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Cataract and latitude

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Abstract. For many years, it has been suggested that exposure to sunlight, particularly its ultraviolet component, may be associated with an increased risk of senile cataract. This paper adresses 1) the physical and geographic variables that affect the entry of ultraviolet light in the eye; 2) the epidemiologic evidence that associates cataract with ultraviolet light exposure; and 3) the effectiveness of personal barrier protection (i.e. sunglasses and hats) in reducing ocular exposure to ultraviolet light. The epidemiologic evidence is drawn from studies in Australia, China, Tibet, and the United States. The U.S evidence consists of data from the Maryland Watermen study and analyses of cataract surgery under the Medicare program which provides health insurance for nearly all Americans age 65 and over (30 million) and pays for 85% of the 1.3 million cataract extractions performed annually in the U.S. Analysis of the Medicard data shown that, after controlling for age, sex, and race, and income of the population and also controlling for supply of ophthalmologists, optometrists, price of surgery and local practice costs, the strongest predictor of cataract surgery likelihood in a Medicare benificiary is the person's latitude of residence. Latitude correlates directly with the UV-B content of sunlight, because the incident angle of the sun determines the atmospheric penetration of ultraviolet radiation. Data suggest that the probability of cataract surgery in the U.S. increases by 3% for each 1 degree decrease (i.e. more Southerly) in latitude.

Part 1: Review

Introduction

Each of us is exposed to some degree of sunlight [1]. The amount of exposure can vary greatly among different occupations and different recreational activities. The process of vision depends upon the constant bleaching and regeneration of visual pigments in retinal photoreceptors. With ordinary exposure these light-induced changes are short-lived and rapidly reversed. However, intense exposure to either the broad band of visible light or to narrower specific bands in the visible spectrum, such as those produced by a laser, can cause permanent ocular damage. For example, the occurrence of retinal burns in eclipse blindness is well known [1], and retinal laser photo-coagulation is one of the major advances in the treatment of eye disease of the last two decades [2].

Not all bands of electromagnetic radiation emanating from the sun are in the visible spectrum, and many of the nonvisible bands can have a serious impact on biological function. While most harmful solar radiation is filtered out by the atmosphere, the sunlight that does reach the earth's surface contains sufficient amounts of ultraviolet radiation (UVR) to cause sunburn [3] and a variety of skin cancers [4].

For many years, it has been suggested that exposure to sunlight (or, more specifically, UVR) may be associated with an increased risk of senile cataract [5] and possibly even with senile macular degeneration (SMD; now also referred to as age-related or aging-related macular degeneration or maculopathy) [1]. Most of the initial suggestions concerning the association between UVR and cataract came from astute observations by experienced physicians [5] rather than rigorous epidemiologic studies. More recent field studies, reviewed in greater detail below, also suggest an association.

The changing lifestyle of Americans is causing a rapid increase in exposure to sunlight and consequently to UVR. The dermatologic and epidemiologic literature, as well as the lay press, documents a sudden rise in the rate of skin cancers. While it is unlikely that people will seek to decrease their sunlight exposure in future years, there are simple, practical measures, such as wearing spectacles or a hat, that effectively protect the eye from solar radiation, including UVR. Thus it is easily within the power of individuals to protect their eyes from excessive exposure and reduce their risk of both ocular and dermatologic sequelae.

Description of ultraviolet radiation

Physical definition of UVR

The spectrum of nonionizing radiation ranges from short wavelength UVR (wavelength 100 nm) through to far infrared radiation (1 mm or 100,000 nm) [6]. The visible spectrum lies between 400 nm (indigo) to 760 nm (red). Above the visible spectrum is infrared radiation, and below the visible spectrum are the shorter wavelengths of nonionizing radiation called ultraviolet radiation (UVR). Much of the nonionizing radiation is absorbed by the earth's atmosphere and does not reach the earth's surface [6]. Wavelengths below 290 nm are totally absorbed by the ozone layer in the stratosphere, and longer wavelengths are absorbed to a lesser extent. Thus, in nature, one does not encounter UVR below 290 nm, although the physical spectrum of UVR ranges from 100 nm to 400 nm.

Although UVR is only 5% of the sun's energy, it is the most hazardous portion encountered by man. UVR has been subdivided into three bands: UV-A (400–320 nm), UV-B (320–290 nm), and UV-C (290–100 nm). This arbitrary subdivision is based on the biologic effects of the different wavelengths or bands [7]. UV-A, or near UV, produces sun tanning (the browning of the skin due to an increase in the skin content of melanin), as well as photosensitivity reactions. UV-A is commonly encountered and is emitted by so-called black lights, which are often used to make objects fluoresce and are also used in tanning salons. UV-B is the sunburn spectrum and causes sunburn (painful erythema) and tissue damage (blistering). UV-B is associated with skin cancer [4–8]. UV-C is germicidal and may also cause skin cancer. UV-C, or far UV, is not commonly encountered on the earth's surface and comes entirely from artificial sources such as germicidal UV lamps or arc welding. Furthermore, although UV-B is only 3% of the UVR that reaches the earth's surface, it is much more biologically active than UV-A [9].

Environmental, temporal, and geographic variations in UVR

The amount of UVR reaching the eye varies enormously by time of season, latitude, altitude, time of day, and reflectivity of the surrounding environment. UVR is scattered across the whole sky by the Rayleigh effect, just as blue light is scattered [8]. Light or broken clouds do not significantly reduce the level of UVR, although levels are reduced by heavy cloud cover [8]. A sky with a clear horizon for 360° provides for a maximal exposure; when hills, trees, or buildings obstruct part or all of the horizon, the UVR exposure is reduced proportionally [10]. UVR can also be reflected by the ground, the amount depending greatly on the type of surface. Grass and soil reflect only 1% to 5% of UV-B, water 3% to 13%, sand and concrete about 7% to 18%, and fresh snow up to 88% [10].

As the sun makes its daily transit, the spectral content of sunlight changes substantially. At low incident angles, nearly all visible and ultraviolet energy is reflected by the atmosphere, giving the familiar reddish hue to early morning and late evening sunlight. The UV-A and UV-B content of sunlight increases as the sun reaches its zenith and progressively decreases during the afternoon. Similarly, the further one is from the equator, the more oblique the angle of sunlight incidence. Many have learned the hard way that an hour's exposure to tropical sunlight imparts a far greater dose of UV-B than does an hour on the beach in Los Angeles. As the Earth tilts to produce changing seasons, so too does the angle of sunlight incidence and the resulting UV content of sunlight, with summer sunlight imparting far greater doses of UV-B than that of other seasons.

While the ambient dose of UV increases at lower latitude, it increases somewhat at higher altitudes, since the atmospere filters less of the sun's UV radiation. UV-B exposure increases approximately 20% per 10,000 feet. Climbers and skiiers have frequently discovered that they are vulnerable to sunburn, even when the sun seems to exert little warming effect.

The eye is protected and shielded from UVR by a number of factors [11, 12] and only receives a small fraction of ambient UV-B under normal circumstances. The normal horizontal alignment of the eye and the orbit significantly reduces ocular exposure to whole-sky irradiation. Further anatomic protection is provided by the brows, the nose, and the cheek [13]. The eye is relatively unprotected laterally, although the transmission of UVR by internal reflection in the cornea may lead to a concentration of UV irradiation at the nasal limbus [14]. The eyelids provide protection that is further enhanced by squinting, a common reflex in bright sunlight [13]. Considerable attenuation of ambient UVR can be achieve by wearing a hat (50% attenuation) and wearing ordinary plastic spectacles (90% attenuation) [11, 12]. Protective sunglasses block between 95% and 100% of UVR [12].

Ocular transmission of UVR

Only a small percentage of UVR that enters the eye, reaches the retina – a fact with important photobiological implications. The amount of radiation that is absorbed determines the potential for damage to the absorbing tissue. Energy from absorbed radiation must be dissipated, and it is this dissipation that results in damage.

The cornea absorbs almost 100% of UV-C radiation (below 290 nm), but transmission rapidly increases for longer wavelengths, so that, for instance, 60% of radiation at 320 nm is transmitted by the cornea [15–18]. The normal, young human lens absorbs most UVR below 370 nm. With age, the human lens yellows and absorbs even more UV-A and also absorbs shorter visible wavelengths [18, 19]. In adults, less than 1% of radiation between 320 nm and 340 nm and only 2% of radiation of 360 nm reaches the retina [20]. The pattern of absorption shown in the classic series of transmittance curves published by Boettner and Wolter [17] indicates that the lens is exposed to and absorbs most of the UV-B that reaches the eye.

Mechanisms of phototoxicity

The mechanisms of phototoxicity are complex and not totally understood. All electromagnetic radiation exhibits both wave-like (oscillatory) and particle-like (photon) characteristics [6]. The energy carried by a photon is directly proportional to its frequency, thus the shorter the wavelength, the higher the energy. The energy of a photon is absorbed by the atom or molecule with which it collides. Low-energy infrared photons will carry enough energy to affect the rotational or vibrational state of an atom or a molecule and can produce warming [7]. The higher energy UVR photons, however, can alter the energy state of the electrons, making the atom or molecule electronically excited and, therefore, relatively unstable. This instability can lead to chemical reactions including photo-oxidation. Even higher energy photons such as gamma rays can cause an electron to be removed entirely from the molecule, thereby causing ionization.

The radiant energy of UVR can be absorbed by nucleic acids, proteins, or other molecules within the cell. Some energy may be dissipated as heat, but an excited molecule may be structurally altered or cleaved or it may react with other molecules by forming new bonds. The capacity of a given atom or molecule to absorb radiant energy is dependent on its physicochemical properties, and the characteristics of a tissue are in turn dependent on the properties of its constituents. The lens proteins are rich in the amino acid residues of tryptophan, tyrosine, and phenylalanine; and these proteins absorb most of the radiant energy below 300 nm. Other chromophores and pigments in the lens appear to absorb most of the energy in the 300 nm to 400 nm range [21].

The ocular action spectrum for UVR

The eye is much more sensitive to damage by some wavelengths than others. The term action spectrum can be defined as the amount of irradiation at a given wavelength or band of wavelengths that is sufficient to cause damage. It is the threshold level for damage and is specific for different tissues [22–26]. In his classic work, Verhoeff showed that repeated subliminal exposures delivered within minutes or hours to the eye are additive for up to 24 h [22]. For suprathreshold corneal damage, at least, there is a period of latency between exposure and evidence of damage which varies with dose but can range from 30 min to 24 h. The latency period accounts for the delay in presentation of welders with flashburns. For the rabbit lens, a latency period of 5 to 10 days has been reported for reversible lesions and 2 to 14 months for irreversible lesions [16]. No data exist for the action spectrum of the human lens or retina.

Association between UVR and cataract

Experimental basis for an association between UVR and cataract

Experiments in animals suggest that UVR may cause cataract. Cortical and posterior subcapsular cataracts have been induced by UV irradiation in a number of different experimental animals. Rohrschneider exposed guinea pigs to a mercury vapor lamp (293–303 nm) and produced clouding of the anterior cortex [27]. Bachem confirmed these findings in both guinea pigs and rabbits, using a number of different light sources, and determined the action spectra [16]. Zigman and coworkers [28] reported subcapsular and punctate cortical opacities in albino mice that had been exposed to broadband UVR from 40 W blacklight lamps (300–400 nm). The mice were exposed for 12 h a day. After 35 weeks of exposure, changes were seen on slit lamp examination, and after 60 weeks of exposure, clear-cut cortical opacities were seen on histologic examination. At this time, the posterior migration of undifferentiated lens epithelium was also noted. Pitts and coworkers produced cortical and posterior subcapsular opacities in pigmented rabbits exposed to short-duration exposures to UVR between 295 nm and 315 nm [24]. They comment specifically on the low radiant exposures of UV-B needed to produce these lenticular opacities. Keeney and Rapton exposed nonpigmented mice to daylight and caused extensive ear damage and corneal changes, but lens opacities were not seen [29].

The epidemiologic basis for an association between UVR and cataract

Epidemiologic and clinical observations also suggest a link between sunlight exposure and cataract. Cataracts occur more commonly in tropical areas than in more temperate regions [5, 30]. This is often ascribed to greater sun exposure, but few epidemiologic studies have examined, even indirectly, the role of sunlight in cataractogenesis. There is a greater prevalence of cataracts in the sunnier part of Romania [31] and cataracts are more common in Israel than in England [32]. People having cataract surgery are more likely to have brunescent cataracts if they live closer to the equator or work outdoors [33]. People in the United States who live more than half their lives in areas with high sunlight or UVR levels have a greater risk of cataract [34, 35]. This association holds for cortical cataract but not for nuclear cataract [36].

An earlier study in Australian aborigines showed an epidemiologic association between the occurrence of senile cataract and resident sunlight exposure and, in particular, local levels of UV-B radiation [37]. The association was specific, consistent, and showed a dose-response relationship. Hollows and Moran also confirmed and extended these findings [38]. They found a strong positive correlation between the intensity of UV-B radiation in the zone of residence and the presence of cataract when they analyzed data from 64,307 aborigines [39].

A study of 125,279 Chinese in seven rural areas found that cataract was more common in areas with more sunlight, and consequently more UV-B radiation, especially areas at higher altitudes [39]. A recent small-scale, case-control study in Tibet showed greater risk of senile cataract in those who worked outside for more than six hours a day [40]. A country-wide survey of

Nepal in which 30,565 lifelong residents were examined also found a positive correlation between sunlight and cataract [41].

In an attempt to control for confounding variables in previous studies, self-selected samples of Maryland watermen and their wives and Pennsylvanian underground coal miners and their wives were examined [42]. Because of intergroup differences, only limited between-group comparisons could be made. The watermen could be grouped by their work-related UVR exposure. Cortical opacities were seen more commonly in those with a higher UVR exposure history than in those with a lower exposure. No association was seen with nuclear opacities. SMD as determined by fundus photography also appeared to be more common in those watermen under 60 years of age who had a higher UVR exposure, but no trend was seen in those over the age of 60 years.

In an effort to better quantify personal lifetime UV-B exposure, another study examined 212 men who had had a skin biopsy taken from the facial area [43, 44]. Each biopsy was graded histologically for actinic elastosis, a marker for cumulative UV-B exposure. A positive, but modest, association was found between actinic elastosis and cortical opacities. This association was strongest in those under age 55. No association between UVR and nuclear opacities was found. In order to quantify the dose-response relationship between UV-B exposure and cortical cataract, an epidemiologic survey was conducted of 838 watermen. The annual ocular exposure for each participant was calculated from age 16 by combining a detailed occupational history with laboratory and field measurements of sun exposure. Cataracts were graded by ophthalmologic examination for type and severity. Some degree of cortical cataract was found in 111 (13%) of the watermen and some degree of nuclear opacity in 229 (27%). A doubling of cumulative exposure to UV-B increased the risk of cortical cataract by a factor of 1.6. Those whose annual exposure was in the upper quartile had a risk increased by 3.30 as compared with those in the lowest quartile. No association was found between nuclear cataracts and UV-B exposure, nor was any association detected between cataract and UV-A exposure.

Evidence from national Medicare data

With approximately 1.3 million cataract extractions per year now being performed on Medicare beneficiaries, cataract surgery has become the most commonly performed surgical procedure within the Medicare program. Annual costs to the Medicare program associated with cataract surgery are estimated to have been approximately $3.4 billion in 1992 [46]. In order to gain insight into the relationship between demographic, environmental, and provider-related factors on the one hand, and the likelihood that cataract surgery will be performed on a Medicare beneficiary on the other, we analyzed the provision of cataract surgery to Medicare beneficiaries during 1986 and 1987. This will be described in the second part of this paper.

Part 2: The Medicare data investigation

Patients and methods

We identified all individuals who underwent cataract surgery in 1986 or 1987 within a 5 percent random sample of Medicare beneficiaries aged 65 years or older, through methods described in detail in prior publications [47, 48]. The dependent variable in our regional analysis was the number of persons per 1000 Medicare beneficiaries residing within a particular Bureau of Economic Analysis Economic Area (BEAEA) who underwent cataract surgery. BEAEAs are relatively large geographic areas, containing a Metropolitan Statistical Area and its surrounding counties. BEAEAs were constructed by the U.S. Department of Commerce to reflect geographic market areas within which residents would most likely consume the majority of required goods and services, including medical care. We confined our analysis to the 181 BEAEAs contained within the 48 contiguous states.

We constructed a logistic regression model to estimate the conditional probability that a Medicare beneficiary with particular characteristics underwent cataract surgery. In this model, each Medicare beneficiary in the 5% beneficiary sample (n = 1.2 million) was considered as an individual, with the logistic outcome variable being whether or not that person underwent one or more cataract extractions during 1986 or 1987.

Rationale for choosing independent variables

In selecting independent variables for inclusion in our models, we considered two categories of factors that might be associated with the rate of cataract surgery: factors that may influence demand for cataract surgery and factors that may affect supply of cataract surgery. These variables are described below, along with our rationale for their inclusion, and are summarized along with their data sources in Tables 1 and 2.

Table 1. Description and source of data forvariables used in the person-level analysis

Variables possibly affecting demand for cataract surgery (source for each variable)	
AGE	Age of the Medicare beneficiary (Medicare denominator file)
SEX	Gender of the Medicare beneficiary (Medicare denominator file)
BLACK	(Self-reported) Race of the Medicare beneficiary (Medicare denominator file)
BLACKM	An indicator variable that equals 1 for black males and 0 otherwise (Medicare denominator file)
% INC < $15,000	Percent of persons aged 65 years or older in each BEAEA with less than $15,000 annual income (1980, Census of the Population)
LATITUDE	Degrees north latitude (Area Resource File)
Variables possibly affecting supply of cataract surgery	
OPHTHALMOLOGISTS	Number of ophthalmologists per 1000 Medicare beneficiaries aged 65 years or older in the BEAEA in which each beneficiary resides (1985, Area Resource File)
OPTOMETRISTS	Number of optometrists per 1000 Medicare beneficiaries aged 65 years or older in the BEAEA in which each beneficiary resides (1981, Area Resource File)
ALLOWED CHARGE	Average allowed charge in the BEAEA allowed for cataract surgery (Medicare Part B Database 1986–87)
PRACTICE EXPENSE	Geographic Practice Cost Index (GPCI); Estimate of practice expense in each BEAEA

Table 2. Conditional probability of cataract surgery

	Coefficient	Significance level	Min.	Max.	Odds ratio impact[a]
INTERCEPT	−2.2706	0.0001			
Demand Variables					
Male	−0.203	0.0001	0	1	0.82
Black	−0.271	0.0001	0	1	0.77
Black Male	−0.082	0.016	0	1	0.57
Age 70–74	0.549	0.0001	0	1	1.73
Age 75–79	0.967	0.0001	0	1	2.63
Age 80–84	1.124	0.0001	0	1	3.07
Age 85–89	1.058	0.0001	0	1	2.87
Age 90–94	0.724	0.0001	0	1	2.06
Age over 94	−0.062	0.474	0	1	0.94
% Income < 15K	−0.109	0.0015	0	1	0.90
Latitude	−0.030	0.0001	26.29	48.38	0.51
Supply Variables					
Ophthalmologists	−0.048	0.088	0.088	1.26	0.82
Optometrists	0.227	0.0001	0.30	1.70	1.37
Allowed charge	0.034	0.0001	955.2	2180	1.53
Practice expense	−0.545	0.0001	0.856	1.22	0.82
Event			59,881		
No Event			965,849		
Total			1,025,710		
−2 Log. Likel. (Intercept only)			444,015		
Joint significance of covariates			0.0001		
Parameters are distributed chi-square with 1 degree of freedom.					

[a]This column represents the effect on the odds of an individual undergoing cataract surgery, controlling for all other variables in the model, of going from the minimum observed value for the variable to the maximum observed value. For example, the difference between the minimum (Southernmost) and the maximum (Northernmost) latitude is associated with a 50% decrease in the odds of undergoing cataract surgery. Odds ratio impact is calculated $e^{(maximumvalue-minimumvalue)*\beta}$. In the case of black males, the calculation is based on the sum of coefficients associated with male sex, black race, and the 'black male' dummy variable.

Variables possibly associated with demand for cataract surgery

Age, sex, and race of beneficiaries

The incidence of cataract is known to be age-related and may also be gender-related [49]. We therefore calculated the percent of the Medicare population in each BEAEA that fell within various five year age intervals (i.e. 65–69, 70–74, ...) and the percent of Medicare beneficiaries aged 65 years or older in each BEAEA who were female. In addition, there is evidence of significant variation in rates of health service utilization across racial groups. In particular, many medical and surgical services have been shown to be provided less frequently to black Americans [50]. For this reason, we also included in our model the percent of Medicare beneficiaries aged 65 years or older in each BEAEA who are black.

Income of beneficiaries

Although the Medicare program covers much of the cost of cataract surgery, we hypothesized that personal income might affect a Medicare beneficiary's decision regarding whether to undergo cataract surgery because the beneficiary is responsible for a 20% copayment on physicians' bills unless the beneficiary has supplemental insurance to cover these costs. In addition, we hypothesized that income might affect a beneficiary's ability to travel to the ophthalmologist's office. Income also may influence the recreational activities an individual performs and the type of personal assistance that is available to them, thereby affecting an individual's perceived need for cataract surgery.

Latitude

Latitude was included as an independent variable because of its strong relationship to UV-B content of sunlight. Because, in preliminary analyses, we found that elevation and sunlight hours were both colinear with latitude, we included only latitude in our model. A second reason for including latitude in our model was the possibility that an individual living in a warmer, sunnier climate might be more likely to engage in activities, such as outdoor sports and driving, which would increase that person's visual needs and therefore might prompt him/her to seek cataract surgery at an earlier point in a cataract's development.

Variables hypothesized to possibly affect supply of cataract surgery

Eye care provider variables

The number of ophthalmologists in a BEAEA relative to the number of Medicare beneficiaries 65 years of age or older in the same BEAEA was included as an independent variable in our model for two reasons. First, we hypothesized that a greater availability of ophthalmologists might increase the likelihood that all appropriate cataract extractions would be performed in that BEAEA. In addition, we reasoned that ophthalmologists might be more likely to establish a clinical practice in areas with a high need for cataract surgery. We also hypothesized that a greater number of optometrists relative to Medicare beneficiaries in a BEAEA might increase the likelihood that cataracts would be detected and that patients with cataract would be referred to ophthalmologists for evaluation for surgery.

Allowed charge for cataract surgery

Because the level of remuneration one receives for performing cataract surgery might influence physicians' inclination to perform the procedure, we included the average allowed charge for cataract surgery in a BEAEA as an independent variable in our model. Data for this variable were based on the mean charge Medicare allowed for episodes of cataract surgery in our dataset. The average allowed charge is not necessarily equivalent to physicians' payment for services, since balance billing for cataract surgery was allowed in 1986 and 1987. It does, however, reflect the reimbursement physicians could expect to receive from Medicare during those years. Finally, we included the Geographic Practice Cost Index (GPCI) employed by the Health Care Financing Administration as a control variable in our model in an effort to adjust allowed charges for the cost of practicing in a given BEAEA.

Results

Demand variables

Our sample of Medicare beneficiaries included 1.03 million persons. In contrast to the regional level analysis, the person level analysis showed a statistically significant association between age, gender, and race of the beneficiary and the odds of cataract surgery. Women were approximately 22% (95% CI: 20–24%) more likely than men to undergo cataract surgery. White beneficiaries were 30% (95% CI: 27–35%) more likely than black beneficiaries to undergo cataract surgery. Our results suggest there may also be an interaction between race and gender, in that a black male is only 57% as likely to undergo cataract surgery as a white female.

Age also was a significant predictor of the likelihood of undergoing cataract surgery, with an increasing probability of surgery associated with increased age through the age 90–94 stratum, but a declining probability thereafter. Imputed household income also was significantly associated with the likelihood of cataract surgery in the person-level analysis. An increase in the proportion of households with less than $15,000 per year in income was associated with a decrease in the likelihood of cataract surgery (Table 2), but the coefficient on this variable was small – the likelihood of cataract surgery was only 10% lower among beneficiaries living in zip codes with the lowest imputed income, compared with beneficiaries living in zip codes with the highest imputed income.

Latitude was strongly associated with the likelihood of cataract surgery in the person level analysis. Our findings suggest that the probability of surgery increases by 3% (95% CI: 2.8–3.3%) for each 1 degree decrease in latitude (60 miles further south) in BEAEA of residence. Over the entire range of latitudes in our sample (Table 2), the odds ratio impact associated with latitude is 0.51 (i.e., beneficiaries living in the northernmost BEAEA were approximately 50% less likely to undergo cataract surgery than beneficiaries in the southernmost BEAEA, everything else being held equal.

Supply variables

As in the regional model, higher concentrations of optometrists in a BEAEA were associated with a higher probability of surgery in the person level analysis. The probability of surgery was 37% greater in the regions with the highest concentration of optometrists compared to the regions with the lowest concentration, controlling for all other variables. Also, as in the regional level analysis, higher concentrations of ophthalmologists in a BEAEA were associated with a lower probability of surgery, although the 95% confidence interval around the coefficient on this variable included zero ($p = 0.088$).

The average allowed charge for cataract surgery was significantly associated with the probability of surgery, after adjusting for regional differences in practice costs, over the entire range of charges. Those living in BEAEA's with the highest allowed charge were approximately 1.5 times more likely to undergo cataract surgery than those living in regions with the lowest allowed charges.

Discussion

Our analysis demonstrates that there is an association between several demographic characteristics of a Medicare beneficiary and that beneficiary's likelihood of undergoing cataract surgery. The fact that black beneficiaries have a significantly lower odds of undergoing cataract surgery than their non-black counterparts raises important clinical and policy questions. The observed difference in cataract surgery rates among men compared to women in our person level analysis is consistent with our previous analysis of inpatient cataract extraction in 1984 [51]. An increased prevalence of cataract among women was reported in the Framingham Eye Study (odds ratio = 1.19; $p < 0.01$) [49] and the National Health and Nutrition Examination Survey (odds ratio = 1.12) [27], although the finding in the latter survey was not statistically significant. Women between the ages of 65 and 74 who were interviewed in the 1990 National Health Interview Survey were 1.7 times more likely to report that they have had cataract than were men, while women 75 years and older were 2.1 times more likely to report a cataract [35].

Cataract development is well-known to be age-related [49] – in fact, any non-age-related cataract is termed a secondary cataract. Beneficiaries between ages 70–94 were at significantly increased odds of undergoing cataract surgery compared with those aged 65–69 (Table 2). However, the highest odds impact is seen in the 80–84 year-old stratum, after which the odds impact associated with age begins to decline. This observation may reflect the likelihood that, with increasing age, beneficiaries will already have undergone cataract surgery prior to our period of observation. This causes an overestimate of patients who actually are elegible for cataract surgery. A second possible explanation for the observed association with age may be worse overall health status among the oldest age groups, which decreases the likelihood of such individuals being considered a surgical candidate.

Although all persons in our analysis had both Medicare Parts A and B coverage, a beneficiary's imputed income still was associated with the odds of that beneficiary undergoing cataract surgery. Latitude was significantly associated with the likelihood of undergoing cataract surgery after adjusting for all other variables in the model. Our analysis also suggests that differences in latitude are associated with a 50% decrease in the likelihood of cataract surgery between the northernmost and southernmost regions of the continental US. While our analysis does not permit etiologic inference [52, 53], this finding is consistent with the hypothesis that increased exposure to the ultraviolet component of sunlight increases the risk of cataract formation.

Latitude of residence also may be associated with the likelihood of undergoing cataract surgery for reasons that have nothing to do with ultraviolet exposure. For instance, individuals living at lower latitude may lead a more active outdoors lifestyle, thereby increasing their need for good visual acuity. If, for instance, elderly persons who live in warmer regions are more likely to drive, engage in active sports, or pursue other activities that depend upon good vision, they may demand cataract surgery at an earlier stage than those of the same age who do not engage in such activities.

This aspect of our analysis is subject to the ecologic fallacy [23, 24] to the extent that there is an implicit assumption that all individuals in a particular region have the same UV-B exposure. Rosenthal and coworkers have demonstrated significant differences in personal UV-B exposure based on personal habits, such as wearing hats or sunglasses, working under cover, etc [54]. Despite individual variation in ocular UV exposure, the mean rate of exposure in a community is likely to be a function of ambient UV light and, therefore, may vary with latitude.

A second limitation of our analysis with regard to latitude is the implicit assumption that individuals have lived most of their lives in the BEAEA in which they reside at the time of cataract surgery. While there is certainly some migration from the Northern U.S. to retirement areas in the Southern US, the net migration to the South is only 2,000 persons annually (27,000 in-migrants, 25,000 out-migrants) among Americans age 65–74 [55]. For Americans 75 years and over, there is a net out-migration from the South of 3,000 persons per year (22,000 in-migrants, 25,000 out-migrants) [55]. Moreover, the association between latitude and cataract surgery rate is seen across the entire U.S., not just in popular retirement areas. Nevertheless, our analysis is limited by the fact that a Medicare beneficiary's residence may not reflect his/her lifelong exposure to UV-B.

A potential limitation which we do not believe biased our analysis is the tendency of some residents of northern states to undergo cataract surgery in the south during the winter months. The latitude variable was imputed based on the residence of the beneficiary, not the location in which surgery was performed. Moreover, only 2% of cataract episodes occured in a state non-contiguous to that in which the beneficiary lived.

The variables most strongly associated with increased regional rate or individual probability of undergoing cataract surgery were latitude, race, age, gender, allowed charges, and concentration of optometrists. We found no evidence that the concentration of ophthalmologists is associated with the regional rate or an individual's odds of undergoing cataract surgery.

Conclusions

The preceding review indicates that an association between UVR and ocular damage, including cataract, could be suspected on photobiological, biochemical, experimental, and epidemiologic grounds. There is evidence to suggest that sufficient UVR may reach the lens to cause damage. *In vitro*, UV exposure can lead to oxidation and denaturation of lens proteins by a number of different pathways, and the changes induced by UVR are similar to those seen in human cataractous lenses. There is experimental evidence in animals that *in vivo* exposure to UVR can cause cataracts. Epidemiologic evidence in man also suggests that high levels of UVR may be associated with cataract.

The establishment of an adverse effect of UVR on the eye would have tremendous public health importance. The ocular diseases attributed to UVR are of major significance in terms of the absolute numbers of people involved. In the United States alone, over 1 million cataract operations are performed each year [56], and worldwide, over 17 million people are blind from cataract [57].

Protecting the eye from UVR has become a multimillion-dollar-a-year industry with the development of UVR-absorbing spectacles, sunglasses, intraocular lenses, and, most recently, contact lenses. Furthermore, there are strong reasons to believe that we may be facing significantly higher levels of UVR because of progressive changes in the earth's atmosphere [58–60]. Recent data indicates that chlorofluorocarbon compounds are causing a significant reduction in the ozone layer in the stratosphere [61]. The ozone layer is the main atmospheric filter of UVR. It is therefore of great importance to examine in detail the association between UVR and ocular damage, specifically senile cataract and senile macular degeneration.

It would seem prudent to protect the eyes from unnecessary exposure to UV-B. The amount of ambient UV-B varies markedly during the day (being highest in summer between 10 a.m. and 2 p.m.). The periods of high levels of UV-B are usually well recognized, as this is the time when one is most likely to become sunburned. As a public health recommendation, therefore, people should be advised to use ocular protection at those times when they are at risk of getting sunburned.

There are two very easy ways to reduce UV-B exposure short of staying indoors, out of the sun. A hat with a brim will reduce ocular exposure by half, and ordinary, close-fitting plastic spectacles can reduce it to about 5% [12]. The effect of hats and glasses are additive. Although special UV-absorbing lenses can stop all UV-B transmission, a sample of 40 clear spectacle lenses showed that all of them significantly reduced ocular UV-B exposure [12]. The shape and position of the glasses were more important in reducing UV-B exposure than the actual lens material. Wrap-around glasses gave almost complete protection, while, if the frames were one inch from the brow, there was only a 25% reduction the amount of UV-B which reached the eye. Thus, to minimize ocular exposure to UV-B cheaply and effectively, people should be advised to wear a hat with a brim and close fitting sunglasses at times when they could get sunburned.

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