Improving Underwater Vision

Contact lenses and other options can help patients safely maximize their vision underwater.

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Water covers more than 70 percent of the earth's surface, often hiding the fascinating world underneath. The human eye is poorly adapted to see underwater. In the air environment the cornea accounts for about two-thirds of the eye's refractive power, but the underwater environment effectively neutralizes the corneal power because the refractive index of the cornea (1.38) is close to that of water (1.33). Consequently, an eye designed for vision in air is typically quite hyperopic underwater.

Natural Accommodation

Do naturally occurring strategies exist in land-dwellers to overcome underwater vision challenges? Indeed, they do. For example, cormorants and freshwater turtles can see in both air and water. These species demonstrate remarkably powerful lenticular accommodation, which makes up for the loss of refractive power of the cornea underwater. For example, in a study by Katzir and Howland (2003), accommodation by cormorants exceeded 64D, allowing underwater vision.

Interestingly, certain humans exert impressive accommodation to see underwater as well. In the Andaman Sea off the coast of Thailand and Burma, the Moken "sea gypsies" have lived for hundreds of years nomadically moving from island to island, living more than half their lives on their boats. These sea-faring people are known for their skill in swimming and diving, collecting sea cucumbers and shellfish off the ocean floor as deep as 75 feet without any special gear. Moken children literally learn to swim

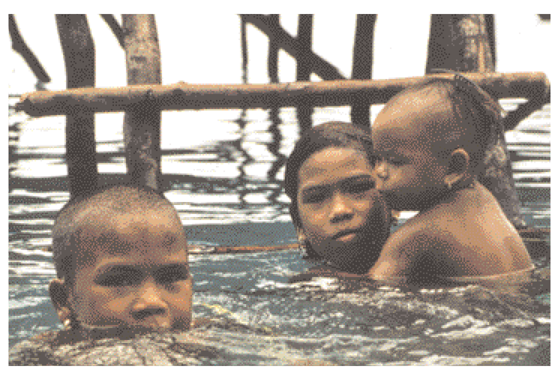

Figure 1. Moken children spend much of their lives on the water and can accommodate up to 16D while underwater. Photo courtesy of Anna Gislén.

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before walking (Figure 1).

Aside from the ability to lower their heart rate to stay underwater twice as long, Moken children are able to resolve spatial frequencies underwater that are twice as fine as that of European children, according to a study by Gislén and coworkers (2003). The Gislén study found that Moken children have significantly better aquatic vision because they accommodate some 15D to 16D when underwater. Additionally, they found that the Moken children's pupils constrict to the limit of human ability to achieve a pinhole effect, also aiding underwater vision.

Underwater Vision with Contact Lenses

In lieu of extraordinary accommodation, could an extremely nearsighted individual see underwater with the naked eye? While there are potential physiological implications of chemical and microbial contamination of the ocular surface, the short answer is yes. This makes extreme myopia advantageous for seeing underwater, which brings up a unique proposition: could contact lenses lend individuals who don't have extreme myopia good vision underwater?

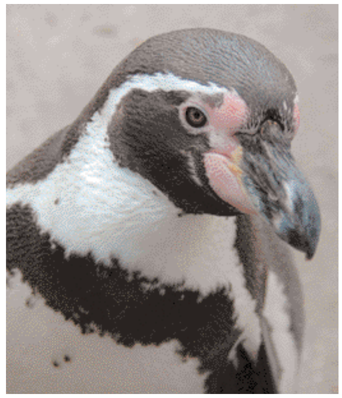

Figure 2. The structure of a Humbolt penguin's eyes allows it to see well in air and water. Photo courtesy of Li-Lian Butcher.

With a high enough amount of plus power, it's surely possible if the contact lens stays on the eye. To be sure, the on-eye stability of a GP lens underwater is suspect, especially with an interpalpebral fit. Yet by comparison, the eyelid stabilizes soft and hybrid contact lenses over the superior and inferior lens edges. Additionally, work by Diefenbach (1988) indicates that when soft hydrogel lenses are exposed to swimming pool water and hypotonic solution, the contact lenses adhere to the cornea and stop moving.

Besides the concerns about the physiological consequences of prolonged eye contact with fresh or saltwater, the resulting quality of vision in air also challenges the widespread use of contact lenses prescribed solely for underwater vision. After all, high myopia simulated with contact lenses would cause mobility concerns for getting in and out of the water.

One answer might be a high-Dk hybrid lens such as the SynergEyes Multifocal with a high-powered center add. We are presently evaluating such a lens design for short durations of amphibious wear. To work, the diameter of the center add for underwater vision should be about 2mm and the radius of curvature would be of the order of 2mm. An aspheric geometry would minimize spherical aberration in the underwater add. With just a 2mm chord diameter, the sagittal thickness of the add above the surface of the contact lens would be about 0.25mm. The design would allow reasonable vision both in and out of water, with the distance-powered annulus providing the vision in air and the center high plus power providing underwater vision. The hybrid platform provides a rigid center that doesn't change in a hypertonic or hypotonic medium, and the large overall diameter is retained well by the eyelids.

For disinfection of the hybrid lens after aquatic use, we follow the guidelines provided by the Centers for Disease Control and Prevention for instruments that directly contact the external surfaces of the eye: a 5- to 10-minute exposure to fresh 3% hydrogen peroxide, followed by subsequent neutralization. Although a chlorine-based system would be ideal, no such system is commercially available in the United States at present.

Non-Contact Lens Options

In addition to achieving a high effective add under water through accommodation, the other naturally occurring strategy that allows for good amphibious vision is having a relatively flat anterior eye surface but a nearly-spherical crystalline lens, exemplified by hooded seals and Humboldt penguins (Figure 2).

Figure 3. The curved optical surface of this diving mask can enhance underwater vision.

With such an optical arrangement, since little refraction occurs at the flat cornea surface whether in air and water, the crystalline lens assumes the majority of the eye's refractive responsibility.

This brings us to the most common strategy humans use to see underwater — a dive mask (or gog-

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gles). Traditional non-prescriptive dive masks have flat front and back lens surfaces. The ophthalmic lenses create an artificial "flat cornea" in front of the eye, allowing the natural cornea to remain the primary refracting element even when underwater.

The weakness in this optical arrangement is fairly narrow field of view underwater. Fish have an anterior-shifted crystalline lens, which provides them with a very wide field of vision. With a dive mask, humans don't have the luxury of moving the refracting elements of their own eye more anterior. Furthermore, traditional dive masks induce image magnification and change the image location while underwater.

The best solution may be a novel diving mask, made by HydroOptix, LLC. Unlike traditional flat masks, the HydroOptix Mega 4.5 DD mask (Figure 3) has a curved optical surface (base curve of +4.50D) which, according to the company, offers a significantly enlarged viewing area by a factor of five times (Figure 4) without changing image size or image distance. By comparison, flat masks make objects appear 25 percent closer and 34.1 percent larger underwater than in reality.

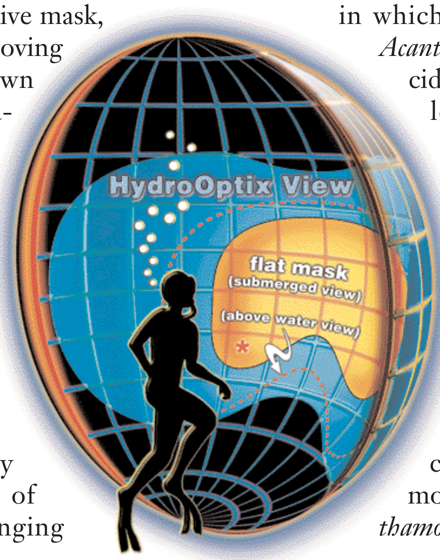

Figure 4. HydroOptix says its diving mask enlarges underwater viewing area without changing image size.

Of course, the optical consequence of a curved mask with a 4.50D base curve is the creation of a –4.50 lens due to the air-water interface. Assuming a vertex distance of 13mm, a +4.25D contact lens worn over an emmetropic eye would cancel out the –4.50 water lens. For this reason, most patients wearing the Mega 4.5 DD mask need to also wear contact lenses to achieve an effective spectacle add of approximately +4.50D. Less add power is necessary for non-presbyopes who can accommodate to achieve the total of +4.50D of add. HydroOptix recommends that wearers of its Mega 4.5 DD undergo a contact lens fitting through one of its eye doctors within its worldwide network. (The company's Web page specifically for eyecare professionals is www.hydrooptix.com/decproprivate.) When wearing contact lenses for use with the Mega 4.5 DD mask, absolute presbyopes would need to wear –4.25D eyeglasses over the contact lenses to achieve good distance vision to safely make it to their diving site.

Underwater Lens Wear Risks and Precautions

While contact lenses can play a role in improving visual performance underwater, there's an understandable concern about whether they significantly increase the risk of *Acanthamoeba* keratitis and other forms of microbial keratitis. Water exposure — whether fresh or seawater — is a commonly cited risk factor for the development of *Acanthamoeba* keratitis.

However, a study by Chynn and coworkers (1997) in which they followed patients who had *Acanthamoeba* keratitis found that the incidence of water exposure was actually lower among study patients than among the general contact lens population. These results suggest that water exposure may be a less important factor in development of the disease than previously assumed. To be sure, *Acanthamoeba* is omnipresent in our environment, including in soil, dust and air. Perhaps these non-water sources, in conjunction with compromised ocular integrity, are more relevant in the genesis of *Acanthamoeba* keratitis.

Due to the blinding potential of this protozoal infection, the role of water exposure as a risk factor for *Acanthamoeba* keratitis, if any, deserves further evaluation. Meanwhile, it's essential that patients properly disinfect lenses after swimming. It's also prudent that patients never sleep in their lenses after participating in water activities.

Discuss Aquatic Lens Wear with Your Patients

Although overlooked by many practitioners, the reality is that millions of contact lens wearers swim and dive without removing their lenses and without experiencing adverse consequences. In the vast majority of these cases, the convenience and safety of unfettered aquatic vision likely outweighs the inherent risks posed by microbial infection. By accepting that patients commonly wear contact lenses for aquatic activities, practitioners can judiciously prescribe contact lenses, with all of the appropriate considerations of proper hygiene, disinfection and ocular physiology, to enhance the recreational water enthusiast's underwater experience. **CLS**

The authors have no financial interest in any products mentioned in this article.

For references, please visit www.clspectrum.com/references.asp and click on document #139.