Bio-inspired design

Many everyday items take nature as their inspiration but will future eye care products be bio-inspired by the eye? Dr Peter Vukusic and Dr Joe Barr look at some common examples of bio-inspired design and how this principle can be applied in the contact lens field

The biological world has many examples of highly functional and adapted design by which animals or plants gain advantage in their interaction with each other and with their surroundings.

Scientists often seek inspiration from the natural world that might offer solutions to technological, biomedical or industrial challenges. Bio-inspired design, sometimes known as biomimetic design,[1] has many applications in everyday products. One invention often used as an example is Velcro (Figure 1).

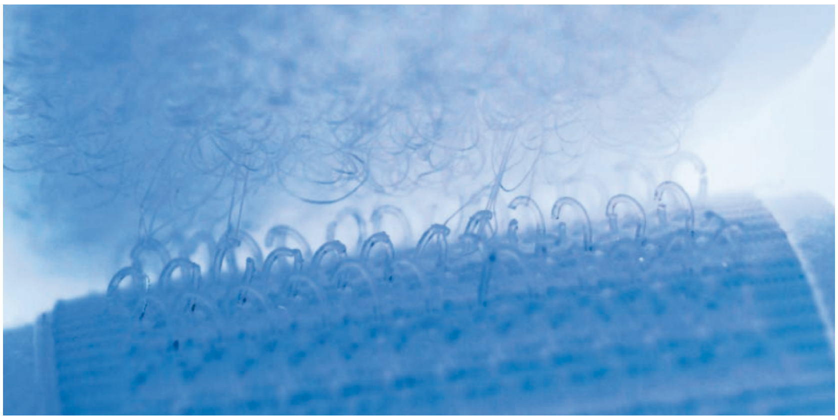

Figure 1 Velcro is an example of bio-inspired design

The discovery of the mechanism behind Velcro is attributed to a Swiss engineer, George de Mestral, in 1941. Returning after a walk in the Alps with his pet dog, he noticed the animal's fur had collected burdock plant seeds. Closer inspection revealed that the seeds comprised many small hooks on the end of their protective spikes. These had bound the seeds tightly to the loops formed by the animal's hair.

de Mestral recognised the opportunity to bind two synthetic surfaces by making an equivalent artificial system comprising hooks and loops that could be fixed to those surfaces. His invention was eventually patented and commercial production began. Since then it has fulfilled a range of functions for various domestic, scientific, industrial and military applications.

Animal analogies

More recently, studies of biology and the natural world have uncovered the potential for many other bio-inspired products. Among these is Gecko Tape, an adhesive tape based on the principle by which geckos' feet adhere strongly to smooth surfaces (Figure 2).

Geckos are known for their extraordinary climbing ability which allows them to run quickly along most surfaces, even vertical ones, and to release their foot adhesion in milliseconds.

Geckos' surface adhesion relies on the presence of microscopic branch-like fibres that cover the undersides of their feet. These fibres, known as setae (shown in the background of Figure 2), comprise stiff spring-like hydrophobic keratin and are self-cleaning. This offers the capacity for rapid attachment and detachment and maintains performance for many months' constant use, often in variable clean or dirty natural conditions.

Figure 2 Geckos' surface adhesion relies on microscopic branch-like fibres, known as setae, on the feet

Synthetic surfaces that have been designed to function in this way are in the early stages of development. For certain niche applications, Gecko Tape will offer far more efficient and appropriate adhesion properties than conventional viscoelastic polymer-based adhesives.

Planting the seed

Though animal systems provide strong potential for bio-inspiration in technology, industry and biomedical fields, plants have also been a valuable source. One example is the leaf of the lotus plant, which exhibits 'superhydrophobicity', often referred to as 'the lotus effect', due to the plant's highly water-repellent leaves (Figure 3a).

The lotus leaf has micro-scale protuberances and nano-scale hair-like structures coupled with a waxy surface composition. When a drop of rainwater falls on the leaf it forms a very high contact angle with the surface that causes it to create a spherical bead (Figure 3b).

These beads have less than 5 per cent of their surface area in contact with the leaf and roll across the surface when the leaf is tilted, aided by the surface structures and by trapped air under the bead. This results in the collection and removal of dirt and bacteria from the leaf's surface.[2]

Among the applications inspired by this effect are aerosol-based architectural spray coatings that render an exterior wall water repellent and self-cleaning, and external glass surfaces textured to produce a self-cleaning effect.

Light and colour

Designing and developing applications for optical functions through bio-inspiration has gained momentum in the last decade. Many biological systems have evolved distinctive ways of manipulating the propagation of light and colour.

The field of photonics is founded on the principles by which electromagnetic radiation may be manipulated strongly when it interacts with periodic variations in refractive index.[3] Simple systems, such as grooves on a compact disc or anti-reflection coatings on spectacle lenses, are everyday examples of this phenomenon. In these examples, spectral colours are observed due to the diffractive effect of the compact disc's grooves, while coloured reflection is observed from lenses due to interference in their multilayer coating.

This form of colour generation is different from that produced by light absorption in pigments or dyes. The latter is produced by chromophores – pigments which selectively absorb some wavelengths while scattering others – whereas photonic systems manipulate light directly by coherent scattering, allowing some bands of wavelength to propagate through the system while preventing others.

Those bands that are inhibited from propagating are reflected, creating or contributing to the system's coloured appearance. Common examples of this are the blue feathers on a peacock, or the silver scales on some fishes.

In certain animal and plant species, photonic-based coloured appearances are very highly evolved. Among these are the brilliant blue iridescent colours of Morpho butterflies (Figure 4a). The intense hues and remarkable conspicuousness of this species result from a series of highly layered coherent scattering structures that cover the scales on their wings. The layered structure and ridges produce the bright iridescence and also enhance the creature's angular visibility.[4]

Cosmetics to counterfeiting

The design of cosmetics has taken inspiration from Morpho and other butterflies. L'Oreal, in particular, has pioneered bio-optics inspiration in the cosmetics industry. By mimicking the way in which light and colour are manipulated in Morpho butterfly scales, but using inert synthetic materials to form a series of periodic micro and nanostructures, L'Oreal has advanced the aesthetic of its cosmetic products using a naturally inspired design (Figure 4b).

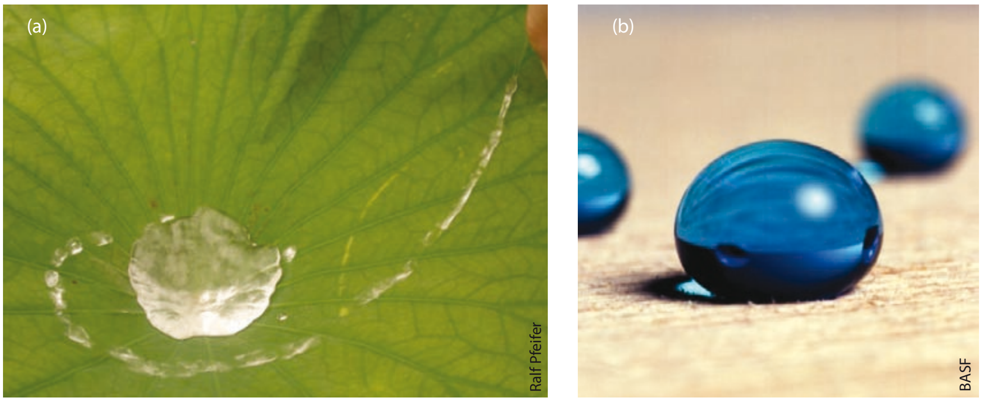

Figure 3 The leaf of the lotus plant (a) is highly water-repellent and has inspired commercial anti-wetting coatings (b)

The visual appearances of many animal species comprise optical features that are overtly conspicuous to human vision and others that are covertly concealed beyond human visual sensitivity. This has led directly to bio-inspiration in another unusual application, anti-counterfeiting devices. Although much of the commercial development work in this area remains highly secretive, patent searches can reveal some information.

One specific bio-inspired anti-counterfeiting logo design, for use in forms of currency, is based on the photonic nanostructure responsible for the visual appearance of a Papilio butterfly (Figure 5a).

Papilio palinurus is green to human vision but its wing scales comprise micron-sized regions of juxtaposed yellow and blue colour centres.[5] Human vision cannot resolve such small individual colour centre regions, so additive mixing processes create the appearance of an entirely green wing.

In a synthetic analogue, the potential for a covert security feature arises due to the nature of the reflection of one of the two individual colours (Figure 6b). Only the blue colour centre components form a double reflection of incident light from the inclined sides of each multilayer structure. This has the effect of polarising the blue reflection and provides it with a property that is absent from the reflected yellow component.

For anti-counterfeiting purposes, synthetic structural variations on this biological system offer distinct advantages and are currently under development to fabricate state of the art currency-related applications like the OVD Kinegram product shown in Figure 5b.

Mimicking the natural eye

Bio-inspired concepts can play a major role in developing medical devices that offer superior products to patients. In the ophthalmic field, accommodating intraocular lens design seeks to mimic the natural crystalline lens as closely

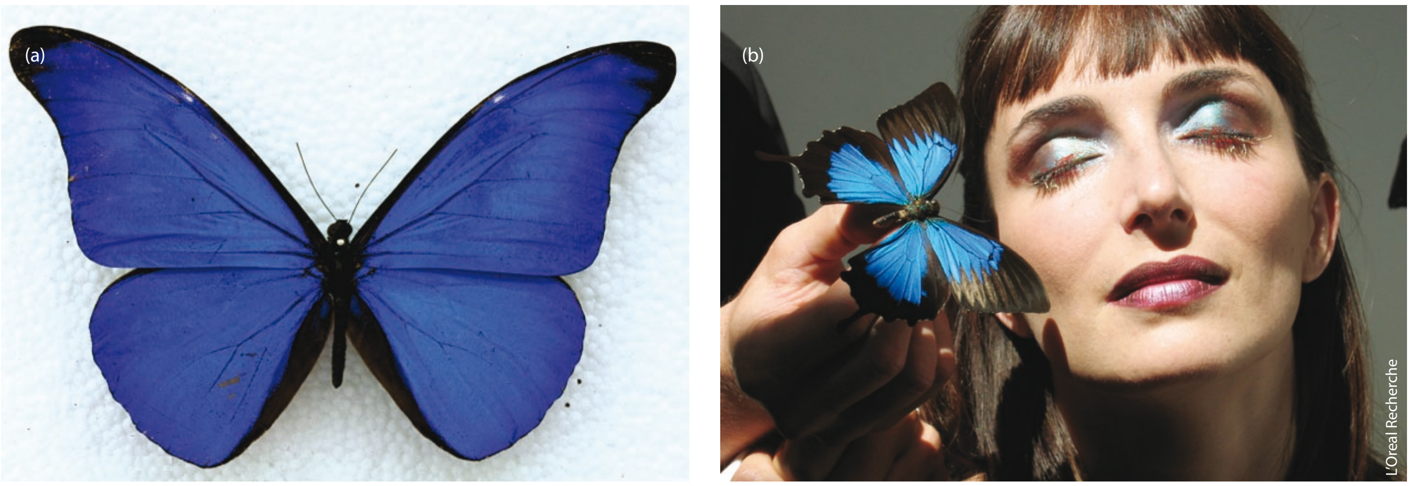

Figure 4 Photonic-based coloured appearances are highly evolved In Morpho butterflies (a) giving inspiration to cosmetics manufacturers (b)

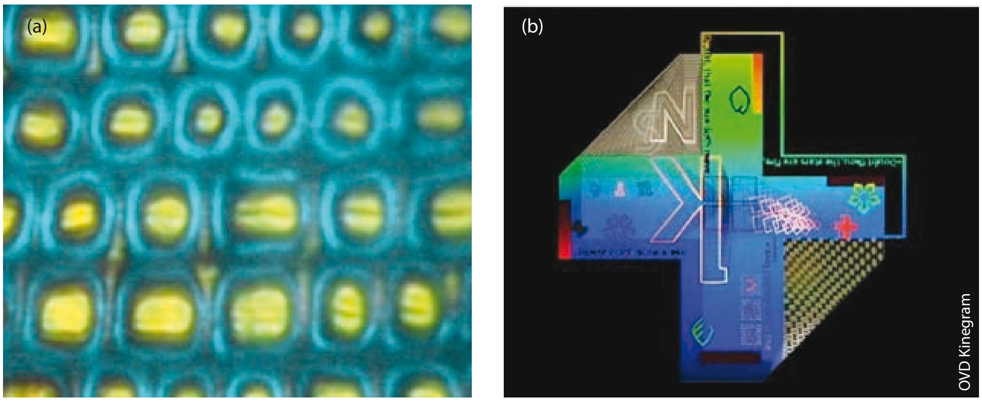

Figure 5 (a) The photonic nanostructure of a Papilio butterfly; (b) An anti-counterfeiting logo design

as possible, moving within the eye and allowing patients to see at near, intermediate and distance with equal clarity. B+L Crystalens HD, an IOL with enhanced accommodative optics that provides patients with the best of both worlds by enhancing the depth of focus, is designed like the natural lens. The everyday function of Crystalens; the way it actually moves in the eye; is as close as you can get to the natural lens (Figure 6).

In the contact lens field, scientists have already applied bio-inspiration to contact lens materials to mimic the properties of the ocular surface, and formulated eye drops to relieve ocular dehydration based on understanding and mimicking the physiology of the eye.

Understanding the human tear film and the components of the tears can also inspire the invention of new designs that offer optimal solutions for contact lens wearers. For example, there are proteins and lipids in the tear film that play a significant role in protecting and lubricating the cornea and conjunctiva. Proteins such as lysozyme and lactoferrin naturally protect the eye against infections based on their anti-microbial attributes.

Tear lipocalin is a protein that binds to lipids and is known to prevent desiccation of the corneal surface. Technologies that mimic the eye in protecting the structure and function of tear lipocalin could preserve homeostasis, which is an important consideration in bio-inspiration.

The future

Enhancing the contact lens wearing experience for our customers is one of the priorities for the contact lens and contact lens care manufacturers and providers. Marketing, R&D, and manufacturing are constantly looking for ways to bring forth new designs to meet this important customer need.

Nature and the human body are wonderful databases of ideas and concepts from which to borrow. Bio-inspiration takes us in new directions that are not products of our own limited experiences but are in fact those of nature's millions of years of evolution. Bio-inspired materials and treatments are already making inroads into all segments of healthcare, including eye care.

Correcting vision with contact lenses while keeping the wearing experience as close as possible to natural conditions can come from bio-inspired approaches.

If the polymers used to make the contact lens were naturally derived or if the lens were designed such that the tear flow between the lens and the corneal surface mimicked the biology of the eye, patients would apply these lenses to the eye and soon forget they were even wearing a lens. They would continue to wear the lens for a whole day under all environmental conditions and yet not feel any irritation or discomfort.

As eye health scientists learn more about the eye and how it maintains itself, additional products that are based on this miraculous organ will follow. That would be the day we could claim the success of bio-inspiration for our contact lens wearers. ●

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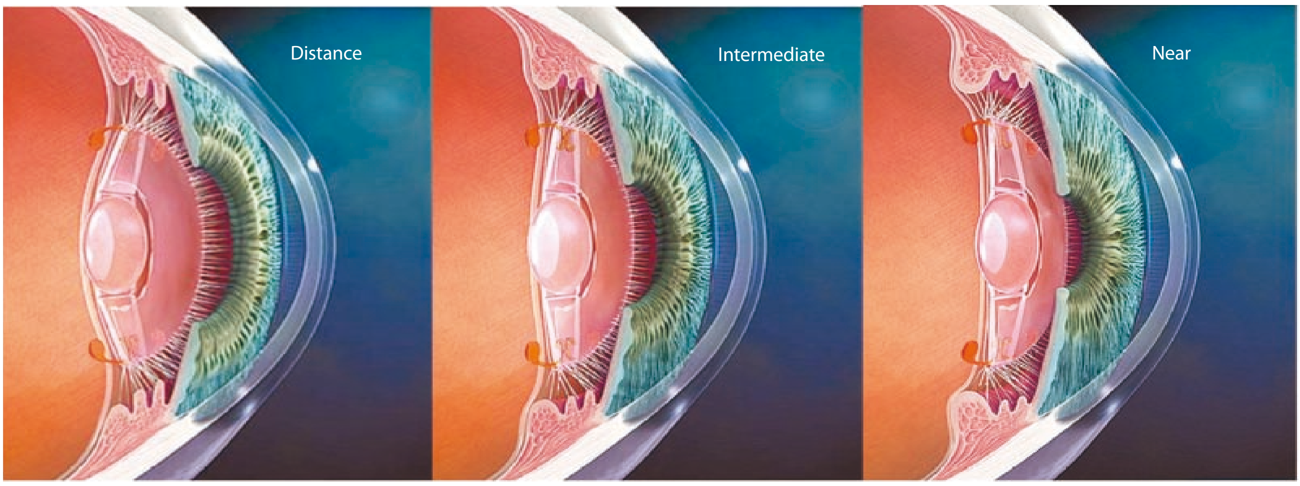

Figure 6 B+L Crystalens HD, an enhanced accommodative optic IOL designed like a natural lens