# 3.
# Types of Contact Lenses and Their Characteristics[1]

The basic categories of contact lenses currently in use are the original hard (polymethylmethacrylate [PMMA]) lenses, soft hydrogels (hydroxymethylmethacrylate [HEMA] and other materials), and gas-permeable hard lenses (cellulose acetate butyrate [CAB], PMMA-silicone, and silicone). There are variations within each group, but their respective properties are similar enough to consider them as essentially the same type of lenses.

## HARD PMMA LENSES

As discussed in the previous chapter, hard PMMA lenses were the first lenses introduced onto the market, and corneal PMMA lenses similar to those currently in use have been available since the early 1950s. Compared to later types of lenses, PMMA lenses can be difficult to adapt to, and perhaps as many as half of the people fitted do not become long-term wearers. Since PMMA is not water- or gas-permeable, wearers must rely on the "tear pump" action of the eye to provide oxygen to the covered portion of the cornea. As the wearer blinks, tear interchange occurs from outside the lens to beneath it, providing the necessary oxygen. Although hard lenses are very small and cover only a portion of the cornea, many persons may not be able to provide enough tears for comfortable wear. Others may "get by" for 8 to 12 hours but beyond that time, they suffer from dryness, swelling, and discomfort of the eye. Thus, hard lenses are, at best, "daily" wear lenses, but for many people they are very comfortable for that duration.

The positive characteristics of PMMA lenses are numerous. PMMA is made by annealing, a process of successive heating and cooling, which leaves it free of toxic chemicals. It thus is an inert material and safe for use in the eye. It can be molded or lathed into lenses with a high degree of precision. Once made, PMMA lenses can be reworked and modified to customize them to an individual's requirements. The result is a safe lens of excellent visual properties which very closely conforms to patient requirements. PMMA lenses require minimal use of cleaning, soaking, and wetting solutions. They may be tinted to reduce excessive light sensitivity, to make them easier to find when dropped, or for appearance reasons. They are durable, can be renewed by polishing away minor surface scratches, and often last 5 to 7 years or more. Last, they tend to be cheaper than other lens types, because they are an older product with many small suppliers and little difference among different brands.

Despite attempts to improve their permeability by drilling small holes in the lenses ("fenestration"), adding hydrogel to the PMMA, or other modifications, impermeability remains the major shortcoming of rigid PMMA lenses. Because of this impermeability, they cannot cover much of the cornea and therefore must be small. They must be light and thin to adhere to the eye, which precludes their use for correcting corneal astigmatism beyond a moderately severe degree.

In summation, then, hard lenses are effective for daily wear for those persons who have normal or better tearing action and who have mainly single vision refractive problems, such as near-

[1]This discussion of lens types and characteristics is drawn from: Aquavella and Gullapali, 1980 (3); Check, 1982 (8); *Consumer Reports, 1980 (9);* Dixon, 1982 (13); Feldman, 1981 (14); Kersley, 1980 (19); and Morrison, 1976 (27).

sightedness (myopia) and farsightedness (hypermetropia). They are not suitable for those with poor tearing action, high corneal oxygen need, difficult multifocal correction requirements, or who are unable to follow a daily regimen of care, insertion, and removal.

## SOFT LENSES

Soft lenses differ from PMMA lenses in many ways. Their basic soft quality comes from their water absorbency. They are usually gas-permeable, allowing oxygen transport to the cornea. This softness and permeability make them considerably more comfortable than hard lenses, and many wearers can adapt to them almost at once. These qualities can be of great advantage to wearers, but they come at the expense of some visual clarity. Soft lenses, which may contain anywhere from 30 to 90 percent water, can be very flexible, but what is called their "bag of water" nature has an effect on refraction, yielding less clear images than provided by hard lenses. Additionally, high water content lenses are usually fragile and easily torn. Reducing the water content in order to increase acuity and durability, however, sacrifices comfort. Reducing the plastic content to increase acuity by making a thinner lens usually increases fragility. These tradeoffs are the major problem with soft lenses. Further, these lenses cannot be easily modified. The extensive, but limited, inventories of ready-made lenses and the lack of post-prescription customizing cannot possibly meet the exact needs of all wearers. Still, lenses are readily available for the most common refractory corrections and may be available for less common corrections. For most wearers the original fit is close enough, and the flexibility of the lens provides an additional, built-in element of modification.

The comfort and permeability of soft lenses allow for uses beyond the correction of nearsightedness and farsightedness. Some brands have been approved by FDA for 15-day and even 30-day extended wear. Extended-wear lenses offer particular benefits to those who find lens insertion and removal difficult, such as persons with extremely poor eyesight or troubled by arthritis or unsteadiness of the hand. Extended-wear soft lenses, therefore, are often used by persons with aphakia (i.e., those who have undergone lens removal, usually due to cataracts) who may not see well enough without contact lenses to insert them properly, and are of particular value to older persons.

The larger size of soft lenses offers another advantage. They can overlap comfortably onto the scleral portion of the eye and under the lid, which stabilizes the lenses. This allows a soft bifocal or multifocal lens to be tried in those cases of presbyopia (loss of flexibility in adjusting from far to near vision, usually associated with age) where hard PMMA bifocals have not proven successful. Multifocal soft lens are still problematical for most users, particularly as other alternatives exist, such as bifocal eyeglasses; single vision lens-eyeglass combinations; and an unmatched pair of monovision contact lenses, one correcting for nearsightedness, the other for farsightedness. The stability of soft lenses has also led to the recent introduction of soft toric lenses, which are used to correct for uneven focusing of the eye (so-called "corneal astigmatism").

Special problems associated with soft lenses relate to their hydrogel construction, fluid content, and extended-wear functions. The potential exists for the accumulation of both surface deposits and bacteria, and the latter, particularly, was thought to be a serious problem. As a result, special cleaning methods are used, and disinfection techniques are also necessary. First, "hot" methods of disinfection (e.g., boiling), and then "cold" methods (chemical solutions) were developed and appear to be equally effective in preventing serious problems that might otherwise develop in wearing waterlogged lenses for long periods of time. However, these cleaning and disinfection methods are costly, raising the expense of maintaining soft lenses to upwards of $100 a year or more and stimulating the growth of a sizable lens care products industry (31).

## GAS= PERMEABLE LENSES

Gas-permeable lenses are the newest type to appear and are made of either CAB, a PMMA-silicone combination, or pure silicone. They are rigid lenses, with the optical properties of PMMA lenses, but approach soft lenses in comfort because of their permeability. They take more getting used to than soft lenses do but require considerably less care. Their rigidity helps to correct astigmatism, they are small but easy to handle, and they have recently become available in tints. Of the three types of gas-permeable lenses, the PMMA-silicone combination is the most preferred at present, but the pure silicone lens has proved popular since its introduction.

## PRESENT USAGE AND FUTURE TRENDS

Both governmental and trade sources provide data on current levels and trends in contact lens use, but they are in some disagreement. Comparisons of the data in table 2, which contains estimates from the National Health Survey on corrective lens usage in 1966, 1971, and 1977, and that of table 3, which contains estimates from industry sources for the period 1970-82, show that, where the two sets overlap, the governmental statistics are considerably more conservative. For example, the National Health Survey estimates of total lens wearers in 1971 and 1977 are 2.4 million and 7.0 million persons, respectively; the trade data for 1970 and 1975 suggest that there were 8.0 million and 11.0 million lens wearers in those years. The wide gap between these two sets of estimates is explainable if the National Health Survey data relate to those who wear contact lenses, and the industry data, to those who have purchased them. In any case, caution is called for in making definitive statements about rates of sales and levels of usage of contact lenses. The subsequent analysis of trends and levels of contact lens wear derives mainly from the data in table 3, which are more detailed and current, if higher, than the data in table 2.

The numbers of eyeglass and contact lens wearers appear to have grown at fairly steady rates since 1979, with eyeglass wearers increasing by about 5 million per year and contact lens wearers by about 1.5 million per year. Since the number of new contact lens patients per year is well above 1.5 million, it appears that substantial attrition or failure rates do occur. The stable growth rate among lens wearers, however, may be only a temporary phenomenon. Since new (as opposed to replacement) contact lenses are expensive and usually represent an alternative to eyeglasses for cosmetic reasons, it is likely that the recession of the early 1980s had a significant negative effect on lens purchases. Additionally, the sales data probably do not yet reflect the ultimate acceptance levels of recent contact lens innovations.

Perhaps the more meaningful implications of the data relate to patterns among contact lens types rather than to aggregated totals. Here, the data tell a less ambiguous story. The older hard lenses are declining in total usage, having dropped from 10 million to 7.1 million wearers between 1975 and 1982. Each year they have accounted for a declining share of both new and replacement

**Table 2.—Persons Wearing Corrective Lenses: 1966, 1971, and 1977**

| | 1966 | 1971 | 1977 |
|---|---|---|---|
| | *In millions* | | |
| Population 3 years and over | 178.9 | 191.6 | 202.9 |
| Wearing corrective lenses | 86.0 | 94.3 | 103.3 |
| Eyeglasses only | 84.2 | 90.3 | 96.3 |
| Contact lenses, with or without eyeglasses | 1.8 | 2.4 | 7.0 |
| | *Percentages* | | |
| Percent of population wearing lenses | 48.1 | 49.2 | 50.9 |
| Eyeglasses only | 47.1 | 47.1 | 47.5 |
| Contact lenses, with or without eyeglasses | 1.0 | 1.3 | 3.5 |

SOURCES: 1966: U.S. Department of Health, Education, and Welfare, *Characteristics of Persons With Corrective Lenses, United States: July 1965-June 1966,* Vital and Health Statistics, series 10, No. 53, prepared by M. M. Hannaford, DHEW publication No. (PHS) 1000 (Washington, DC: U.S. Government Printing Office, June 1969). 1971 and 1977: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States,* 1982-83 (103 cd.), Washington, DC, 1983.

**Table 3.—Persons Wearing Corrective Lenses: 1970, 1975, 1978"-2 (trade data sources) (millions)**

| | 1970 | 1975 | 1978 | 1979 | 1980 | 1981 | 1982 (est.) |
|---|---|---|---|---|---|---|---|
| Population requiring vision correction | 100.0 | 107.0 | 112.5 | 118.0 | 125.0 | 131.5 | 138.0 |
| Corrective lens wearers | | | | | | | |
| Eyeglasses | 92.0 | **96.0** | 100.1 | 105.2 | 110.5 | 115.0 | 120.0 |
| Contact lenses | 8.0 | 11.0 | 12.4 | 12.8 | 14.5 | 15.0-16.5 | 16.3-18.0 |
| Hard | 8.0 | 10.0 | 9.0 | 8.0 | 8.0 | 7.8 | 7.1 |
| soft | – | 1.0 | 3.4 | 4.8 | 6.2 | 6.6-8.1 | 8.3-10.0 |
| Gas-permeable | — | — | — | — | 0.3 | 0.6 | 0.9 |
| New contact lens patients | — | 0.9 | 3.3 | 4.5 | 3.0-4.4 | 3.2-4.6 | 2.8-4.3 |
| Hard | — | — | 1.7 | 1.8 | 1.2 | 1.0 | 0.5 |
| soft | – | 0.9 | 1.6 | 2.4 | 1.4-2.8 | 1.8-3.2 | 1.9-3.4 |
| Gas-permeable | — | — | — | 0.3 | 0.4 | 0.4 | 0.4 |
| Replacement contact lenses (pairs)[a] | — | 0.3 | 1.6 | 2.1 | 2.2 | 2.5-4.1 | 2.7 |
| Hard | — | — | 0.9 | 1.0 | 0.8 | 0.7 | 0.4 |
| soft | – | 0.3 | 0.7 | 1.1 | 1.3 | 1.7-3.3 | 2.7 |
| Gas-permeable | — | — | — | — | 0.1 | 0.1 | 0.1 |
| Total contact lens sales (pairs)[a] | — | 1.2 | 4.9 | 6.5 | 6.6 | 7.0-7.2 | 7.0 |
| Hard | — | — | 2.6 | 2.7 | 2.0 | 1.6 | 0.9 |
| soft | – | 1.2 | 2.3 | 3.5 | 4.2 | 4.9-5.1 | 5.6 |
| Gas-permeable | — | — | — | 0.3 | 0.4 | 0.5 | 0.5 |

[a]Includes single lenses as half pairs.

SOURCES: L. Schwarz and D. K. Temple, Contact *Lens Industry-The Shakeout Continues* (New York: Salomon Bros., Inc., 1983).

levels, and now represent only a small proportion, estimated at less than 15 percent, of each category. Soft lens wearers have increased substantially, particularly as the result of their dominance in the new lens market. (While soft lenses also account for most of the replacement market, a high fraction of these sales probably replace previous soft lenses, which, as noted earlier, have a short life span.) Gas-permeable lenses, the newest type on the market, exhibit a steady growth rate, accounting for 5 percent or more of all contact lenses in use, 10 to 15 percent of the lenses for new wearers, and about 10 percent of all current lens sales. Market share data for the three lens types are given in table 4.

Current trends are easily ascertained, but what of the future? That question can be addressed by dividing the actual and potential lens wearer population into four groups according to their visual correction requirements, and considering each separately in relation to the present and future characteristics of contact lenses.

Those with uncomplicated single vision problems (nearsightedness and farsightedness) comprise the first and largest of these groups. Because they represent a large share of the total market and are easy to fit with one or more types of lens, this is where the greatest market penetration has occurred, although, as was implied by the data in tables 2 and 3, the overwhelming majority within this group still rely wholly on eyeglasses. Since, on average, the total costs of contact lenses (lenses and fittings) are more than for eye glasses, price remains unimportant variable in determining the rate of shift from ''eyeglasses only'' to contact lens use, with or without eyeglasses.

**Table 4.–Share of U.S. Contact Lens Market by Lens Type, 1978.87 (est.)**

| | 1978 | 1979 | 1980 | 1981 | 1982 (est.) | 1987 [est.] |
|---|---|---|---|---|---|---|
| Soft lenses | 49% | 54% | 64% | 70% | 75% | 65-75% |
| Hard lenses | 51 | 39 | 27 | 21 | 15 | 5 |
| Gas-permeable lenses | — | 6 | 8 | 9 | 10 | 20-30 |
| Total | 100% | 100% | 100% | 100% | 100% | 100% |

NOTE: Figures may not add due to rounding.

SOURCE: L, Schwarz and D. K. Temple, Contact *Lens Industry-The Shakeout Continues* (New York: Salomon Bros., Inc., 1983)

The second and third components of the total market also are large, but the difficulties in developing wearable lenses have left most of this market untapped. These two groups are, respectively, the moderate-to-severe astigmatic, and those with presbyopia, for which bifocal or multifocal corrective lenses are usually employed.

By and large, the use of contact lenses in these three groups can be considered "cosmetic," since, with some exceptions, eyeglasses readily afford satisfactory levels of correction. For the fourth market segment, however, contact lenses can be considered therapeutic, since, using the same criterion, eyeglasses have limited capability for correction. In this group are those who suffer from corneal abnormalities such as keratoconus and other pathological conditions such as trachoma, corneal ulcers, and scarred corneas *(20).*

Projections for contact lens use for the short-run future can be made by extrapolating current market trends; for the medium-run future by estimating the effects of changes currently underway or impending but which have not yet materialized as strong market factors; and for the long-run future by predicting the effects of changes that today may be only hypotheses, concepts, or ideas.

In the short run, current trends are likely to continue. Contact lens wearers will increase steadily, if slowly, as a percentage of the total vision-corrected population. Soft and gas-permeable lens wearers will grow and hard lens wearers will decline as percentages of the total contact lens-wearing population. Sales of soft lenses will grow as the currently strong competition in innovation and improvement creates increasingly satisfactory products for those who have not yet adopted lenses or have failed with hard lenses. The unique qualities of soft lenses will make them increasingly attractive to those persons with visual problems not resolvable with hard or the earlier soft lenses. Accordingly, growth in the use of soft lenses is likely, perhaps at a rate of 10 to 15 percent per year as their uses for single vision problems, astigmatism, presbyopia, and therapeutic applications expand. Further, as the majority of lens wearers shifts to soft lenses, their fairly short average duration *(9* to 18 months) will generate a very sizable replacement lens market.

The use of gas-permeable lenses will also grow rapidly as users of hard lenses switch over, nonusers adopt them, and those who might otherwise select soft lenses are attracted by the lower long-term costs (from less frequent replacement and simpler care procedures), and excellent vision correction of the gas-permeables. An additional attraction is that these lenses, unlike the soft ones, can be readily custom-fitted. Thus, over the next 5 years gas-permeable contact lenses will contribute substantially to the decline of hard lenses and may also take part of the market that would otherwise be won by soft lenses. Their percentage growth rate will be especially impressive, given the present small base against which that rate will be calculated.

Beyond the extension of present trends into the short-run, certain projections for the medium-run future can be made if one looks at forces of change currently in their incipiency. At present, soft lenses are fragile and not reworkable. However, promising advances in plastics and in lens manufacturing technology will result in more durable and more precisely fit soft lenses. Combined with their comfort and extended-wear capabilities, these improvements will enable soft lenses to protect their market position relative to gas-permeable lenses. As long as they remain distinguishable lens types, both soft and gas-permeable lenses will grow steadily in use. Together, they will render hard lenses obsolete, and each will find its respective market position. Soft lenses will be the product of choice for those with single vision problems who place a high premium on comfort and extended wear, and they will be especially useful for presbyopia and for conditions not correctable with eyeglasses. On the other hand, gas-permeable lenses will be attractive to the single vision problem wearer who finds them sufficiently comfortable and prefers their overall economy, ease of application, and current availability in tints.

The recent introduction of extended-wear gas-permeable lenses, however, provides a strong hint that the eventual merging of the two main types of lenses has begun and that the future will bring a new, hybrid type of lens combining the best features of both. But in the long run, many other

changes which today may only be in their basic research stages will play prominent roles, and all predictions are very uncertain. However, based on what is on the horizon today, the long-run futures of both soft and gas-permeable lenses look promising, possibly more so for soft lenses, if the distinction continues. New soft lens developments, such as optically superior, nontoxic materials requiring minimal care even in extended use, and lens-making methods that allow more exact fitting and duplication, can be expected. And as new manufacturing methods—e.g., improvements of today's low-cost spin-casting method—reduce costs, the popularity of soft lenses should increase. Accordingly, the lens of the future may well be a low-cost, easy-to-wear, visually near-perfect, extended-wear, disposable lens.

A hybrid lens that provides the best qualities of both soft and gas-permeable lenses is a distinct possibility, as mentioned. If it develops, then the terms soft and (hard) gas-permeable will be obsolete. An additional quality of the lens of the future will be durability, which may make lenses still more affordable by reducing replacement costs, and may increase their attractiveness to users by making them more interchangeable with eyeglasses, since they will be able to be handled more often without damage.

Finally, in the past, many of the important developments in contact lenses originated from a wide range of scientific and industrial sources. This lesson of the long-term past is particularly applicable to the long-term future. The technologies of electronics, imaging, optics, and all of the other sciences are expanding exponentially. In the long run, then, contact lenses will make substantial gains as a form of corrective eyewear. Given their potential development, it is at least conceivable to project their displacement of eyeglasses as the dominant method of vision correction in the not-too-distant future.