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Cataract

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"Cataract" refers to an opacity in the natural, crystalline lens of the eye. Although cataract surgery has been performed for more than 2,000 years, cataract remains the most common cause of blindness in the world today (Dawson and Schwab 1981; Whitfield and others 1983; Al Salem and Ismail 1987; Schwab 1987). The World Health Organization (WHO) estimates suggest that 17 million people are currently blinded by cataract (Wilson 1980) worldwide. New data show that in China alone there are 5.4 million cases of cataract blindness, suggesting that the world total may be higher than previously thought (CDC 1983). As of 1983, incident cases of cataract-related blindness exceeded 1.25 million annually (CDC 1983). Because of increasing life span and an expanding elderly population in the developing world, the prevalence of blinding cataract is expected to double by the year 2010.

The crystalline lens of the eye is normally transparent and, together with the cornea, focuses light on the retina. Although a small degree of opacity may interfere minimally with vision, cataract can and frequently does cause severe vision loss. Cataract blindness, according to the definition of the World Health Organization, results when the degree of opacity reduces vision to less than 3/60 (i.e., inability to recognize the largest letter) on the standard eye chart.

Cataract progression is characterized by painless, progressive loss of vision. In general, vision loss induced by cataract is entirely reversible upon removal of the opacified lens. Only occasionally can cataract-induced lens swelling or leakage cause permanent damage to the eye.

Like many degenerative and disabling conditions associated with age, blindness from cataract is associated with complete disability, an increased need for support from family members, loss of social status and authority within the family and community, and early demise. Unlike many degenerative and disabling conditions, however, cataract blindness is entirely curable. The current cost of restoring sight in a mass-surgery program ranges from $15 for cataract extraction in an Indian eye camp (temporary mass surgical facility) to $22 in an African mobile surgical facility to $33 in an urban Latin American public hospital (HKI 1986). The limited studies conducted to date suggest that restoration of sight by cataract surgery produces economic and social benefits to the individual, the family, and the community that far outweigh the investment in surgery. A study in rural India found that individuals undergoing cataract surgery demonstrated increased productivity amounting to a 1,500 percent annual return on the cost of the surgery (Javitt, Venkataswamy, and Sommer 1983).

Public Health Significance of Cataract

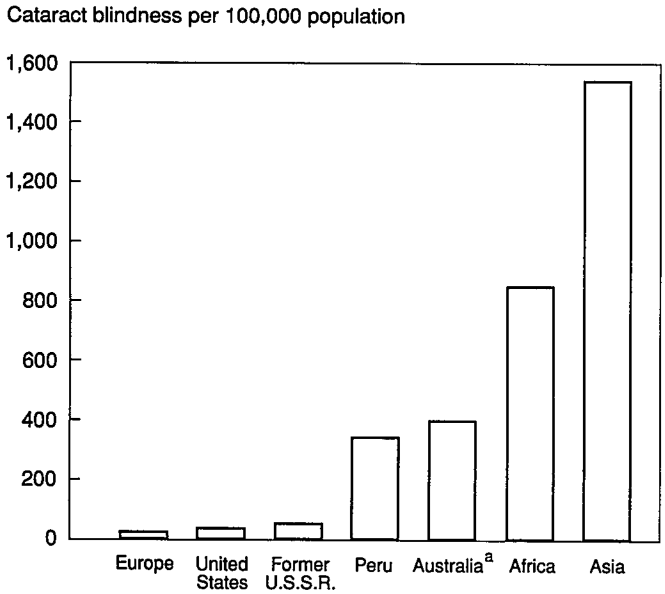
The current backlog of curable blindness from cataract is the result of an interplay between disease incidence, surgical rates, and mortality. As illustrated in figure 26-1, most individuals in the developing world who are blind from cataract are likely to be so for the rest of their lives. Only the minority are likely to have sight restored. Decreasing the backlog of cataract blindness can be achieved both by increasing the volume of curative surgery and decreasing risk factors for cataract wherever possible. These strategies must include not only increased provision of care but also operations research to determine methods for increasing individual participation in care.

Current Levels and Trends in the Developing World

Enormous variation exists in the prevalence of cataract blindness worldwide. As can be seen from figure 26-1, rates range from 14 per 100,000 people (0.014 percent) in Scandinavia to 1,525 per 100,000 (1.525 percent) in Asia (WHO Programme for the Prevention of Blindness 1987). The prevalence of a disease in the population is a function of its incidence in that population, the duration of disease in those affected, and the likelihood that the disease will resolve on its own, be cured, or result in an increased risk of mortality. Variations in any one of these factors may lead to variation in observed prevalence. There are several possible explanations when the prevalence of cataract blindness is higher in one region than another:

- An increased incidence of cataract by age group
- An increased longevity of those with cataract or of older persons in general
- A decreased likelihood that individuals with cataract will have sight-restoring surgery

Figure 26-1. Prevalence of Cataract Blindness, by Region



a. Aboriginal population.
Source: Wilson 1980.

- Errors and biases in data collection that may affect data validity

In considering the epidemiology of cataract blindness, one must study variations in the incidence of cataractous change, in the rate of progression to cataract blindness, in the likelihood that an individual will receive cataract surgery, and in the longevity of individuals who are blind from cataract.

The prevalence of cataract blindness varies substantially, not only from continent to continent but within smaller regions as well. The prevalence of blindness reported from survey data published by the World Health Organization is shown in table 26-1. The data presented are all drawn from government-sponsored blindness surveys that specifically addressed the rate of cataract-related blindness in relation to other causes of blindness. A critical consideration of the sampling techniques and survey methodology employed in each country is beyond the scope of this chapter. The reader must evaluate the reliability of the underlying data, however, before drawing conclusions based upon small variations in cataract rates from one region to another.

Even within a country, rates of cataract blindness obtained from survey data may vary considerably. In table 26-2 the rates from nine provinces of China are shown (WHO 1987). In comparing Hunan and Sichuan, it is important to note that, although the overall prevalence of blindness is the same, the prevalence of cataract blindness in Sichuan is double that of Hunan. Because of the large number of people examined, the reliability of these data is unusually high and, assuming that unbiased samples were obtained, the likelihood that the observed difference could have been observed if chance alone was operating is less than 1 percent ($p < .01$).

Cataract Surgery in Developing Countries

Approximately 1 million cataract extractions were performed in 1988 in both India (Venkataswamy, 1987) and the United States (HCFA 1986), although the population of India is more than triple that of the United States. Even if the prevalence of cataract were equal in the two countries, the lower rate of surgery might account for a good portion of the excess in cataract blindness. Fewer than 10 percent of blinding cataracts are extracted annually in developing countries (HKI 1986). Although cataract has recently been shown to be the leading cause of blindness in an American urban population, the overall prevalence of cataract blindness is an order of magnitude lower than in the developing world (Sommer and others 1991).

One way to estimate the effect of variations in rates of cataract surgery on overall prevalence of cataract blindness is to examine the prevalence of cataractous change by age. If individuals with cataract and those who have had cataract extraction are combined, such a survey should yield a reliable indication of the overall prevalence of cataract by age in the population.

Few surveys of this type have been conducted because the survey methodology to detect any clinically significant degree of cataract is far more complex than that required to detect blinding cataract. In the United States, researchers for the Framingham Eye Study examined a representative sample of residents of Framingham, Massachusetts, a primarily white, middle-class community (Sperduto and Hiller 1984). Researchers for a second American study, the National Health and Nutrition Examination Survey, drew a random sample of all Americans, based upon census data (Ederer, Hiller, and Taylor 1981; Hiller, Sperduto, and Ederer 1983). In figure 26-2 the U.S. data are compared with those obtained in the Nepal Blindness Survey, a random cluster sample of the entire kingdom of Nepal (Brilliant and others 1988). This is the only epidemiologic survey in developing countries in which the entire population of a country has been sampled and studied for eye disease.

As is readily apparent from figure 26-2, even when cataractous and aphakic individuals are combined, the prevalence of cataract is substantially higher in Nepal than in the United States in each age group. Thus, the difference in surgical rate alone does not account for the higher rate of cataract blindness observed in at least one developing nation. Because some degree of lens change inevitably accompanies aging, these data may also be interpreted to suggest that individuals in Nepal develop cataract at a younger age than their counterparts in the United States.

If the prevalence of cataract itself is truly greater in the developing world, there are only two possible explanations. Either the incidence of cataract by age is greater in developing countries, or persons with cataract in such countries live longer

Table 26-1. Prevalence of Cataract Blindness, by Country

Country	Prevalence of blindness	Percent of blindness from cataract	Prevalence of cataract blindness	Population (millions)	Population with cataract blindness (millions)
Africa					
Botswana	1.4	0.45	0.63	1.01	0.01
Chad	2.3	0.48	1.104	4.79	0.50
Egypt	3.3	0.32	1.056	44.50	0.47
Ethiopia	1.3	0.46	0.598	33.68	0.20
The Gambia	0.7	0.55	0.385	0.80	0.00
Kenya	1.1	0.67	0.737	18.78	0.14
Liberia	2.1	0.45	0.945	2.06	0.02
Malawi	1.3	0.40	0.52	6.43	0.03
Mali	1.3	0.32	0.416	7.53	0.03
Nigeria	1.5	0.41	0.615	89.02	0.55
Sudan	6.4	0.30	1.92	20.36	0.39
Togo	1.3	0.45	0.585	2.76	0.02
Tunisia	3.9	0.52	2.028	6.89	0.14
Zimbabwe	1.2	0.40	0.48	7.14	0.03
Americas					
Brazil	0.3	0.10	0.03	129.70	0.04
Peru	1.0	0.34	0.34	18.70	0.06
United States	0.2	0.13	0.026	233.70	0.06
Asia					
Afghanistan	2.0	0.31	0.62	17.22	0.11
Bangladesh	0.9	0.33	0.30	94.65	0.28
China[a]	0.875	0.22	0.14	1040.00	1.41
Hong Kong	0.2	0.34	0.07	5.31	0.01
India	0.5	0.55	0.27	732.00	2.01
Indonesia	1.2	0.67	0.80	159.00	1.28
Japan	0.3	0.23	0.07	119.00	0.08
Korea	0.1	0.361	0.04	40.00	0.01
Nepal	0.8	0.67	0.54	15.74	0.08
Pakistan	2.3	0.60	1.38	89.00	1.23
Saudi Arabia	1.5	0.55	0.82	10.40	0.09
Sri Lanka	2.0	0.46	0.92	15.00	0.14
Syrian Arab Rep.	0.3	0.35	0.10	9.60	0.01
Thailand	1.1	0.57	0.62	49.00	0.31
Viet Nam	0.8	0.39	0.31	57.00	0.18
Yemen, Rep. of	3.6	0.34	1.22	2.16	0.03
Europe					
Germany	0.1	0.04	0.004	61.42	0.002
Norway	0.2	0.07	0.014	4.13	0.001
Sweden	0.3	0.05	0.015	8.00	0.001
U.S.S.R.[b]	0.27	0.16	0.0432	272.50	0.12

a. Average.
b. Entire country (European and Asian parts).
Source: WHO Programme for the Prevention of Blindness 1987.

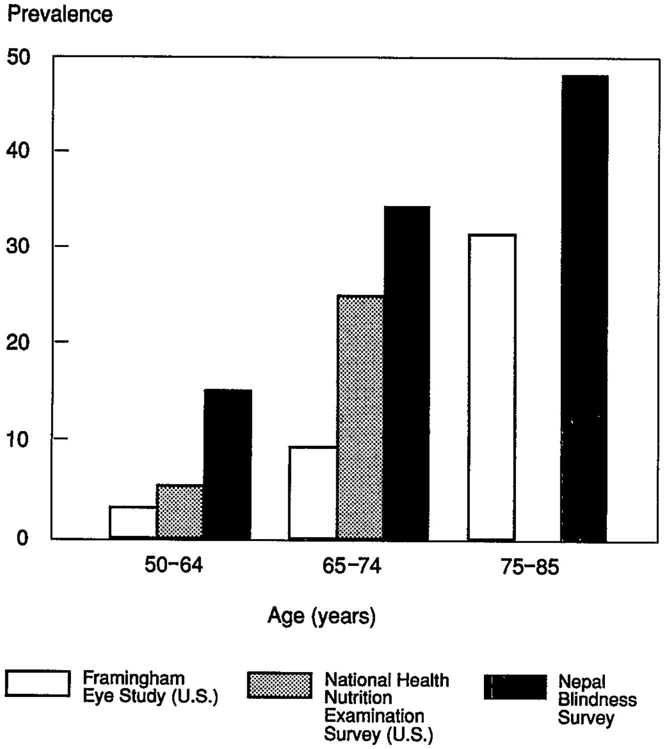
than those in the industrial world. Because the rate of mortality from all causes of those between the ages of forty-five and sixty-five in Asia is 1.65 times that of the industrial world and the mortality rate of those over sixty-five 1.25 times greater, increased longevity is an unlikely explanation for the increased prevalence of cataract. Increased incidence of cataract in developing countries must play a significant role.

Although the evidence strongly suggests an increased incidence of cataract in the developing world, few actual studies of cataract incidence have ever been conducted. Whereas prevalence surveys require that a large population be randomly sampled, recruited for study, and examined, incidence surveys require that those same individuals be located and reexamined after a defined time interval. The logistics and expense of conducting a longitudinal study of this nature are orders of magnitude greater than for a prevalence study.

Possible Explanations for Increased Cataract Incidence

One cannot rule out genetic differences as an explanation for increased cataract incidence in developing countries, but these factors are least amenable to modification. During the past

Figure 26-2. Prevalence of Cataract by Age, United States and Nepal



Note: No data for population age 78–85 in the National Health Nutrition Examination Survey.
Source: Framingham Eye Study (Sperduto and Hiller 1984); National Health Nutrition Examination Survey (Hiller, Sperduto, and Ederer 1983); Nepal Blindness Survey (Brilliant 1988).

decade, epidemiologists and lens biochemists have worked to gain a better understanding of the process of cataract formation and the role played by nutritional and environmental factors.

Although "age-related" or "senile" cataract is the most prevalent form, cataracts may be metabolic, traumatic, nutritional, or toxic in etiology. In general, cataract results from a denaturation of natural proteins within the lens of the eye. Just as the clear albumin of an egg white congeals, opacifies, and turns white with heat, the natural crystalline proteins of the lens are known to coalesce and discolor in response to certain stimuli.

Table 26-2. Prevalence of Cataract Blindness in Nine Provinces of China

Province	*Prevalence of blindness*	*Percent of blindness from cataract*	*Prevalence of cataract blindness*	*Population examined*
Fujian	0.2	0.35	0.07	50,620
Sichuan	0.3	0.4	0.12	21,869
Hunan	0.3	0.2	0.06	94,222
Anhui	0.7	0.36	0.25	13,852
Tianjin City	0.3	0.39	0.12	74,348
Guangdong	0.4	0.571	0.23	10,180
Guangxi	0.5	0.37	0.19	26,210
Heilonjiang	0.2	0.39	0.08	40,097
Huairon County	0.5	0.16	0.08	10,063

Note: Based on government-sponsored surveys.
Source: WHO Programme for the Prevention of Blindness 1987.

Cross-linking and denaturation of lens proteins have been produced in laboratory settings by ultraviolet light and chemical oxidants. Thus, "oxidative-stress" from a variety of causes may be a common mechanism in the formation of cataract. The human lens is constantly exposed to oxidant stress, both from environmental light and from naturally occurring free radicals that are ubiquitous in the human body. Highly efficient enzyme systems are present within the eye to prevent damage from these agents. Inquiry into the etiology of cataract has therefore focused upon the environmental and nutritional exposures of individuals with cataract as well as any deficiencies that may exist in their antioxidant enzyme systems.

ASSOCIATION WITH DIABETES. Diabetes has been associated with an increased risk of cataract in Americans under fifty-five years of age (Hiller, Sperduto, and Ederer 1983) as well as with an increased rate of cataract surgery (Hiller and Kahn 1976). However, diabetes-related cataracts account for only 6 percent of all cases in the United States and an even lower proportion of cases worldwide. Despite this, cataract formation in diabetics is of substantial research interest, because of evidence that the underlying biochemical mechanism may involve the abnormal formation of sugar alcohols (sorbitol) in the lens, resulting in subsequent lens swelling and opacification. Human studies are now under way to determine if inhibition of this biochemical pathway is feasible and if such inhibition reduces the rate of cataractogenesis in humans. The longevity of diabetics in the developing world is substantially lower than elsewhere, and thus diabetes is unlikely to account for the excess cataract rate.

ASSOCIATION WITH SUNLIGHT. The association of cataract and sunlight has long been suspected on the basis of case-control studies. Hiller and colleagues found a higher cataract-to-control ratio for persons age sixty-five or older in areas with longer duration of sunlight (Hiller, Giacometti, and Yuen 1977; Hiller, Sperduto, and Ederer 1983). Taylor (1980a) reported an association of cataract with increased ultraviolet light, latitude, and average hours of sunlight. Other investigators have noted higher prevalence of cataract among Tibetans living at altitudes of 4,000 meters than those living at altitudes of 2,000 meters (Wen-shi 1979). Although a survey of 29,683 residents of the Punjab revealed a lower prevalence of cataract among those who lived in mountain regions than among those on the plains (Chatterjee, Milton, and Thyle 1982), this study did not control for the effect of cloud cover on the actual hours of sunlight exposure in each region. Researchers in the Nepal Blindness Survey calculated mean sunlight exposure for each village sampled on the basis of altitude, skyline obstructions, and cloud cover. As can be seen from table 26-3, there was a strong association between average daily sunlight hours and cataract prevalence (Brilliant and others 1983, 1988). Even so, this study controlled only for the sunlight exposure of the

Table 26-3. Cataract Prevalence by Average Daily Hours of Sunlight

Sunlight[a]	Population examined	Cataract cases	Prevalence (per 100)	Odds ratio
Low (7–9 hours)	7,236	133	1.84	1.0
Medium (10–11 hours)	10,263	221	2.15	1.2
High (12 hours)	10,286	476	4.63	2.6

a. Based on sunlight exposure for lifelong residents of ninety-seven rural villages.
Source: Brilliant and others 1988.

village and did not take into account the exposure of individuals based upon their occupations and use of such protective clothing as hats.

Taylor and co-workers (1988) addressed the issue of individual exposure to sunlight and ultraviolet radiation in their survey of 838 Maryland watermen who earn their living by fishing on the Chesapeake Bay. Using dosimeters, the researchers correlated the watermen's actual ocular exposure to ultraviolet radiation (UVR) with working hours, sheltered vs. unsheltered work sites, and protective devices worn. They found a clear association between increased exposure to UVR and the presence of cortical cataract. As reported in a related paper by Bochow and others (1989), the outdoor worker wearing sunglasses and a hat has only twice the exposure to UVR of the indoor worker. When no eye protection is worn, however, the exposure of the outdoor worker to UVR is eighteen times that of the indoor worker. The authors of this related study compared patients suffering from posterior subcapsular cataract who were exposed to UVR during sunlight hours with normal controls who were similarly exposed. A strong association ($p < .001$) was detected between ocular sunlight exposure and cataract.

ASSOCIATION WITH NUTRITIONAL AND METABOLIC FACTORS. Although nutritional factors might be intuitively associated with cataract, their significance is quite difficult to prove. Blood levels of vitamins reflect only current nutritional status and cannot detect previous periods of hypovitaminosis. An association between cataract and diet was observed in the Nepal Blindness Survey, in which vegetarians who never ate meat or fish were found to have twice the cataract prevalence of those who ate fish or meat, even occasionally (Brilliant and others 1988). A caveat in interpreting these data is that vegetarianism was most common in the regions with the highest sunlight exposure and it was impossible to separate these two possibly interacting variables.

In their study of the Punjab, Chatterjee, Milton, and Thyle (1982) reported a relative increase in prevalence of cataract among individuals with lower protein consumption. The authors of the Indian and U.S. case-control study of age-related cataracts (Mohan, Sperduto, Angra, and others 1989) similarly detected an increased risk of posterior subcapsular and nuclear cataract in those individuals who had a history of a diet deficient in protein. Biochemical analysis from the same study detected an association with lower levels of ascorbic acid. In a case-control study of Americans with and without senile cataract reported by Jacques and co-workers, the risk of cataract was reduced for individuals with higher blood levels of carotenoids, vitamin D, and vitamin E, whereas the risk was increased for those with lower levels of vitamin C (Jacques, Hartz, Chylack, McGandy, and Sadowski 1988).

Carotenoids, along with vitamins C and E, are potent antioxidants and thus quench free radicals. Therefore, if the theory of oxidative stress is valid, it should not be surprising that their levels are associated with cataract risk. Jacques, Chylack, McGandy, and Hartz (1988) reported that higher levels of an "antioxidant index," composed of vitamins C and E and carotenoids, along with antioxidant enzymes found in red blood cells were associated with lower risk of cataract. Corroborating data regarding this antioxidant index were reported from the Indian and U.S. case-control study (Mohan and others 1989).

ASSOCIATION WITH SEVERE DIARRHEA AND DEHYDRATION. Minassian, Mehra, and Jones (1984) have advanced the theory that severe diarrhea and subsequent dehydration might lead to an elevated level of blood urea nitrogen and, thus, to alteration of lens proteins and cataract. This theory, attractive from the biochemical point of view, has not been corroborated in epidemiologic studies. Khan, Khan, and Sheikh (1987) found no correlation between cataract risk and cholera-related diarrhea in a case-control study performed in Bangladesh. Similarly, Bhatnagar and colleagues (1988) found no association between cataract and remembered episodes of severe diarrhea from a study in South India.

Lowering or Postponing Disease Incidence

Currently, there are no proven interventions that prevent cataract or delay its onset. Although cataract surgery is likely to remain the most cost-effective means of treating an existing cataract, strategies that decrease or delay the onset of cataract are of vital importance. Because of the strong association between cataract and aging, a ten-year increase in the average life span in developing countries is likely to double the prevalence of cataract. Similarly, a ten-year delay in the onset of cataract would halve its prevalence in the population. Although this may seem an impossible task, one must remember that eighty-year-old residents of Framingham, Massachusetts, have the same prevalence of cataract as seventy-year-old residents of India and Nepal. Although nutritional and metabolic deficiencies may serve as a risk factor for cataractogenesis, interventions in this area go far beyond the scope of eye disease. Even if improved nutrition does delay the onset of cataract, the interventions required are identical to those required to combat all other malnutrition-associated conditions in developing countries.

If, in fact, exposure to ultraviolet radiation is a risk factor for cataractogenesis, public health interventions that decrease ocular UVR exposure may have a useful role. They are intriguing from the international development point of view in that they may be quite inexpensive. Rosenthal and co-workers (1988) have shown that a brimmed hat reduces ocular UVR exposure by approximately 50 percent, and the addition of UVR-absorbing sunglasses further lowers transmission to 1 percent of ambient UVR. Whereas UVR-absorbing sunglasses are expensive to manufacture and obtain by the standards of developing countries, locally manufactured hats of straw or other ubiquitous materials are practically free. Furthermore, although properly manufactured UVR-absorbing sunglasses may potentially block 86 percent to 99 percent of ambient UVR, a 0.6 centimeter displacement of sunglasses away from the forehead results in a substantial increase in ocular UVR exposure (Rosenthal, Bakalian, and Taylor 1986). Additional studies need to be performed in which individual exposure to UVR is measured during outdoor activities and inexpensive interventions are tested.

Reducing the Burden of Cataract Blindness

The National Eye Institute and its collaborating institutions have embarked on a long-term research effort to develop drugs that may delay the onset of cataract. Although this research has yielded invaluable insight into the biochemistry of the lens and possible metabolic pathways of cataractogenesis, clinical trials are only in the earliest planning stages. A chemotherapeutic strategy that could delay the onset of cataract by ten years in the United States would have the potential to save $500 million or more annually in surgical costs. Because of the low cost of cataract extraction in developing countries and the likely high cost of chronic use of any new drug, it will probably be many years before this can be a cost-effective strategy for the developing world.

Cataract Surgery in Developing Countries

Once cataract has developed, the only known treatment is surgical removal. Helen Keller International has reported that the cost of cataract extraction ranges from $15 in a mass-surgery setting on the Indian subcontinent to $22 in an African mobile surgical facility, to $33 in an urban Latin American public hospital (HKI 1986). Fortunately, cataract extraction is highly successful, even with the limited resources, lower standards of sterility, and older instruments found in developing countries. Substantial improvements in outcome of surgery were achieved during the 1960s and 1970s, when microsurgical techniques and watertight closure of cataract wounds with fine silk or nylon sutures were universally adopted.

There remain two main methods of cataract extraction today: extracapsular cataract extraction (ECCE), which has been adopted by nearly all the industrial world, and intracapsular cataract extraction (ICCE), which is employed in less than 10 percent of cases in the United States and considerably more frequently in the developing world. The latter type of extraction involves removing the entire lens with disruption of the zonular fibers which form the attachment of the lens capsule to surrounding ocular structures. The former entails incising the lens capsule, expressing the lens nucleus and aspirating remaining lens cortex, leaving intact, if all goes well, the lens capsule and its zonular attachments. The ECCE method enables the surgeon to insert an intraocular lens into the remaining lens capsule and is thought to preserve better the anatomy of the eye.

Christy and Lall (1973) reported an infection rate of 0.46 percent for 54,000 ICCEs performed at a mass-surgery program in Pakistan. Although this is higher than the 0.17 percent infection rate following ICCE in the United States (Javitt and others 1991a), it is certainly acceptable by local standards.

In this setting, functional vision is restored to between 85 percent and 92 percent of patients who undergo surgery (Javitt, Venkataswamy, and Sommer 1983; Al Salem and Ismail 1987; Whitfield 1987; Brilliant and others 1988). Suboptimal outcomes are a function of preexisting retinal disorders, as well as complications of surgery. The standard intracapsular cataract extraction commonly performed in developing countries is a mature surgical procedure that requires little in the way of technical improvement.

Because an aphakic eye (one that has undergone cataract extraction) is left with an extreme refractive error, corrective spectacles, contact lenses, or intraocular lens implants (IOLs) are required for visual rehabilitation of the patient. In most developing nations, locally manufactured spectacles in a standard aphakic power are available for $5 to $12. At present, IOLs are considerably more expensive, and contact lenses with their need for frequent replacement and sterile solutions are totally impractical. Davies and colleagues (1986) have shown that IOLs are more cost-effective than contact lenses in the National Health Service of the United Kingdom and may offer considerable advantages in patient comfort and reduction of subsequent complications.

Although conventional wisdom has long held that intracapsular cataract extraction with provision of aphakic spectacles is the appropriate technology for the developing world, this approach needs re-evaluation. Aphakic spectacles are notably thick and uncomfortable to wear. Although straight-ahead vision can be corrected to 20/20, they cause considerable distortion of peripheral vision and complete obscuration of objects between 30° and 45° in the periphery. Moreover, magnification induced by aphakic spectacles makes objects such as steps and curbs appear closer than they are. Ellwein and others (1991) have noticed that as many as half of those who receive aphakic spectacles in cataract surgery programs in the developing world do not wear them and hence, suffer extremely limited postoperative vision.

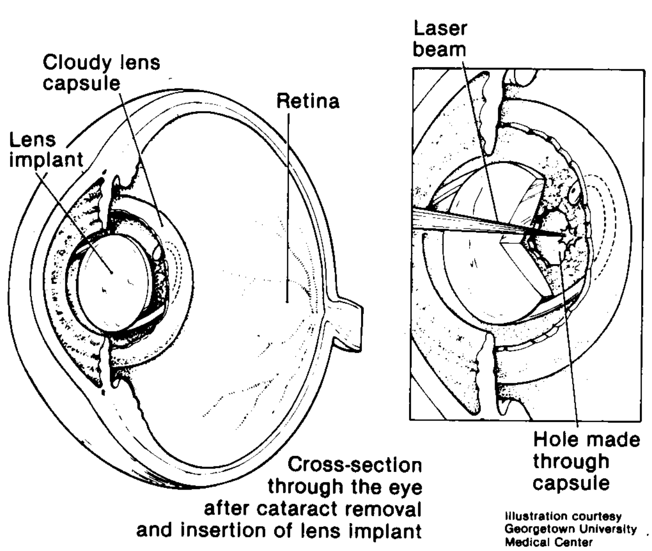
In recent years, there has been increased interest in converting to extracapsular cataract extraction with intraocular lens implantation, which is currently the dominant procedure in industrial nations. Analysis of 330,000 cases of cataract extraction in the United States reveals that patients who undergo ICCE have a 1.7-fold higher likelihood of infection and retinal detachment than those who undergo ECCE (Javitt and others 1991a and 1991b). Although there is likely to be an improvement in outcome and reduced risk of complication following

ECCE, this procedure requires the use of an operating microscope, more delicate surgical techniques, and sterile irrigating solutions. Approximately three to six months of full-time training is required to teach the newer extracapsular technique to a skilled ophthalmologic surgeon familiar with older methods.

Extracapsular cataract extraction enables the surgeon to place an intraocular lens in the posterior lens capsule (see figure 26-3), where it is least likely to cause ocular discomfort and long-term corneal complications. However, the lens capsule itself is likely to opacify over a period of years in 25 percent of those who undergo the procedure. In the industrial world, this circumstance is routinely managed by using a solid state (Neodymium: YAG) laser to create an opening (capsulotomy) in the opacified lens capsule. An alternative is to incise the lens capsule with a needle-knife, which is easily performed in the physician's office. This latter approach was routinely employed in the United States and Europe until introduction of the solid state laser in the early 1980s. While the capsulotomy procedure is quite simple to perform, opening the lens capsule in this manner increases the risk of subsequent retinal detachment to approximately the same level as that following intracapsular cataract extraction.

An alternative to postoperative capsulotomy in the 25 percent of patients who are likely to develop capsular opacity is to perform a capsulotomy at time of surgery after placement of the intraocular lens. The disadvantage of this approach is that all patients will be subject to higher risk of retinal detachment associated with disruption of the posterior capsule. Conversely, this approach may be the only practical one in settings where long-term follow-up of patients is infeasible.

Figure 26-3. Lense Implant with Subsequent Capsulotomy



Note: Following extracapsular cataract extraction, the lense implant is placed into the remaining capsule of the natural lense (figure left), which may subsequently opacify. The Neodynium: YAG laser can then be used to make an opening (capsulotomy) in the opacified lense capsule without harming the implant (figure right).

Current techniques achieve the purpose of restoring functional vision to most of those who are blinded by cataract. Unless an individual is accustomed to reading or performing similarly demanding tasks, the visual outcome of ICCE with spectacle correction may be acceptable. As the price of an intraocular lens continues to decline, however, it may even rival the cost of aphakic spectacles. With improved technology ECCE may become the preferred method of cataract extraction in the developing world, as well.

Economic Return on Cataract Surgery

The economic cost associated with cataract reflects the near-total disability associated with this condition. My colleagues and I performed a pilot study to determine the cost-benefit ratio of restoring sight via cataract surgery in developing countries (Javitt, Venkataswamy, and Sommer 1983). The Aravind Eye Hospital in Madurai, India, is a private charitable institution that currently performs more than 20,000 free cataract extractions annually on indigent patients who are functionally blind at the time of surgery. The cost of surgery is funded by revenues from paying patients and private voluntary organizations. One hundred patients were randomly selected from among those who visited the hospital for follow-up care between six months and two years after surgery. By means of an interview in their native language, the patients were queried as to the effect of losing their sight on their economic and social circumstances. In addition to earning ability before and after surgery, patients were asked about other members of the family who were able to return to work after the patient's surgery or who were forced to leave work when the patient initially became visually incapacitated. The interview data were correlated with the outcome of surgery.

Eighty-five percent of the patients surveyed achieved postoperative visual acuity of 6/36 or better. Eight percent had vision of 6/60, and 7 percent had visual acuity of less than 6/60. Patients were included in the study data regardless of the surgical outcome.

Eighty-five percent of the males and 58 percent of the females who had lost their jobs as a result of blindness regained those jobs. A number of those who did not return to work did free other family members from household duties, thereby enabling them to return to work. Eighty-eight percent of male patients and 93 percent of female patients who reported having lost authority within their family and their community stated that they had regained their social standing.

At the time of the study the marginal cost of performing a cataract extraction was $5 dollars (53 rupees). Economic data were compared with that investment cost. The results showed that the average individual regaining functional vision through cataract extraction in this setting generated 1,500 percent of the cost of surgery in increased economic productivity during the first year following surgery. This benefit was generated both by the patients and by their family members who were able to return to work. No data yet exist on the annual return on investment for the long term.

Cost-Effectiveness, or Cost Utility, of Cataract Surgery

Elsewhere in this collection, a year of the life of a functionally blind person has been equated to a loss of 0.5 disability-adjusted life-year (DALY). Torrance (1982) reported empirical data suggesting that individuals associate a utility value of 0.39 (with perfect health represented as 1.0) with a lifetime of being "blind, deaf, or unable to speak." Drummond and co-workers (1987, 1988) employed a utility scale calibrated in disability-adjusted life-years (DALYs) and reported that a year of life for a poorly adjusted (poorly rehabilitated) blind person is valued at 0.35 DALY, whereas a year of life for a well-adjusted (well-rehabilitated) blind person is valued at 0.48 DALY.

For consistency with other chapters, in my comparison of cataract extraction with other potential health care interventions I have employed the DALY model in which healthy years of future life are discounted at a rate of 5 percent. I have assumed a year of life following successful bilateral surgery to equal 1.0 healthy years of life and a year of life following successful unilateral surgery to equal 0.84 healthy years of life. This is consistent with data from a U.S. study of cataract patients in which the improvement in visual function following cataract surgery in the second eye was approximately 50 percent of that associated with improvement following surgery in the first eye (Javitt, Street, Brenner, and others 1993). I have assumed bilateral cataract surgery costs in the developing world to be between $18.00 and $42.50 per eye in 1990 and the cost of spectacles to be $6.00.

In assessing the benefits accruing from any procedure, the survival of the underlying population must be considered. Data from 330,000 U.S. Medicare patients undergoing cataract extraction indicate 75 percent survival at five years after surgery with an absolutely straight survival curve (Street and Javitt 1992). Based on the U.S. data, I have assumed the average patient undergoing cataract surgery in the developing world to have a 5 percent annual mortality risk after surgery. Because cataract patients in the developing world tend to be ten years younger on average than those in the United States, however, survival may be different in that setting.

Surgery in a single eye has an 85 percent chance of restoring vision, for a probable gain of 2.00 DALYs in the patient's expected future lifetime. On the basis of this assumption, bilateral surgery has a 72 percent chance of restoring vision in both eyes, and a 96 percent chance of restoring vision in at least one eye (assuming independence of eyes) for a probable gain of 3.05 DALYs. I further assumed that a new pair of spectacles is required every five years of life.

Table 26-4 is a comparison between the projected cost-utility ratios of unilateral and bilateral cataract surgery and several other health care interventions reported elsewhere in this collection. As can be seen from the table, cataract surgery compares quite favorably with several interventions that are generally accepted without question in the public health arena.

Table 26-4. Cost-Utility of Cataract Surgery and Other Types of Health Interventions

Intervention	*Cost per DALY saved (dollars)*
Bilateral cataract surgery	
$18.00 per eye	15.70
$26.80 per eye	21.50
$42.50 per eye	31.80
Unilateral cataract surgery	
$18.00 per eye	15.00
$26.80 per eye	19.00
$42.50 per eye	27.00
Noncataract intervention	
Passive case finding and short-term chemotherapy for TB	10.00
DPT and polio immunization	20.00–40.00
Oral hypoglycemic management of NIDDM	330.00

Source: Jamison, chapter 1, this collection.

Increasing Availability of Cataract Surgery

Although shortage of qualified surgeons is commonly invoked as an explanation for the backlog of blinding cataract in developing countries (Wilson 1980; Foster 1987), it bears careful scrutiny. The ratio of ophthalmologists to population in India is 1:100,000, the same as that for Great Britain (Venkataswamy 1987). Yet, in the face of an alarming prevalence of cataract blindness, Indian ophthalmologists remain concentrated in the cities, where many are underemployed, if not unemployed. There remains an undersupply of ophthalmologists in rural areas. The cost of starting a surgical facility is beyond the resources of most individuals, and government jobs that would allow one to practice in a public hospital are scarce. Thus, the Indian subcontinent is faced more with a maldistribution of surgeons than with a true shortage. Africa, to the contrary, truly presents an example of worker shortage, where there is only one ophthalmologist per 1 million people, or one ophthalmologist for every 4,000 blind individuals (Foster 1987; Schwab 1987).

MASS SURGICAL STRATEGY. High-volume surgical facilities have been in place in India and Pakistan for the past twenty years (Christy and Lall 1973; Liu and others 1977; Wilson 1980; Foster 1987; Venkataswamy 1987). They have demonstrated that cataract surgery can be performed inexpensively and safely on an assembly-line basis. Costs have traditionally been borne by a combination of government funding, private voluntary organization support, and patient fees. Not surprisingly, patients recognize the value of sight restoration and will contribute to their own care within their means. Unfortunately, when family resources are stretched thin, even the cost of food during hospitalization may be too large a burden for a family in a subsistence economy.

Fixed surgical facilities may succeed in areas of high population density, but rural areas might best be served by satellite or mobile facilities. A study in Tanzania reported that only 39 percent of patients scheduled for surgery actually appeared if the facility was more than twenty-five miles from home. A decrease in the distance that patients were required to travel meant substantially increased rates of participation (HKI 1985).

Thus far, mass surgery has generally relied upon expatriate ophthalmologists for at least a portion of their surgical workers. This arrangement is necessary if a large volume of surgery is to be performed and the backlog reduced. Because this is clearly not a self-sustaining arrangement, training programs must be devised to provide local ophthalmic surgeons who will remain in the community.

TRAINING OF LOCAL PROVIDERS. An ongoing problem in training local ophthalmologists has been a tendency for those who go to large urban centers for training to remain in those urban centers. The training they receive may not be ideally suited to the problems they will encounter if they do return home. In recent years, Helen Keller International has mounted a highly successful program to train eye surgeons in the Philippine outer islands. General medical officers are selected at the local level and are trained in situ by visiting faculty. Their training focuses on the problems that face their community. Thus far the dropout rate has been minimal and the cost of training far less than would be required if travel and housing were required for training in urban centers.

A pilot program in Kenya has demonstrated that nonphysician ophthalmic clinical officers can be trained to perform cataract surgery with acceptable results (Whitfield 1987). Although the mechanical aspects of surgery can be learned by individuals of good dexterity, there is no evidence yet that surgical judgment and the judgment required to manage complications can be taught without duplicating most of a formal residency in ophthalmology. A second problem in this strategy is that most developing countries have physician licensing laws that are as strict as those of any Western country. Because of the public health menace of semiskilled itinerant cataract surgeons, countries such as Pakistan have laws that mandate jail sentences for nonphysicians who perform eye surgery.

Increasing Participation in Care

Although providing care at an affordable cost (which may mean free of charge in some areas) is an essential step in the eradication of cataract blindness, the simple provision of care is not sufficient to guarantee its acceptance. Only 20 percent of blind individuals in southern India who were offered free cataract extraction appeared for surgery within three years (Venkataswamy and Brilliant 1981). The remaining blind persons declined because of mistrust, lack of access to the facility, inability to pay for food while hospitalized, or other concerns. The result is that community-based facilities may remain underused in the face of an overwhelming backlog of cataract blindness.

Several researchers have studied factors that affect rates of participation in cataract surgery at a community-based program in India (Christy and Lall 1973; Venkataswamy and Brilliant 1981). The provision of free transportation to the hospital and food while hospitalized substantially increased the frequency with which patients appeared for cataract surgery (Bhatnagar and others 1988). Since blind individuals are essentially immobile without assistance in that society, the provision of transportation not only relieves the patient of a monetary burden but eliminates the need for another family member to be away from work during the patient's hospitalization. Similar findings have been reported from Nepal by Brilliant and Brilliant (1985).

Research Priorities for Ending Cataract Blindness

In 1986 the National Eye Institute co-sponsored a conference with Helen Keller International in which leading public health ophthalmologists and policymakers articulated long-term research priorities for the eradication of cataract blindness (HKI 1986). Research goals were divided into three focus areas:

Operations research techniques for improving the efficiency and effectiveness of cataract care in developing countries. The aim of specific projects would be the following:

- To compare the effectiveness of various methods of identifying cataract-blind people within a community and, through the reduction of psychosocial and economic barriers, motivate them to seek surgery
- To compare alternatives for improving access to cataract surgery, such as eye camps or the establishment of temporary satellite hospitals
- To evaluate alternative forms of minimum-level ophthalmic surgical facilities in regions that are currently underserved
- To improve operating room efficiency
- To determine ways of reducing the postoperative stay following cataract surgery
- To increase the number of ophthalmic personnel trained to perform cataract surgery in underserved areas

Epidemiologic research designed to measure the magnitude of the cataract blind population in different regions, study the risk factors for cataract, and evaluate methods of delaying the onset of cataract through controlled clinical trials. Following are specific priorities:

- Developing a standard, reproducible system for classifying and documenting the type and severity of cataractous change
- Identifying the risk factors for aging-related cataracts in populations that have widely varying prevalence of disease
- Studying migrant groups who move from high-prevalence areas to low-prevalence areas in order to determine the relative importance of genetic and environmental factors in cataract development

- Developing noninvasive techniques that can be used to measure precisely the progression of human cataract
- Implementing randomized controlled clinical trials to test the potential of strategies intended to delay cataract onset

Biological research designed to elucidate the biochemical and physiologic mechanisms of cataractogenesis. The goal of specific projects would be the following:

- To test the hypothesis that oxidative damage to lens proteins is a significant cause of human aging-related cataract and to develop mechanisms for preventing that damage
- To develop a method to grow human lens cells in tissue culture in order to study the normal and abnormal production of lens proteins
- To study the molecular biology underlying the formation of congenital and hereditary cataracts in the hope of shedding light on the process of age-related cataractogenesis

Conclusions

Cataract is the leading cause of blindness and disability in developing countries. Current surgical methods of treating cataract are highly effective and cost between $15 and $33 per patient. Initial research suggests that the patient who benefits from sight-restoring cataract surgery may generate a 1,500 percent or greater annual return on the cost of surgery.

The elimination of cataract as the main cause of world blindness requires initiatives on multiple levels in order to formulate short-term, intermediate-term, and long-term solutions. The most pressing need is to begin immediately to reduce the backlog of cataract blindness through mass surgery. This requires a commitment of resources along with initiatives in operations research designed to reduce barriers to surgery and increase the effectiveness of public health programs. Economic research is similarly required to study net savings to patients, their families, and society of sight restoration through cataract surgery.

Although the strategy of mass surgery using expatriate ophthalmologists has the potential to reduce the current backlog, only by training local ophthalmologists and ancillary personnel will it be self-sustaining. Additional epidemiologic research is needed in order to elucidate better the relationship between cataract and environmental factors as well as the effects of reducing known risk factors.

The currently used technology for cataract extraction is adequate for the needs of developing countries, but eventually the instrumentation required for extracapsular extraction and lens implantation will become economically feasible in these countries. The new technologies of surgical extraction combined with the long-term hope of affordable pharmacologic intervention may one day make the current burden of cataract blindness a dim vision of the past.

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