnson & Johnson's Acuvue* lenses have a powerful wetting agent incorporated into the lens matrix to make the surface more wettable.

As good as these lenses are, none has been able to completely stop the powerfully hydrophobic silicone from coming to the surface and affecting wettability. This, in turn, makes these lenses inherently more difficult to keep wet than traditional hydrogels.

THE BOTTOM LINE: While silicone hydrogel lenses are all brilliant pieces of industrial chemistry, none is inherently able to stay highly wettable on the eye.



WHY DO LENSES START OUT COMFORTABLE AND BECOME LESS SO AS THE DAY PROGRESSES?

Surface chemistry can supply at least part of the answer. In the chemistry of polar and nonpolar solvents (as exemplified by oil and vinegar salad dressing) we recall that “like attracts like.” Thus, the salad dressing is stable when the oil has separated out from the aqueous phase; and it is unstable when shaken and mixed (ie, the oil isn’t stable in droplet form—the dressing is more stable when the water has squeezed out all the oil to form two distinct phases). Like attracts like and repels unlike.

Similarly, when a nonpolar (hydrophobic) group rotates to the surface and finds air (which is hydrophobic), it is more stable than if it found water. And because it is in a stabilizing microenvironment, the hydrophobic group tends to stay on the surface. Similarly, the presence of many hydrophobic groups on the surface stabilizes new groups that randomly “bloom” to the adjacent surface. If the ocular surface is dry because the tear film covering it breaks up quickly after each blink, then the dry surface environment can hold more

hydrophobic portions of the underlying polymer on the surface, and the lens will slowly get drier as the day wears on.

This happens in traditional hydrogel lenses and in silicone hydrogels, but it is a much greater problem in silicone hydrogels because of the quantity of silicone in these lenses, all of which is hydrophobic. When a silicone moiety, which is inherently hydrophobic, migrates to a dry surface, it is chemically stable, and additional energy is required to displace it.

THE BOTTOM LINE: Over the course of the day, the movement of hydrophobic moieties to the lens/tear film interface can cause the lens to become drier. When that happens, the lens is less lubricated and there is greater lens/lid interaction, causing increased discomfort with time.



BUT ISN'T THE SURFACE OF THE LENS MADE WET BY THE TEAR FILM?

While a contact lens isn't large, it is a massive object to immerse in the tiny volume of the tear film. If the tears are to keep the eye comfortable, they must coat both the anterior and posterior surfaces of the lens. Thus, the tear film on the anterior surface of a contact lens is thinner than it would be on a cornea without a lens; and the tear film breaks up more readily than it would on ocular surface tissue, which is evolved to hold tears to the surface.

Thus, it is no surprise that tear film breakup time (TFBUT) is much shorter on the front surface of a contact lens than it is on a normal cornea. Where in a normal lens-free eye the TFBUT is typically greater than 7 seconds (10 seconds is a common “normal” value), on the anterior surface of a contact lens the tear film breakup time can be as low as 3 seconds.

If the average person blinks 4 to 6 times each minute, the interval between blinks is about 10 or 15 seconds.¹ Since that interval is comparable to the normal TFBUT, the cornea stays protected between blinks—the interval between blinks rarely gives the tear film enough time to break up. But put a contact lens in that eye and the tear film in front of the lens can break up and create dry spots each time the eye blinks.

THE BOTTOM LINE: The dry spots created by tear film breakup will create microenvironments that stabilize the hydrophobic entities that rotate to the surface from the lens matrix. In turn, these dry spots on the lens surface don't rewet well with blink and so hasten tear film breakup.



THERE ARE LOTS OF REWETTING DROPS FOR CONTACT LENSES AND ARTIFICIAL TEARS THAT INCREASE THE TFBUT. WON'T THOSE HELP WITH CONTACT LENSES?

Unfortunately, these artificial tears don't work very well on a lens surface because the tear film on the corneal surface presents an entirely different dynamic from the tear film on the front surface of a contact lens. Although the cell membranes themselves are hydrophobic, the cells on the ocular surface have multiple specific mechanisms that function to keep the surface of the eye wet (Figure 2). To begin with, the cell membranes form villi and microvilli that increase the surface

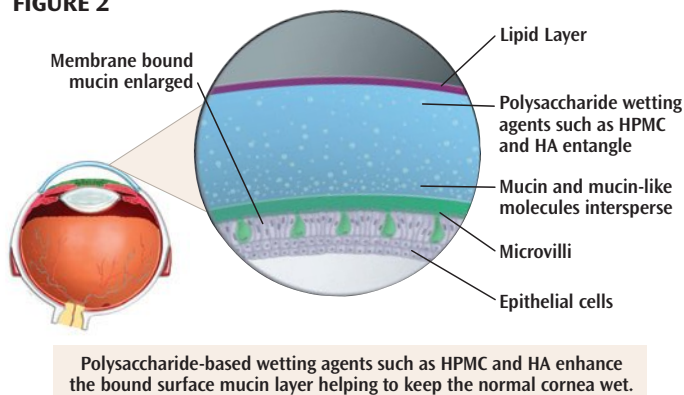
that binds the aqueous/mucin component of the tear film to the ocular surface.⁶ The product of eons of evolution, the system works brilliantly to hold a protective and nourishing layer of tears on the eye.

When the system breaks down—and surface cells are lost—the mucin barrier can be damaged. Artificial tears and gels with large “mucomimetic” polymers (eg, carboxymethylcellulose [CMC], hydroxypropylmethylcellulose [HPMC], hyaluronic acid [HA], etc.) can attach to intact portions of the bound mucins and form a protective coating that simulates the glycocalyx.⁷ This, in turn, holds tears to the eyes and protects the ocular surface. But the attachment of polysaccharide polymers like HA and HPMC to the ocular surface is possible only because there is an underlying mucin scaffold that the cells have built.

A contact lens has nothing like the biologic glycocalyx to which these artificial polymers can attach, and so the polymers can't adhere to and support the wetting of the contact lens. Thus, while using these polymers in contact lens comfort drops or multipurpose disinfecting solutions can provide a cushioning effect for a brief period, the polymers don't adhere well to hydrogel or silicone hydrogel

surfaces the way they do the corneal epithelium, and their effect is, at best, modest and short-lived.

FIGURE 2



On the ocular surface, membrane-bound mucins can hold soluble mucins and mucin-like substances to form a hydrophilic glycocalyx that holds aqueous tears to the surface.

area available for mucin attachment. These surface cells also produce a membrane-bound mucin that is covalently attached to the cell membrane.

In addition to the mucins that are bound to cell membranes, other cells (primarily conjunctival goblet cells) produce mucins that float free in the aqueous portion of the tear film. The cell-bound mucins provide a platform to which the soluble mucins can attach to create a glycocalyx—a protective meshwork

THE BOTTOM LINE: Polymer solutions that can effectively wet the ocular surface have little effect on the contact lens surface because contact lenses lack the mucin glycocalyx that these polymers need to adhere.

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BUT WHAT ABOUT BIOMIMICRY? ISN'T USING HYALURONIC ACID LIKE RECREATING THE NATURAL TEAR FILM?

It can be argued that “biomimicry” can enhance ocular surface wetting. And polymers like hyaluronic acid do just that. The problem for contact lens wear is that the front surface of a hydrogel or silicone hydrogel contact lens isn't a biological surface.

Although hyaluronic acid may be a natural wetting agent found in the eye, the front surface of a contact lens bears little relation to the front surface of the eye. The contact lens doesn't have

the eye's mucin structure to hold biological substances like hyaluronic acid to their surfaces. In this situation, “biomimicry” doesn't apply.

THE BOTTOM LINE: While it may be helpful on a naked eye, when it comes to wetting the surface of a contact lens, hyaluronic acid may be the “wrong thing in the wrong place.”

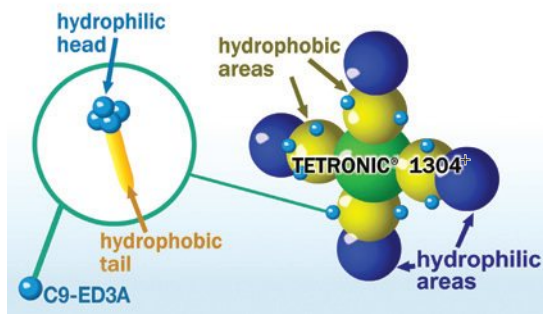


WHAT WILL PROVIDE LENS WETTING AND COMFORT?

So what will wet contact lenses, especially silicone hydrogel contact lenses? The critical issue is finding a molecule capable of adhering to an intrinsically hydrophobic surface. For this, we want surface active agents, molecules with large hydrophobic areas that are segregated from the hydrophilic portion of the molecule.

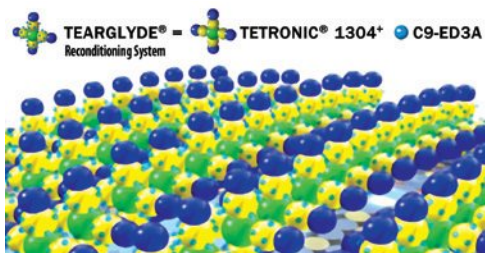
If we look at the molecular species,

FIGURE 3



The elements of the TearGlyde® system: the surface active agents C9-ED3A and TETRONIC® 1304⁺. With large hydrophobic regions, TETRONIC® 1304⁺ can attach to hydrophobic regions of the contact lens surface, which grow throughout the wearing day. In turn, the hydrophobic portion of the smaller C9-ED3A can attach to and make wettable the exposed hydrophobic portions of the TETRONIC®⁺.

FIGURE 4



On the lens surface TearGlyde® Reconditioning System attracts and holds moisture.

TETRONIC® 1304⁺ and C9-ED3A, used in the TearGlyde® contact lens surface reconditioning system in OPTI-FREE® RepleniSH® MPDS, we can see how they effectively hold moisture to the lens surface. Both agents have large hydrophilic and hydrophobic regions (Figure 3). This allows them to adhere to the continually shifting hydrophilic and hydrophobic areas of the contact lens surface and then hold water to that surface (Figure 4).

THE BOTTOM LINE: The goal of rewetting is to condition the surface so that it can hold a thin film of moisture to the lens to lubricate while also providing a smooth and uniform refracting surface.

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