IN THE BEGINNING

What were the first contact lenses made of? Water! In the early 16th century, Leonardo da Vinci instructed a visually-impaired man to open his eyes in a bowl of water. Suddenly, the man saw clearly. Buoyed by the success, da Vinci attempted to make a device that held water and could be placed directly on the eye. Unfortunately, he could not master a practical design. Even though da Vinci was working on the contact lens concept before the development of glass and plastic lenses, he was on to something, which only came about a half a millennium after his initial investigation. Water! It continues to be an important component in contact lens materials.

Thomas Young tried to improve on da Vinci’s idea in 1801. He made a crude set of contact lenses—tiny bowls filled with water—and attached them to his eyes with wax. The water neutralized his refractive error, and he added a pair of lenses for acuity. Of course, while innovative in concept, this idea proved impractical and uncomfortable.

While the concept of a corrective lens that rested directly on the eye was not abandoned, practical applications eluded developers. It was not until 1887 that F. A. Mueller used glass to make the first actual contact lenses. They were scleral lenses, which extended past the corneal limbus to rest on the sclera, but had no refractive power. A year later, Eugen Fick was able to use Mueller’s idea to make a glass scleral lens that had refractive power. Unfortunately, they were difficult to make and heavy, making them difficult to wear.

In 1937, optometrist William Feinbloom developed a scleral contact lens with a glass center and rigid plastic skirt. This first use of plastics had a profound impact on contact lens development. Following on the heels of Feinbloom’s innovation, Theodore Obrig created scleral contact lenses made entirely of polymethylmethacrylate (PMMA) in 1938. As we will see, PMMA contact lenses are still in use today.

SOFT LENSES ARRIVE ON THE SCENE

While PMMA scleral lenses were a great leap in contact lens technology, they were difficult to use and could not be worn for long periods. Not only were the size and rigid material uncomfortable, but the scleral lenses did not allow enough tear flow behind the lens to maintain corneal health. Sometimes the lenses were fenestrated to improve oxygen flow, but they still could not be worn for more than a few hours at a time. Kevin Tuohy developed a rigid corneal lens in 1947 that increased tear flow behind the lens and was healthier and more comfortable. Later, grooves were added...
to the back of the lens to further increase tear flow. Even with these smaller lenses and design improvements, however, eyecare professionals began to realize the necessity of providing more oxygen to the cornea.

In 1951, chemist Otto Wichterle developed hydroxyethylmethacrylate, a hydrophilic (affinity for water), hydrogel polymer now known as HEMA. Remember Leonardo? While da Vinci was more interested in the refractive power of water, his idea had an unforeseen benefit. The hydrophilic lenses’ affinity for water allowed oxygen to pass through the material to the cornea, resulting in better health and more comfort.

Contact lenses were first made from this new material in 1958. They came from molds, but the rough lens edges had to be smoothed by hand. Wichterle persisted, and in 1961 created a spin casting machine out of parts from an Erector set, a bicycle and a doorbell. In 1965, Bausch & Lomb began its first venture into contact lenses when it used Wichterle’s process and became the primary mass producer of contact lenses.

As researchers began to understand the importance of a contact lens that allowed oxygen to pass to the cornea, and with the wide availability of soft contact lenses, the use of PMMA lenses diminished. Still, the applications for rigid lenses, such as for correcting astigmatism and in keratoconus, remained and research continued. Wöhlk-Contact-Linsen introduced a rigid gas permeable lens (RGP) that was softer and more pliable than PMMA, made from cellulose acetate butyrate (CAB) in 1977. In 1980, Syntex launched the Polycon lens, made of highly gas permeable silicone acrylate. The PMMA-Silicone Polycon II lens followed shortly after.

At the same time, the search for better soft lens materials continued with a push for higher water content. In the early 1970s, the Bionite Naturalens was in production. Bionite, at about 60 percent water, is twice as permeable to oxygen as HEMA. Even today, 60 percent is considered to be a high water content lens.

Higher water content contact lenses had a drawback, however. Although they provided more oxygen to the cornea than the earlier materials, they dehydrated in dry conditions and after long wearing times. And so the search continued for even better materials. Syntex produced CSI, the first use of silicone in a contact lens, in 1978. Although the croficon material was only 38 percent water content, it had high oxygen permeability without the dehydration issues associated with high water content lenses. The explosion of silicone use in contact lenses began.

Along with silicone, the original hydrogel polymers continue to evolve as well. There are about 27 hydrogel materials currently available, as compared with about 10 silicone polymers. While the lenses in both groups vary in water content and oxygen permeability, in general, hydrogels have a higher water content, and silicone polymers have higher oxygen permeability.

**SILICONE HYDROGELS**

HEMA lenses offered comfort and convenience, and patients wanted to wear them for longer periods of time. In the early 1980s, J. de Carle developed the Permalens, a hydrogel with 71 percent water content, which the Food and Drug Administration subsequently approved for 30-day continuous wear. It wasn’t long, however, before researchers found that even high water content lenses could not deliver enough oxygen to the cornea for continuous wear. Because the water in the high water content lenses decreased the refractive index of the lens, thicker lenses were needed. Thicker lenses offset some of the oxygen delivery benefit of having higher water content. The contact lens industry needed a material that could deliver oxygen better than HEMA.

Oxygen is highly soluble in silicone, which made silicone appear to be a good choice. The original lenses, made of silicone elastomer, contained no water and therefore had a tendency to adhere to the cornea. What’s more, they had poor edge shape, liquids did not disperse across the surface well, and the material attracted deposits. Researchers had to look for something else.

It was then that researchers thought to combine the best features of hydrogel lenses with the benefits of silicone. The idea of silicone hydrogels was born, combining the oxygen permeability of silicone with the water permeability of hydrogels. The work of the Toyo Contact Lens Company, which received a patent for a silicone hydrogel copolymer that could be used for contact lenses in 1979, attracted attention. Making that copolymer, however, required a complex process that slowed widespread production of the material.

Researchers, scientists and chemists from around the world collaborated to make the idea of silicone hydrogel contact lenses a reality. In 1999, CIBA Vision, one of the collaborators, introduced Focus Night & Day lenses made of the silicone hydrogel lotrafilcon A. In 2001, the FDA approved the lenses for 30-day continuous wear. At the same time, Bausch & Lomb launched PureVision as a daily wear silicone hydrogel lens. Subsequently, the FDA approved those lenses for 30-day continuous wear as well.

Since then, advancements in silicone hydrogel lenses, called SiHy, have gone beyond the continuous wear application to daily wear and disposables. Research continues to improve comfort and reduce dryness, incorporating surface treatments and wetting agents. The ultimate goal is to make a contact lens that mimics the cornea itself. That way, wearing contact lenses should have zero negative impact on ocular health.

**DK—DIFFUSION AND SOLUBILITY**

How is it that different materials with different water contents allow oxygen to pass through to the cornea? The answer is through diffusion and solubility. Diffusion is defined as “the movement of ions or molecules from an area of higher concentration to an area of lower concentration.” Solubility is defined as “the amount of a substance (oxygen) that can be dissolved in a given amount of solvent (water).” Thus, various materials having different combinations of diffusion...
and solubility can allow similar oxygen permeability values. We measure this permeability with the term Dk, where D represents diffusion and k represents solubility. The value of Dk is the quantity of oxygen that passes through a contact lens over a specific time period and pressure difference between the front and back of the lens. Going a step further is Dk/t, which takes into account the thickness of the lens.

The combination of diffusion and solubility allows for contact lenses made of very different materials such as hydrogels and gas permeables to have similar Dk values. The water content of hydrogels results in oxygen permeability mostly through solubility, that is, oxygen dissolved in water. In gas permeable lenses, oxygen permeability is primarily the result of diffusion, the movement of oxygen through the lens. In either case, the higher the Dk value, the greater the oxygen permeability.

**Wettability**

Tear film is as important to healthy contact lens wear as is oxygen permeability. With contact lenses available in both hydrophilic (affinity for water) and hydrophobic (water resistant) materials, how can both work in conjunction with tear film? The answer is wettability. Wettability is the way a liquid spreads across a surface. It is measured by what is called wetting angle, which is the angle formed when a drop of liquid is placed on a surface. A high wetting angle of more than 90 degrees indicates a surface with poor wettability, while a low wetting angle of less than 90 degrees indicates better dispersion of tear film across the lens surface.

Although silicone hydrogels have high oxygen permeability and dehydrate more slowly than hydrogels, by nature, silicone is hydrophobic and tends to attract deposits which reduce permeability and can lead to infection and other complications. Contact lens manufacturers have found several ways to alleviate the problem. Innovations include designing the lens material so that the silicone is not on the surface of the lens, adding a wetting agent to the lens material, and surface treatments including plasma, making the lenses more hydrophilic. An example of adding wetting agents to the lens material is Alcon’s Dailies Aqua Comfort Plus lenses, in which the wetting agents are released gradually over 20 hours to provide consistent lubrication. Alcon made another innovation with its Dailies Total1 lenses. The lenses have a silicone core with a 33 percent water content and a hydrophilic surface gel that approaches 100 percent water content.

Another method to improve wettability is the use of lubricant drops and artificial tears, although it can be inconvenient for contact lens wearers who then may use the drops inconsistently. Other methods include the use of surfactant contact lens cleaners and solutions. Not only do the cleaners help remove protein deposits, they interact with the lens surface to make it more attractive to water. Therefore, not only are contact lens materials important in our fitting decisions, but cleaning and disinfecting solutions are as well.

**LENS GROUPS, MATERIALS AND USES**

Let’s take a closer look at the different types of lenses.

**PMMAs**—Although they are still available, “hard” contact lenses have been replaced almost completely by rigid gas permeable lenses. PMMA lenses do not allow oxygen to pass through to the cornea, which makes the permeable RGP lenses preferable and more comfortable. The primary market for PMMA lenses today seems to be patients who “have always worn them” and are resistant to change. Patients also liked being able to use the same lenses for a year or more because scratches could be polished out, while RGP lenses should be replaced every 6 to 12 months, and polishing affects wettability.

**RGPs**—Rigid lenses are a good option for patients with irregular corneas or keratoconus. They are custom made to specific base curves and diameters, and the tear film behind the lens masks the refractive error of the irregular cornea. RGP’s are also available in scleral lenses, which are used when a medical condition such as keratoconus requires a lens that vaults the cornea.

Current RGP contact lenses, with the exception of Menicon Z, are made of either Fluorosilicone Acrylate (Group 3) or Silicone Acrylate (Group 2) and are approved for seven-day wear. Dk values range from 12 to 125. Menicon Z lenses are made from Fluoro-Siloxanyl Styrene, have a Dk of 163 and are approved for 30-day wear. Fluorosilicone Acrylate and Silicone Acrylate brands include Boston, Fluoroperm, Paragon and Optimun.
Lenses in Group 1 are made from CAB and are rarely used because of the availability of higher Dk materials. Likewise, the lenses in Group 4, primarily fluorocarbons, have dropped out of use.

**Hybrid Lenses**—Remember Feinbloom’s glass and plastic scleral lenses? Today’s hybrid lenses have a center of gas permeable material surrounded by a soft skirt to combine the comfort and oxygen permeability of both. After Feinbloom, it was not until 1983 that Precision-Cosmet made the Saturn II, the first true hybrid contact lens.

Prior to the development of hybrid lenses, practitioners would fit a rigid lens on top of a soft lens, known as a “piggyback” fit for patients who needed the correction a rigid lens provided, as in keratoconus and other types of irregular corneas, but the comfort of a soft lens. Of course, working with two lenses, one on top of the other, was cumbersome for patients and limited oxygen permeability.

The early hybrids had design and performance issues including low oxygen transmission and splitting between the rigid and soft materials. In 2005, after four years of development, SynergEyes received FDA approval for its hybrid lens. This lens was an improvement over its predecessors because it consisted of a high Dk gas permeable center with a low water, nonionic skirt and an improved bond between the two materials.

Today, SynergEyes is the primary manufacturer of these lenses, available as single vision and multifocal in a broad range of powers and base curves. In addition to its namesake, other lenses are ClearKone, Duette and UltraHealth.

**HEMA Group 1, Low Water, Nonionic**—This group includes spherical, toric and multifocal lenses made of tefilcon, tetrafilcon A, helfilcon A and B, mafilecon, polyamacon and hioxifilcon B. Water content ranges from 33 percent to 49 percent, with Dk values from 8.9 to 15. Because they are nonionic, these lenses tend to be stable and deposit-resistant. Low water content lenses dehydrate more slowly than higher water content lenses. These characteristics make Group 1 lenses a consideration for patients who experience dry eye and/or heavy deposits. Brands representative of this group include: Preference, Alden, Menicon and Flexlens.

**HEMA Group 2, High Water, Nonionic**—Spherical, toric, multifocal, daily and soft lenses for keratoconus belong to this group. The materials are alfafilcon A, omafilcon A, hioxifilcon A and D, nelfilcon A, nesofilcon A, hilafilcon B, acofilcon A and samfilcon A. Water content ranges from 46 percent to 78 percent, with Dk values from 21 to 163. A number of the lenses in this group are designed for extended wear, a logical result of higher water content and deposit resistance. The higher water content also makes these lenses suitable for comfort in daily disposable lenses. Brands representative of this group include: Proclear, Extreme H2O, Focus Dailies and SoftLens Daily.

**HEMA Group 3, Low Water, Ionic**—Only one product, Metrosoft, fits in this category. These are custom soft lenses available in spherical, toric and multifocal designs. The material is delafilcon A with a water content of 43 percent and a Dk of 10. The manufacturer, Metro-Optics, cites ease of handling and variety of parameters as reasons to consider this lens for custom soft lens fits.

**HEMA Group 4, High Water, Ionic**—This large group includes spherical, toric, multifocal, daily and colors. Materials are etafilcon A, focofilcon A, ocufilcon A, B, C, D and E, phemifilcon A, methafilcon A and B, and vifilcon A. Water content ranges from 46 percent to 65 percent, and Dk values are 15 to 28. Although ionic lenses are more prone to deposits, the high water content of these lenses makes them comfortable for daily disposables, frequent replacement and flexible wear lenses. Brands in this group include Acuvue, Biomedics, Freshlook and Frequency.

**Silicone Hydrogels Group 5**—Lenses in this group include spherical, toric, multifocal and daily. They are subdivided into groups called generations. The generations differentiate lenses by material and treatment to make them more hydrophilic. First generation lenses have surface treatments to make them more hydrophilic. Second generation lenses incorporate wetting agents into the lens material. Third generation lenses have neither surface treatments nor wetting agents, but are made from a more hydrophilic material.

Lenses in the overall group are made from lotrafilcon A and B, narafilcon A, senofilcon A, comfilcon A, enfilcon A, babafilcon A, efrofilcon A, delefilcon A and somofilcon A. Water content ranges from 24 percent to 74 percent, with Dk values from 60 to 140. High oxygen permeability, low water content, comfort, ease of handling because they are a little less flexible than HEMA lenses and variety of lens types makes silicone hydrogels a good choice for most contact lens patients. Brands in this group include Air Optix, PureVision, Biofinity and Clariti 1 Day.

**CONCLUSION**

It has been more than 500 years from da Vinci’s modest start with a bowl of water. Each chapter in the history of contact lenses reinforces the demand for corrective lenses that could be worn on the eye with safety and comfort. The pioneers in contact lens development took advantage of new materials as they became available in addition to coming up with some of their own. This in turn spurred the development of new manufacturing methods to make the lenses more readily available.

The variety of lens designs and materials available today can be daunting to the eyecare practitioner trying to find the best lens for a patient, but it shouldn’t be. The basic principles of contact lens fitting guide the practitioner to the best choice. First, the patient’s vision and eye health needs will indicate whether a rigid or soft lens is preferable. From there, the reason the patient wants contact lenses and how he or she will use them will narrow the field. Remembering the characteristics of the different lens groups leads to brand selection. The fitter’s experience with various brands is invaluable, but don’t be afraid to try something new. As we have seen, something new is always happening with contact lenses.
1. Hydrophobic means the material has:
   a. High water content
   b. Low wetting angle
   c. Resistance to water
   d. Affinity for water

2. Wichterle created this new method to produce contact lenses in 1961:
   a. Lathe cutting
   b. Spin casting
   c. Molding
   d. Extruding

3. The Bionite Naturalens was a:
   a. High water content lens
   b. Low water content lens
   c. PMMA lens
   d. RGP lens

4. Hybrid lenses replaced:
   a. RGPs
   b. “Piggyback” fits
   c. Silicone hydrogels
   d. Hydrogel polymers

5. The first true contact lenses were made of glass in 1887 by:
   a. Mueller
   b. Feinbloom
   c. Wichterle
   d. Obrig

6. High water content lenses:
   a. Are always ionic
   b. Are rigid lenses
   c. Dehydrate more slowly
   d. Dehydrate more quickly

7. Soft lenses are grouped according to:
   a. Diameter
   b. Wettability
   c. Base curve
   d. Water content and electrical charge

8. The first silicone polymer lens was:
   a. Menicon Z
   b. CSI
   c. Synergeyes
   d. Focus Night & Day

9. Dk stands for:
   a. Ionic
   b. Nonionic
   c. Diffusion and solubility
   d. Wettability

10. Ionic and nonionic refers to:
   a. The electrical charge of the lens
   b. Wettability
   c. Oxygen permeability
   d. Affinity for water

11. Da Vinci introduced the concept of a corrective lens that rested directly on the eye using:
   a. Glass
   b. Plastic
   c. Water
   d. Air

12. Hydrophilic means the material has:
   a. Positive electrical charge
   b. Affinity for water
   c. Negative electrical charge
   d. Water resistance

13. Wöhlk-Contact-Linsen introduced a lens made of CAB that was softer and more pliable than:
   a. HEMA
   b. RGP
   c. PMMA
   d. Silicone hydrogel

14. Rigid lenses are grouped according to:
   a. Silicone and fluorine content
   b. Wetting angle
   c. Electrical charge
   d. Diameter

15. The HEMA group containing only one product is:
   a. Group 1, Low Water, Nonionic
   b. Group 2, High Water, Nonionic
   c. Group 3, Low Water, Ionic
   d. Group 4, High Water, Ionic

16. A lens having a rigid center with a soft skirt is:
   a. Impossible to manufacture
   b. Called a hybrid lens
   c. Not recommended for daily use
   d. Difficult to fit

17. Low water content lenses:
   a. Dehydrate more slowly
   b. Dehydrate more quickly
   c. Are made of PMMA
   d. Cannot be ionic

18. Wetting angle is:
   a. Always more than 90 degrees
   b. Always less than 90 degrees
   c. Tear film behind the lens
   d. Angle formed between a drop of liquid and a surface

19. Silicone hydrogel lenses belong to Group:
   a. 5
   b. 4
   c. 3
   d. 2

20. In 1938, Obrig developed a scleral contact lens made of:
   a. HEMA
   b. CAB
   c. RGP
   d. PMMA