PMP across adjusted 1959 municipal boundaries for ophthalmologists was 53.4 (± 104.6) and 58.5 (± 94.9), in 1996 and 2006, respectively. That for all physicians was 1356.9 (± 1715.9), and 1488.8 (± 1681.1), in 1996 and 2006, respectively. Table 1 shows minimum, first quartile, median, third quartile, and maximum value of PMP for ophthalmologists and all physicians in two time points.

Table 2 shows the median (25th percentile–75th percentile) of PMP for ophthalmologists and all physicians in municipalities categorized (into 7 categories) by their population in 1996 and 2006. Medians rather than means were taken for this analysis because PMPs did not distribute normally (Shapiro-Wilk and Shapiro-Francia tests: $P < 0.05$). This table indicates that, for all physicians, less populous municipalities except for the least category had lower value of PMP in both 1996 and 2006, and PMP increased between 1996 and 2006, regardless of population sizes. The same can be observed for ophthalmologists in municipalities with population over 30,000.

The Lorenz curves for ophthalmologists and all physicians as of 1996 and 2006, based on aggregate data from the 1,959 municipalities, are shown in Figure 1 and Figure 2. The four curves are far from being a straight line. But the curve representing the ophthalmologists in 2006 is closer to the perfectly even line, if compared to that for ophthalmologists in 1996 (Figure 1).

The Gini coefficient (95% CI) for ophthalmologists in 1996 and 2006 was 0.405 (0.314–0.496) and 0.353 (0.272–0.434), respectively. That for all physicians in 1996 and 2006 was 0.341 (0.314–0.369) and 0.328 (0.301–0.355), respectively (Table 3). This analysis indicates the geographical distribution of ophthalmologists and all physicians in 2006 was better than that in 1996, although there was no statistically significant change. Other inequality measures, the CV and the $75^{th}/25^{th}$ percentile ratio, are also shown in Table 3. Each measure for both ophthalmologists and all physicians declined between 1996 and 2006.

DISCUSSION

The number of ophthalmologists and all physicians at the national level increased more rapidly than the population grew in Japan. As a consequence, the median value of PMP for ophthalmologists and all physicians across the geographical units also increased on the whole. Our analysis chiefly looked at changes of the overall geographical distribution of ophthalmologists and all physicians across adjusted municipal boundaries from 1996 to 2006. The findings provided no evidences that the geographical distribution of ophthalmologists and all physicians became less even, though the more populous municipalities, in general, had more physicians per capita.

TABLE 1 Physicians per million population for ophthalmologists and all physicians in 1996 and 2006

	Ophthalmologists		All physicians	
The year	1996 (n=10,982)	2006 (n=12,362)	1996 (n=230,297)	2006 (n=263,540)
Physicians per million population				
min	0	0	0	0
25th percentile (P_{25})	0	0	617.2	688.0
Median	34.0	45.9	1,045.8	1,158.5
75th percentile (P_{75})	74.0	84.1	1,568.0	1,756.2
MAX	2,616.4	2,226.1	40,511.8	31,380.2

TABLE 2 The median (25th percentile–75th percentile) of physicians (ophthalmologists and all physicians) per million population in municipalities categorized (into 7 categories) by their population in 1996 and 2006

Size of population	Ophthalmologists				All physicians			
The year	1996		2006		1996		2006	
	Median	(P_{25}–P_{75})	Median	(P_{25}–P_{75})	Median	(P_{25}–P_{75})	Median	(P_{25}–P_{75})
-5,000	0	(0–0)	0	(0–0)	608.9	(330.1–930.0)	646.4	(341.4–943.8)
5,001–10,000	0	(0–0)	0	(0–0)	565.5	(357.3–852.8)	614.9	(366.6–945.3)
10,001–30,000	0	(0–59.8)	0	(0–67.7)	822.1	(546.3–1,320.6)	930.2	(600.6–1,390.6)
30,001–50,000	46.6	(25.9–79.3)	57.1	(30.8–86.8)	1,217.5	(849.5–1,589.8)	1,268.7	(888.0–1,766.5)
50,001–100,000	59.0	(38.5–86.7)	68.7	(50.3–96.1)	1,317.2	(972.1–1,714.6)	1,469.1	(1,102.1–1,894.4)
100,001–300,000	71.9	(53.7–103.7)	84.2	(63.3–114.5)	1,552.8	(1,199.7–2,089.9)	1,785.1	(1,370.3–2,323.2)
300,001–	90.1	(70.8–119.2)	100.9	(81.1–127.9)	1,682.0	(1,295.4–2,629.1)	1,923.7	(1,628.8–3052.2)

Note: The number of the municipals in 5,000 or less, 5,001–10,000, 10,001–30,000, 30,001–50,000 and 50,001–100,000, 100,001–300,000 and 300,001 or more were 202, 273, 540, 267, 312, 293, and 72, in 1996, and 229, 272, 513, 267, 301, 301, and 76, in 2006, respectively.

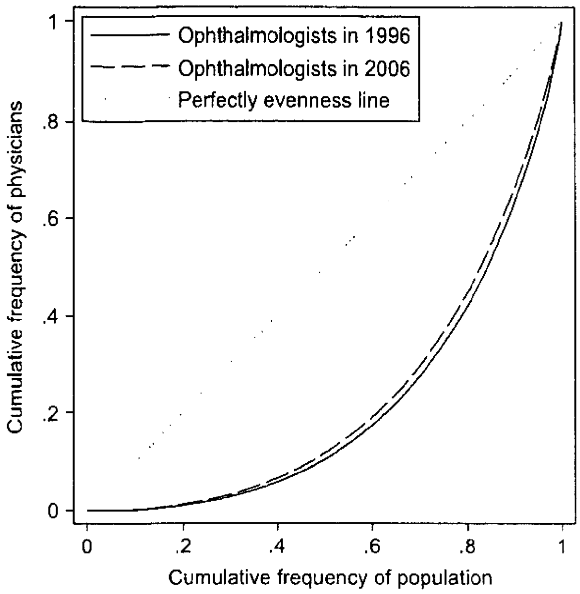

FIGURE 1 The Lorenz curves representing for the distributions of ophthalmologists in 1996 and 2006.

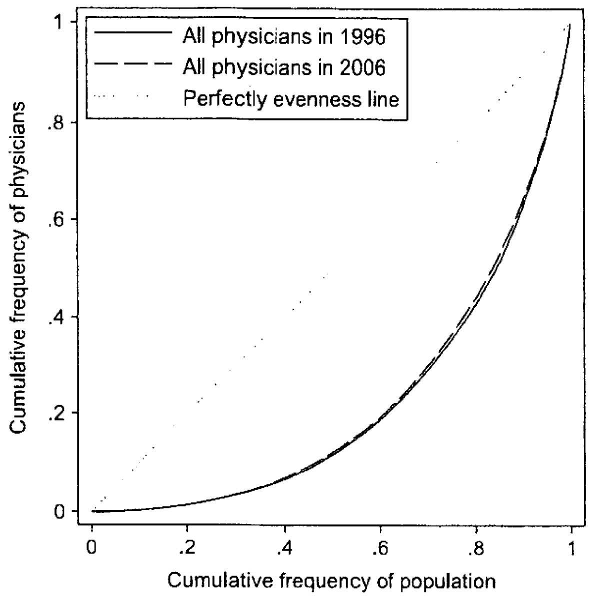

FIGURE 2 The Lorenz curves representing for the distributions of all physicians in 1996 and 2006.

TABLE 3 Inequality measures of ophthalmologists and all physicians

	Ophthalmologists		All physicians	
Year	1996	2006	1996	2006
Gini coeffcients	0.405	0.353	0.341	0.328
(95% confidence interval)	(0.314–0.496)	(0.272–0.434)	(0.314–0.369)	(0.301–0.355)
Coefficient of variation	1.96	1.62	1.26	1.13
Percentile ratio (P_{75}/P_{25})	2.13	1.90	1.92	1.31

The CV is a simple and well-known measure to assess inequality. The limitations of the CV are that it does not have an upper limit, and is influenced by extremely high or low values (outliers). The percentile ratio allows us to compare different parts of the distribution to each other (most common are the 75th/25th, 90th/10th, 90th/50th percentile ratios). But, the 75th/25th percentile ratio, for example, sees only the two points (the 75th and the 25th) and misses the inequality within the top 25 percentage of PMP, between the top 25 percentage and the bottom 25 percentage, or within the bottom 25 percentage. Thus the Gini coefficient is a better measure to investigate and compare the overall distribution of physicians. Kobayashi and his colleague reported that the Gini coefficient for all physicians across all municipalities (n = 3,268) in Japan was 0.331 and 0.340, respectively, in 1980 and 1990.[1] Their study and our results indicated that, in fact, the geographical distribution of all physicians became less balanced until, at least, the year 1996 and improved after that, with the geographical distribution of all physicians in 2006 being almost the same as in 1990. However, it would be incorrect to accept this result, because there are obviously large variations of all physicians between particular municipalities and analysis of smaller geographical units has a disadvantage. Thus, the overall geographical distribution of physicians has improved since 1996, but has not reached that in 1990. We had no exact data on the distribution of ophthalmologist other than our results. But this trend could be similar to the distribution of ophthalmologists, because of the same dispatching system of clinicians in our country.

It is true that ophthalmologist or all physicians in Japan did not show a completely even distribution, but their distribution for 2006 was better than that for 1996. Our results seemed to differ from the generally accepted view of Japanese citizens that unequal access to medical care has worsened, particularly after the advent of the new postgraduate training system. The reasons are probably that it was not the actual distribution of all physicians, but rather the balance between physicians working at hospitals and in private practice, the balance between physician subgroups, and the number of physicians working in ambulatory departments, influenced the quality of access to medical care. In so far as ophthalmic care, even blinding eye conditions/diseases are not, in general, life-threatening diseases and a patient has time to visit an ophthalmologist at the primary level, and to be referred to a tertiary or a secondary level hospital. This situation may allow the Japanese citizen to accept the uneven distribution of ophthalmologists. But we should notice the fact that the distribution of ophthalmologists is even worse than that of general internists (the Gini coefficient [95% CI]: 0.291 [0.267–0.315] and 0.248 [0.229–0.268] in 1996 and 2006, respectively) and general surgeons (the Gini coefficient: 0.354 [0.310–0.399] and 0.344 [0.292–0.395], in 1996 and 2006, respectively). (Data not shown)

The unequal access to medical care is also associated with the absolute number of physician subgroups. As proof, the number of general internists and general surgeons, who usually fill the role of emergency physicians at primary or secondary hospitals in addition to their routine work, decreased by 3.1% and 13.4%, respectively, between 1996 and 2006.[15] It is true that ophthalmologists increased by 12.6% over the last decade, but we cannot make the achievement of a similar rate of increasing number of ophthalmologists, because local government has already started providing monetary incentive for medical students to be pediatricians, perinatal physicians, or emergency physicians, and because more certificated ophthalmologists are employed at refractive clinics with a high salary in the most urban areas. Without guarantees of increasing number of ophthalmologists, re-distribution of ophthalmologists in proportion to the population would be one of the highest priorities in a public health perspective.

There were several limitations to our study. First, our analysis may not reflect the distribution of physician activities, because the influences of sex, age and the workload of physicians (ie, full-time or part-time job) were not examined. Japan is still a male dominant society so that most of female physicians quit their jobs or choose part-time jobs after they give birth. If we regard them as the same value as full-time equivalent physicians, we may overestimate PMP in municipalities. Second, physicians should not be distributed simply according to the size of a population, but according to the health needs. Morbidity or mortality due to specific diseases could be a good indicator of actual health needs, but it is unclear which diseases should be selected and it is not always easy to obtain epidemiological data. Third, we do not know what an acceptable level of distribution imbalance is. Perfect balance between spatial distribution of physicians and that of population is probably the best. However, the Gini coefficient of 0 is too ambitious to achieve. In general, specialists distribute more unevenly than general practitioners, because specialists provide secondary and tertiary medical care.[25] Our study and one report from Canada (the Gini coefficient for ophthalmologists, family physicians and all physicians in 2004 is 0.387, 0.151 and 0.247, respectively[10]) support it. Further research is needed to determine an acceptable level of the Gini coefficients for ophthalmologists.

The geographical distribution of ophthalmologists and all physicians did not worsen even after the new postgraduate training program commenced, although there was no statistically significant change. But, ophthalmologists do not show perfectly even allocation yet. In fact, the most recent distribution of ophthalmologists is statistically significantly worse than that of general internists. This trend may degenerate, unless we create a policy such as an educational program for rural ophthalmologists, and monetary incentives. All citizens have the right to medical service of equal quality (Article 25 of the Japanese Constitution). To achieve this public health policy, a government department responsible for administration and allocation of physicians, Japanese Ophthalmological Society, and Japan Ophthalmologists Association, should monitor the number and the distribution of ophthalmologists, and should create any possible policy to re-distribute them equally, prior to the historic demographic transition.

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Economic Cost of Visual Impairment in Japan

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Objective: To quantify the total economic cost of visual impairment in Japan.

Methods: A prevalence-based approach was adopted using data on visual impairment, the national health system, and indirect costs to capture the economic impact of visual impairment in 2007.

Results: In 2007, visual impairment affected more than 1.64 million people in Japan and cost around ¥8785.4 billion (US $72.8 billion) across the economy, equivalent to 1.7% of Japan's gross domestic product. The loss of well being (years of life lost from disability and premature mortality) cost ¥5863.6 billion (US $48.6 billion). Direct health system costs were ¥1338.2 billion (US $11.1 billion). Other financial costs were ¥1583.5 billion (US $13.1 billion), including productivity losses, care takers' costs, and efficiency losses from welfare payments and taxes. Community care was the largest component of other financial costs and was composed of paid and unpaid services that provide home and personal care to people with visual impairment. The findings of this study are in line with those of similar studies in Australia and the United States.

Conclusions: Visual impairment imposes substantial costs on society, particularly to individuals with visual impairment and their families. Eliminating or reducing disabilities from visual impairment through public awareness of preventive care, early diagnosis, more intensive disease treatment, and new medical technologies could significantly improve the quality of life for people with visual impairment and their families, while also potentially reducing national health care expenditure and increasing productivity in Japan. The results of this study should provide a first step in helping policymakers evaluate policy effects and to prioritize research expenditures.

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THE COSTS OF VISUAL IMPAIRMENT have been characterized in the United States, Australia, and some European countries, including the United Kingdom.[1-3] Although direct comparison of results is difficult because of differing methodologies, these reports show that visual impairment places a heavy burden on individuals, families, and society.

Increasing eye disease and vision loss is often driven by an aging population and social and environmental changes. Population-based studies from Australia, Europe, and the United States have demonstrated that the prevalence of visual impairment approximately triples with each decade of life beyond the age of 40 years.[4-6]

The Organization for Economic Cooperation and Development reported that in 2006, health expenditures in Japan accounted for 8.1% of the country's gross domestic product. Although Japanese health expenditure was lower than the Organization for Economic Cooperation and Development average of 8.9%, Japan has one of the world's oldest and longest living populations. Measuring the cost of health care is essential for designing future health financing.

Rapid economic development, growing public awareness of treatable eye diseases, and the national medical insurance system have enhanced prevention and treatment of visually impairing conditions in Japan. However, the economic consequences of visual impairment have not been documented, apart from some top-down estimates based on national statistics. This is a timely first study to assess the economic impact of visual impairment in Japan.

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METHODS

This study adopts the prevalence-based costing method used in similar studies for Australia[1] and the United States (unpublished data, Access Economics, 2006), measuring the number of people with visual impairment in 2007 and the cost of treating their conditions plus other financial and nonfinancial costs from their vision loss in that year. Understanding cost components is crucial for appropriate allocation of health care resources.

All costs were originally calculated in Japanese yen (¥) and are presented with United States dollar equivalents based on the Organization for Economic Cooperation and Development's purchasing parity 2007 rate of ¥120.66 per US dollar.

PREVALENCE

Prevalence of visual impairment (best-corrected visual acuity <6/12) was calculated as the sum of low vision (best-corrected visual acuity between 6/12 and 6/60) and blindness (best-corrected visual acuity ≤6/60). Visual impairment was defined as <6/12 (<20/40) because this is a well-accepted international definition, thus enabling cross-country comparisons, and because these data were available in Japan.

Prevalence rates by age were based on data from the Japanese Ministry of Health, Labour and Welfare, presented by the National Committee of Welfare for the Blind in Japan, and a major epidemiological study. Sex and severity splits were based on epidemiological data sets by cause of visual impairment. Prevalence rates were multiplied by Japanese census data to estimate the number of people with visual impairment.

DIRECT HEALTH COSTS

Health costs were based on Japanese health expenditure data,[20] which concord with the World Health Organization's *International Statistical Classification of Diseases, 10th Revision (ICD-10)*. In the absence of more granular data, the *ICD-10* code VII for "diseases of the eye and adnexa" was used. These expenditures were related to all eye health costs and may include some conditions that are not potentially visually impairing. However, these are likely to be small relative to the total, as in other studies in which data do not support separation of visually impairing conditions.[1] Health expenditures were converted to 2007 values using official health inflation data.

OTHER FINANCIAL COSTS

Other financial costs are composed of productivity losses, costs of care outside the health system, vision aids, and efficiency losses from government transfers and expenditure. People with visual impairment may work less than otherwise, retire early, or die prematurely, representing real productivity losses to the economy. A human capital approach was used to measure productivity losses, as is appropriate in countries with low unemployment like Japan.[21] Age- and sex-standardized employment rates, absenteeism, and mortality rates were estimated for people with visual impairment using official estimates and government survey data.[7,22] Productivity costs were estimated, assuming that in the absence of visual impairment, people would have worked at the same rate as the general population. Productivity costs from increased absenteeism were calculated as the average number of days absent per year owing to visual impairment × the total number of people employed with visual impairment × average annual wages. Production losses arising from premature mortality from falls and depression associated with visual impairment were calculated as a net present value using World Health Organization data for Japan on retirement age, average life expectancy, average age of death, and an estimated discount rate of 1.5%, calculated as long-term nominal bond rates minus expected inflation and growth in productivity.

Additionally, any taxation foregone requires equivalent revenue raising, imposing real efficiency costs on the economy, known as deadweight losses (DWLs). Internationally, DWLs are estimated to be in the range of 9, 16, and 50 cents (9%, 16%, and 50%, respectively) for every additional tax dollar raised by the government. The parameter estimate of 16% was used, since no Japanese studies were found to provide a local estimate.

To estimate the cost of community care services, an opportunity cost method valued time devoted to care giving responsibilities that cannot be spent in the paid workforce. This was calculated as the estimated number of people with visual impairment who require some level of care × the average number of hours of care required[10] × by an average hourly rate for the wage forgone by the caregiver,[21] and weighted by age, sex, and the probability of alternative employment.[22]

LOSS OF WELL-BEING

Loss of well-being from visual impairment was measured in disability-adjusted life years (DALYs). Disability-adjusted life years have 2 components: the years of life lost as a result of premature death (the mortality burden) and the years of healthy life lost as a result of disability (the morbidity burden).

Years of healthy life lost as a result of disability from visual impairment were calculated by multiplying prevalent cases by disability weights for mild, moderate, and severe visual impairment (0.02, 0.17, and 0.43, respectively) based on the global burden of disease study. These disability weights represent losing 2%, 17%, and 43%, respectively, of a year of healthy life. Years of life lost were calculated from the age when a person dies from comorbid conditions attributable to visual impairment and the life expectancy for people of that age and sex. To calculate the burden of disease, Japanese prevalence rates for low vision were subdivided into mild and moderate visual impairment using weights from Australian prevalence data.

The loss of well-being in DALYs was converted into a monetary value using an estimate of the value of a statistical life. The value of a statistical life in Japan has been valued between ¥675.9 million (US $5.6 million) and ¥1783.5 billion (US $14.8 million).[30] The lower bound of US $5.6 million was used with a discount rate of 3.0% during 40 years to generate an estimate for the value of a statistical life year (VSLY) of ¥28.3 million (US $234 552).

SENSITIVITY ANALYSIS

The effects of 20% changes in health care costs, the number of people requiring informal care, and earnings for men and women were examined. The effect of reducing the DWL parameter estimate to the lower bound of 9% was tested. We also assessed the effects of a 20% change in the value of a statistical life used for Japan and in the distribution of low-vision severity.

RESULTS

PREVALENCE

There were 1.64 million people with visual impairment in Japan in 2007; almost 188 000 were blind. Of those with visual impairment, 93.2% were aged 40 years or older, 61.2% were aged 65 years or older, and 33.5% were aged 75 years or older (**Table 1**).

DIRECT HEALTH COSTS

The direct financial costs in Japan for the treatment of all disorders of the eye and adnexa were estimated to total ¥1338.2 billion (US $11.1 billion) in 2007 (**Table 2**) and may include some conditions that are not visually impairing. However, the cost overestimation is expected to be slight as a result of this data constraint and is countered in that costs of screening programs and eye health promotion are not included, so health cost coverage was not exhaustive. The largest component of health costs for visual impairment related to general medical expenditure (¥977.5 billion [US $8.1 billion]), of which outpatients represented 77.7% (¥759.4 billion [US $6.3 billion]).

Table 1. Prevalence of Visual Impairment in Japan by Age, Sex, and Severity

	No. × 1000 (%)		
Age, y	Men	Women	Total
Total visual impairment			
[illegible]	56 (0.20)	53 (0.10)	1[illegible] (0.15)
[illegible]	792 (2.40)	733 (1.9[illegible])	1525 (2.17)
[illegible]	519 (4.44)	482 (3.06)	1001 (3.65)
[illegible]	281 (5.9[illegible])	267 (3.37)	548 (4.32)
Total	850 (1.3[illegible])	787 (1.25)	1637 (1.28)
Low vision			
[illegible]	[illegible]	41 [illegible]	[illegible] (0.17)
[illegible]	705 (2.12)	646 (1.74)	1351 (1.92)
[illegible]	460 (3.93)	427 (2.71)	88[illegible] (3.23)
[illegible]	249 (5.24)	236 (2.99)	485 (3.87)
Total	75[illegible] (1.21)	696 (1.06)	1449 (1.12)
Blindness			
[illegible]	7 (0.02)	[illegible] (0.02)	12 (0.02)
[illegible]	91 (0.25)	84 (0.23)	175 (0.23)
[illegible]	59 (0.51)	56 (0.35)	115 (0.42)
[illegible]	32 (0.65)	31 (0.30)	63 (0.50)
Total	98 (0.16)	9[illegible] (0.14)	18[illegible] (0.15)

OTHER FINANCIAL COSTS

Other financial costs of visual impairment were estimated as ¥1583.5 billion (US $13.1 billion) in 2007 (**Table 3**). Productivity losses from visual impairment (¥563.1 billion [US $4.7 billion]) reflected the lost earnings from lower employment participation (¥510.4 billion [US $4.2 billion]) and worker absenteeism costs (¥46.4 billion [US $384 million]). There are also additional costs totaling ¥6.4 billion (US $53.0 million) associated with premature mortality due to comorbid consequences.

As a substantial component of overall costs, the cost of community care represented both unpaid and paid home care for people with visual impairment. Using the opportunity cost method, the cost of community care in 2007 was estimated as ¥797.3 billion (US $6.6 billion).

The DWL resulting from raising additional taxation revenue to pay for costs borne by the government in relation to visual impairment was composed of losses from health care costs (¥130.9 billion [US $1.1 billion]), lost-

Table 2. Summary of Health Care Costs for Visual Impairment in Japan

Cost Item	¥ in Billions	US $ in Billions	% of Total Health Costs	% of Total Economic Costs
General medical expenditure	977.5	8.102	73.0	11.1
Inpatient	218.2	1.809	16.3	2.5
Outpatient	759.4	6.294	56.7	8.6
Drugs	168.3	1.395	12.6	[illegible]
Meal service on admission	18.0	0.148	1.3	0.2
Home visit nursing	1.5	0.012	0.1	0.0
Health care administration	57.3	0.475	4.3	0.6
Long-term care insurance	19.6	0.162	1.5	0.2
Eye care research	96.0	0.795	7.2	1.1
Total Health Care Costs	**1338.2**	**11.091**	**100.0**	**15.1**

Table 3. Summary of Other Financial Costs for Visual Impairment in Japan

Cost Item	¥ in Billions	US $ in Billions	% of Total Other Financial Costs	% of Total Economic Costs
Productivity losses	563.1	4.667	35.6	6.4
Lower employment	510.4	4.230	32.2	5.8
Absenteeism	46.4	0.384	2.9	0.5
Premature mortality	6.4	0.053	0.4	0.1
Deadweight losses	194.1	1.609	12.3	2.2
Health system costs	130.9	1.085	8.3	1.5
Foregone taxation	33.8	0.280	2.1	0.4
Social security payments	24.8	0.205	1.6	0.3
Other costs	4.6	0.038	0.3	0.1
Community care	797.3	6.608	50.3	9.1
Institutional care	28.7	0.238	1.8	0.3
Vision aids	0.2	0.002	0.0	0.0
Total Other Financial Costs	**1583.5**	**13.124**	**100.0**	**18.0**

Table 4. Cost Summary of Visual Impairment by Item and Bearer in Japan

	US $ in Billions			
	Cost Bearer			
Cost	Individual	Government	Other Society	Total
Health care costs	1.698	6.781	2.612	**11.091**
Other financial costs	3.618	1.991	7.515	**13.124**
Loss of well-being	48.598	0	0	**48.598**
Total Economic Costs	53.914	8.772	**10.127**	**72.813**

taxation (¥33.8 billion [US $280 million]), welfare payments (¥24.8 billion [US $205 million]), and other costs associated with providing institutional care and vision aids (¥4.6 billion [US $38.4 million]).

Expenditure on other institutional care and rehabilitation for people with visual impairment in Japan was based on the average cost of institutional care per person per year (derived from long-term care insurance facilities, estimated at ¥7 445 863 [US $61 711.63]) and multiplied by the number of people admitted (3857 people, minus the adjustment to account for the 30% overlap in the data with long-term care insurance facilities). In total, it was estimated that expenditure for institutional services (over and above that provided by long-term care insurance facilities) for the visually impaired was ¥28.7 billion (US $238 million) in 2007.

LOSS OF WELL-BEING

In 2007, the years of healthy life lost as a result of disability and years of life lost attributable to visual impairment in Japan were estimated as 220 022 DALYs and 9063 DALYs, respectively. In total, the burden of disease was 229 085 DALYs.

The gross value of the burden of disease (DALYs multiplied by the VSLY) was ¥6503.1 billion (US $53.9 billion). However, the gross value includes some costs borne by the individual—notably, lost earnings and out-of-pocket health expenditures, for example, which have already been captured. As such, these costs were subtracted and the net cost of the loss of well-being in Japan was calculated as ¥5863.6 billion (US $48.6 billion) for 2007. Costs by item and bearer are summarized in **Table 4**.

INTERNATIONAL COMPARISONS

The cost methodology used here for Japan has also been applied in Australia in 2004 and in the United States in 2005. The estimates can be compared by inflating those costs to 2007 values using domestic inflation data and to US dollars using purchasing power parity. **Table 5** shows the economic costs per person with visual impairment.

The results in Table 5 show that while the costs vary across categories, it is evident that visual impairment incurs a large overall cost in each country. The differences across countries largely reflect differences in the structure of each health care system, the delivery of elderly and community care, productivity estimates, and the value of the burden of disease owing to different values of a statistical life for each country.

Table 5. Cost of Visual Impairment per Person With Visual Impairment by Country

	Cost per Person/y, US $		
Cost	Australia	Japan	United States
Health care costs	7614	6776	15 617
Other financial costs	13 395	8018	6085
Loss of well-being	20 106	29 690	32 193
Total Economic Costs	**41 116**	**44 484**	**53 896**

SENSITIVITY ANALYSIS

Varying direct health costs, the number of people requiring informal care in the community, and male and female average earnings ±20% produced a variation in the baseline of total visual impairment costs of ±2.9%, ±1.9%, and ±2.2%, respectively. Our results did not vary significantly when the assumption used for the DWL parameter estimates was dropped from 16% to 9%, resulting in a fall of total costs of 1.0%. The value of a statistical life used for Japan to estimate the burden of disease was varied by 20% resulting in changes of ±15.1% of total costs; the sensitivity of this result is discussed subsequently. The distribution of low vision (between mild and moderate vision) was altered by 20%, resulting in changes of ±1.5% of total costs.

COMMENT

While no single data set provided a complete picture of the prevalence of visual impairment in Japan, all surveys provided valuable input. The prevalence of visual impairment was principally based on epidemiological studies of larger sample sizes. These sources were considered representative of the rapid economic development in Japan during the past half century, public awareness of treatable ocular diseases, and the universal medical insurance system in Japan. Additionally, the smaller surveys provided valuable information on prevalence by sex and severity for low vision and blindness.

In the present study, we have shown that in 2007 visual impairment affected more than 1.64 million people in Japan, or 1.3% of the population, and cost an estimated ¥8785.4 billion [US $72.8 billion], or 1.7% of the gross domestic product of Japan. These findings are consistent with other studies that also found substantial expenditures to be associated with visual impairment.[27,28]

The total cost of visual impairment presented in this report captures the direct and indirect costs incurred across the economy by individuals, family and care takers, employers, society, and government. It was important to include indirect costs to gain an accurate picture of the total economic burden of visual impairment.

Our analysis suggests that community care costs account for 50% of indirect costs of visual impairment in Japan. This suggests that substantial resources are dedicated to care for individuals with visual impairment at home through informal care. Community care costs were composed of both paid and unpaid home care. Official usage data were available for paid home care[29] and used as a proxy for unpaid care. Usage data ranged from all-day care to care only when required. A weighted average of 17.1 hours per week based on the percentage distribution of the usage data was applied to those with visual impairment most likely to require some form of community care. It was assumed that those with mild visual impairment would not require any form of community care and those in institutional care were accounted for in other financial costs.

The loss of well-being comprises a large part of the costs of visual impairment in Japan as well as in Australia and the United States. There has been some controversy about placing a monetary value on DALYs, and the value of the VSLY chosen has a large impact on the estimated burden of disease from visual impairment. As a conservative approach, the lower end estimate was used because the VSLY for Japan was already at the high end of estimates of that among comparable countries. Accordingly, the estimated loss of well-being from visual impairment per person per year in Japan was between that in Australia and the United States.

Even in a developed country like Japan, avoidable vision loss is now a major problem and will increase in the future in the absence of policy change. Because prevalence rates of visual impairment increase with each decade of life, the number of Japanese individuals with visual impairment is expected to increase by 23% during the next 20 years. Although specific interventions may increase health costs, they can also bring significant savings in other financial costs and loss of well-being. Taylor and associates[24] have shown that many eye care interventions are cost-effective.

Owing to good access to high-quality cataract surgery, the prevalence of visual impairment from cataract is low in Japan. On the other hand, glaucoma is the leading cause of visual impairment.[8-10] Compared with the United States and Australia, the rate of undiagnosed glaucoma is very high in Japan,[11] and this may partially explain the high prevalence of visual impairment from glaucoma in Japan. Diabetic retinopathy is the second most common cause of visual impairment. The prevalence of diabetes is relatively high in Japan and this would contribute to a high prevalence of diabetic retinopathy and visual impairment.[5] Access to good medical services in Japan through its universal health care system enables people with diabetes to have better systemic control. However, the high proportion of visual impairment due to diabetic retinopathy also raises questions about the adequacy of coverage of screening and close coordination with general physicians and ophthalmologists and the use of photocoagulation and vitreous surgery, which are readily available in Japan.

Reducing the burden of visual impairment through factors such as public awareness of preventive care, early diagnosis, more intensive disease treatment, more research, and the advent of new medical technologies could significantly improve the quality of life for people with visual impairment and their families, while at the same time potentially reducing national expenditures for health care services and increasing productivity in the Japanese economy.

The comparability of epidemiological and economic estimates between illnesses is also important to inform decisions on the distribution of research effort, as suggested by Leal and colleagues.[30] Japan already has good primary, secondary, and tertiary eye care services as well as good data on the distribution and impact of eye diseases. Additionally, Japan has extensive health and financial data that permit economic modeling of any related prevention or treatment. Our study is the first to quantify the burden of visual impairment in Japan. We believe that our study will be of particular interest to policymakers. It highlights, above everything else, the need for comparable and accurate information on the prevalence, severity, and resource use associated with visual impairment in Japan.

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The method of operation followed the principles laid down by Elliot: a broad conjunctival flap, splitting of the cornea with a broad-bellied miniature scalpel, and a 2 mm trephine. This size was found necessary after experience with soft eyes and where the aqueous escaped prematurely. If the trephine opening is too small, it was found difficult to cleanly divide the attachment of the sclera disk, and through this small opening it was very difficult to fish out the iris. It was soon observed that the buttonhole iridectomy must be large to insure filtration.

The complications may be regarded as three, namely, iritis, hypotony and late infection. The tendency to iritis is unquestionably pronounced, as must be the experience of any one who is performing this operation, and even the early use of atropin does not prevent the proliferation of some uveal pigment and consecutive deposit on the lens capsule. We are in the habit of bringing atropin ointment into the conjunctival sac at the close of the operation. The complication of hypotony is a very serious one. We cannot at the present day state what the outcome of an eye is whose tension is reduced to 5 or 6. It surely must be a pathological condition. The danger of late infection is a particularly real one. Considerable attention has been drawn to this in recent literature. There can be no question that an eye with a cystoid cicatrix is not a sound eye, nor an eye enjoying the benefit of a normal protecting membrane. The sight of a large cystoids cicatrix which we have repeatedly observed measuring 4 or 3 mm is surely one to cause some anxiety. On the other hand, the advantages of a trephining operation seem to me to consist in that the operation is a safer one in hard eyes than any other operation that has been suggested for reducing the tension.

Reference: Knapp A. Some results after trephining. *Arch Ophthalmol*. 1914;43:121-125.

Note: Arnold Knapp (1869-1956) was born the same year as the *Archives of Ophthalmology* and was its second editor. He was the son of Hermann Knapp, the first editor of the *Archives*, and served as editor for 38 years.

Global Inequality in Eye Health: Country-Level Analysis From the Global Burden of Disease Study

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Objectives. We assessed global inequality in eye health by using data on the global burden of disease measured in disability-adjusted life years (DALYs).

Methods. We estimated the burden of eye disease by calculating the sum of DALYs (from the Global Burden of Disease study, 2004 update) due to trachoma, vitamin A deficiency, glaucoma, cataract, refractive errors, and macular degeneration. We assessed the geographic distribution of eye disease in relation to economic status and etiology by calculating the Gini coefficient, the Theil index, and the Atkinson index.

Results. The global burden of eye disease was estimated at 61.4 million DALYs worldwide (4.0% of total DALYs). Vitamin A deficiency and trachoma were distributed more unevenly than were noncommunicable eye diseases, regardless of economic status. For noncommunicable eye diseases, the major contributor was refractive errors, regardless of economic status. The most uneven distribution was observed for cataract (high-income countries) and refractive errors (middle- and low-income countries).

Conclusions. Creating new eye health service for refractive errors and reducing the unacceptable eye health disparity in refractive errors should be the highest priorities for international public health services in eye care and eye health. (*Am J Public Health.* 2010;100:1784–1788. doi:10.2105/AJPH.2009.187930)

The World Health Organization (WHO) estimates that 314 million people have visual impairment worldwide, of whom 269 million have low vision and 45 million are blind.[1] Ninety percent of all blind and visually disabled people live in middle- and low-income countries.[2,3] However, blindness is not always prioritized by health and public health practices, especially when mortality indicators are used. It is true that some population-based studies have suggested an indirect relationship between visual impairment and mortality,[4–8] but this is difficult to prove.

The first Global Burden of Disease (GBD) study quantified health effects by employing a new metric known as the disability-adjusted life year (DALY).[9] This is a summary measure of population health, integrating mortality with morbidity and disability information in a single unit. One DALY can be thought of as 1 lost year of "healthy" life, and the burden of disease measures the gap between the current health status and an ideal situation in which everyone would live to old age while remaining free of disease and disability.[10] Therefore, the GBD study lifts the curtain on the true magnitude of underestimated diseases and conditions, most of which are not direct causes of mortality.

Our goals in this study were as follows: (1) to calculate DALYs due to visual impairment at the global and regional levels, (2) to compare DALYs due to specific causes of visual impairment in relation to economic status, and (3) to measure the global imbalance of eye disease in relation to economic status and specific causes by using recent data from the GBD study.

METHODS

DALYs are calculated as the sum of years of life lost (YLLs) through premature death and years lived with disability (YLDs). YLDs are computed by multiplying the number of incident cases by a weighting factor of between 0 (perfect health) and 1 (death) and the mean duration of the disease with a 3% time discount.[11] To estimate DALYs due to each eye disease, the weighted value for low vision due to any eye diseases and cornea scar due to vitamin A deficiency were fixed at 0.170 and 0.277, respectively, whereas the weighted value for blindness due to trachoma, glaucoma, cataract, refractive errors, and macular degeneration were fixed at 0.581, 0.600, 0.570, 0.430, and 0.600, respectively.[12] Thus, the YLD value is higher if a disease or condition leads to more severe disability at a younger age.

The data for our study came from the GBD study (2004 update). A summary of cause-specific death and DALY estimates for WHO member states in 2004 was obtained from the WHO Web site.[13] This file included estimates of total deaths, of total DALYs, of deaths per 100000 population, of DALYs per 100000 population, of age-standardized death rates per 100000 population, and of age-standardized DALYs per 100000 population stratified by cause and member state. For the GBD study, the data set divided the causes of death into 3 groups: Group I (communicable, maternal, perinatal, and nutritional conditions), Group II (noncommunicable diseases), and Group III (injuries). Each group was then divided into subcategories (5 subcategories in group I, 14 in Group II, and 2 in Group III). A third level of categorization was then used to identify additional specific causes within each subcategory. From Group I, trachoma and vitamin A deficiency were used for our analysis but not onchocerciasis, because the sequelae of onchocerciasis consist of visual impairment and the dermatologic complication of itching.[12] From Group II, glaucoma, cataract, refractive errors, and macular degeneration were used. We did not use DALYs due to diabetes mellitus because DALYs due to diabetic retinopathy were not available (DALYs due to diabetes mellitus were the sum of case, diabetic retinopathy, diabetic foot, neuropathy, and amputation[12]). No data on eye injuries were available in Group III.

First, we estimated the global burden of eye disease by calculating the sum of total DALYs due to trachoma, vitamin A deficiency, glaucoma, cataract, refractive errors, and macular degeneration, and then compared these figures with estimated total DALYs due to conditions in Groups I, II, and III. Second, to investigate the global imbalance of eye disease, we calculated the burden of eye disease for each World Bank region[14] and specific cause. Third, the 192 WHO member states were divided into 2 groups (high-income states and middle- and low-income states), according to the World Bank's classification. To measure the eye health disparity related to economic status, we computed 3 summary measures (the Gini coefficient, the Theil index, and the Atkinson index) of maldistribution of the DALY data from the estimated DALYs per 100 000 population. If estimated DALYs per 100 000 population for a particular eye disease in a specific country was zero, we substituted a value of 0.0000001 when measuring inequality. These measures were initially designed to assess income inequity, but they have also been used to assess the distribution of health resources.[15–18]

The principles of these measures have been reviewed elsewhere[19] or summarized on the World Bank Web site.[20] In brief, the Gini coefficient (the best-known index) ranges from zero, which reflects perfect evenness, to 1, which indicates perfect unevenness. The Theil index (a generalized entropy index) ranges from zero, which means an equal distribution, to infinity (a higher value is more uneven). The Atkinson index ranges from zero to 1, with zero meaning a state of evenness. For our analysis, the sensitivity parameter (ε) was set at 0.5. We performed statistical analysis using Stata SE 10.0 for Windows (StataCorp LP, College Station, TX).

RESULTS

The 6.43 billion people in the 192 WHO member states were included in the GBD study (2004 update). The total burden of all diseases and conditions in the world was estimated to be 1.52 billion DALYs. The global burden of Group I disease (communicable, maternal, perinatal, and nutritional conditions) was 603.4 million DALYs (39.7% of the total), whereas that of Group II (noncommunicable diseases) and of Group III (injuries) was 730.3 million DALYs (48.0%) and 187.2 million DALYs (12.3%), respectively. The global burden of eye disease was estimated to be 61.4 million DALYs, accounting for 4.0% of total DALYs (8th of 21 subcategories; Figure A, available as a supplement to the online version of this article at http://www.ajph.org).

The highest number of DALYs were found in East Asia and the Pacific (including China) and South Asia (including India), followed by sub-Saharan Africa and the high-income economies (Figure 1). As can be seen in Figure 1, the burden of refractive errors predominantly affects East Asia and the Pacific, South Asia, and high-income economies.

Table 1 shows the burden of eye disease in DALYs stratified by specific cause and economic status. Contributors to the burden of eye disease at the global level were refractive errors (27.7 million DALYs), cataract (17.7 million DALYs), macular degeneration (9.3 million DALYs), glaucoma (4.7 million DALYs), trachoma (1.3 million DALYs), and vitamin A deficiency (0.6 million DALYs). Thirty-nine countries with a population of 0.98 billion were classified as high-income countries, and 153 countries with a population of 5.44 billion were classified as middle-income or low-income countries. There was no burden due to trachoma in the high-income countries, except for Australia and Germany, or in 92 middle- or low-income countries. Five high-income countries (Saudi Arabia, Kuwait, Republic of Korea, Brunei, and Singapore) and 108 middle- and low-income countries had a disease burden due to vitamin A deficiency. Every country had a burden due to all of the eye diseases in Group II. Table 1 also shows that in high-income countries, the largest eye disease burden was caused by refractive errors, followed by macular degeneration, cataract, and glaucoma, and that in middle- and low-income countries the largest burden was from cataract, followed by macular degeneration and glaucoma.

The highest number of DALYs per 100 000 was observed in the middle- and low-income countries of East Asia and the Pacific, South Asia, and sub-Saharan Africa. (Figure B, available as a supplement to the online version of this article at http://www.ajph.org, shows a global map of estimated DALYs for eye disease per 100 000 population.) Table 2 shows the median value (25th percentile–75th percentile) of DALYs per 100 000 stratified by each specific cause and by economic status. Median rather than mean values were used for this analysis because of the skewed sample distribution. The median value of country-level DALYs for refractive errors was found to be the highest worldwide and in high-income countries, whereas it was equal to that for cataract across the middle-income and

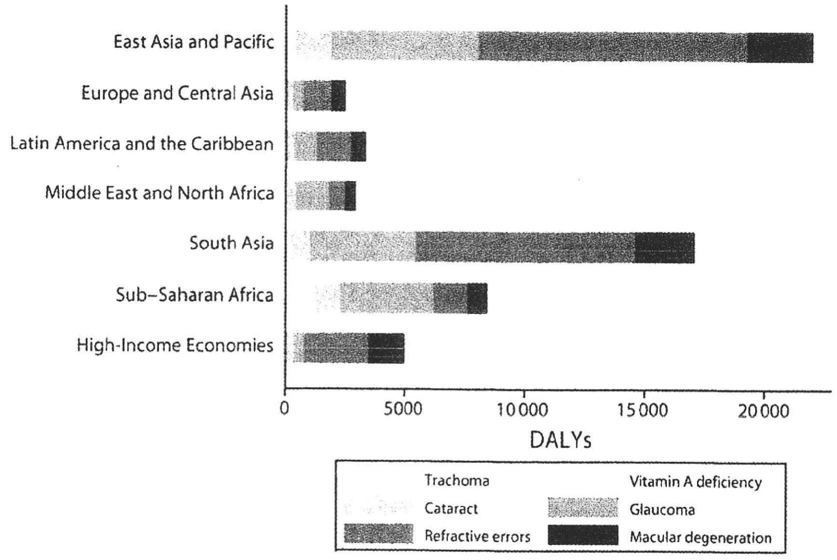

FIGURE 1—Disability-adjusted life years (DALYs) due to eye disease, by World Bank region and specific cause: Global Burden of Disease Study, 2004

TABLE 1—The Global Burden of Eye Disease, Measured in Disability-Adjusted Life Years (DALYs), by Specific Cause and Economic Status: Global Burden of Disease Study, 2004

	Worldwide, 1000 DALYs (%)	High-Income Countries, 1000 DALYs (%)	Middle- and Low-Income Countries, 1000 DALYs (%)
Group I causes			
Trachoma	1 331.9 (2.2)	0.11 (0.0021)	1 331.8 (2.4)
Vitamin A deficiency	628.7 (1.0)	0.08 (0.0016)	628.6 (1.1)
Group II causes			
Glaucoma	4 716.6 (7.7)	366.6 (7.3)	4 350.0 (7.7)
Cataract	17 719.8 (28.9)	394.1 (7.9)	17 325.6 (30.7)
Refractive errors	27 715.5 (45.1)	2 729.0 (54.7)	24 986.5 (44.3)
Macular degeneration	9 279.0 (15.1)	1 501.1 (30.1)	7 777.9 (13.8)
All eye diseases	61 391.4 (100)	4 991.0 (100)	56 400.4 (100)

low-income countries. Refractive errors and macular degeneration had a higher median burden in high-income countries than in middle- and low-income countries.

The distribution of DALYs by specific cause and economic status was assessed with the 3 inequality measures (Table 3). Inequality was greater for the eye diseases in Group I than for those in Group II, regardless of the index used and economic status. In Group II, the disease with the most uneven distribution at the global level was cataract, followed by refractive errors, glaucoma, and macular degeneration. Across high-income countries, cataract was distributed most unevenly, followed by refractive errors, glaucoma, and macular degeneration. Across middle- and low-income countries, refractive errors were distributed most unevenly, followed by cataract, glaucoma, and macular degeneration, according to all 3 of the indices.

DISCUSSION

Chiang et al., using data from the GBD study in 2001, reported that the global burden of visual impairment due to onchocerciasis, trachoma, vitamin A deficiency, glaucoma, cataract, and age-related visual disorders was 53.7 million DALYs (3.5% of the total).[21] Our study, however, represents the first attempt to measure eye health disparity by using DALY data from the GBD study. According to our findings, major contributors to the worldwide burden of eye disease were refractive errors, cataract, macular degeneration, and glaucoma in descending order of DALYs. This ranking was different from the recent estimate of the major causes of blindness by the WHO, which was cataract (39.1%), refractive errors (18.2%), glaucoma (10.1%), and age-related macular degeneration (7.1%).[1] Possible reasons for the differences are (1) the GBD study not only included blindness but also low vision and (2) DALYs have a 3% time discount and are age-weighted. In other words, a specific leading cause of blindness at a younger age will attract a higher number of DALYs. It is therefore reasonable for refractive errors to have higher DALYs than cataract because refractive errors generally occur at a younger age than cataract. Some epidemiological studies have indicated a higher prevalence of blindness due to macular degeneration than glaucoma at a younger age.[22–24] This would contribute to the burden of macular degeneration and higher DALYs, although the prevalence of blindness due to glaucoma is higher than that due to macular degeneration.

Regional differences were also obvious, with a higher eye disease burden in East Asia and the Pacific (including China), South Asia (including India), and sub-Saharan Africa. Overall, more than 90% of the eye disease burden occurred in middle- and low-income countries. A greater proportion of the eye disease burden in middle- and low-income countries was due to refractive errors and cataract, whereas that in high-income countries was due to refractive errors and macular degeneration.

In our study, the ranking of eye health disparity was not influenced by the index selected, as Kawachi and Kennedy reported.[25] Eye diseases from Group I showed a more uneven distribution, because trachoma and vitamin A deficiency have been controlled or eliminated in many countries. In Group II, cataract was most unevenly distributed around the world, which has motivated various international organizations to perform cataract surgeries in developing countries. Our results, however, suggested that the eye health disparity in cataract was greater among high-income countries than middle- and low-income countries. One reason is that necessary cataract surgery is not being performed in some high-income countries,

TABLE 2—Median Value of DALYs per 100 000 Population by Specific Cause (Eye Disease) and Economic Status: Global Burden of Disease Study, 2004

	Worldwide, Median DALYs (Range[a])	High-Income Countries, Median DALYs (Range[a])	Middle- and Low-Income Countries, Median DALYs (Range[a])
Group I causes			
Trachoma	0.00 (0.0-4.1)	0.00 (0.0-0.0)	0.00 (0.0-15.4)
Vitamin A deficiency	0.14 (0.00-4.21)	0.00 (0.0-0.0)	0.37 (0.0-12.2)
Group II causes			
Glaucoma	67.2 (40.7-130.0)	39.2 (37.1-68.5)	73.0 (48.8-136.2)
Cataract	196.8 (103.1-478.9)	11.9 (11.4-160.1)	248.6 (144.7-507.4)
Refractive errors	253.3 (205.3-282.9)	284.9 (259.0-292.5)	247.3 (201.0-264.4)
Macular degeneration	122.3 (105.9-145.1)	142.7 (135.1-153.0)	114.1 (102.3-142.2)
All eye diseases	677.7 (508.3-1040.9)	486.5 (472.1-624.0)	796.4 (575.2-1068.9)

Note. DALY = Disability-Adjusted Life Year.
[a]25th percentile to 75th percentile.

TABLE 3—The Global Distribution of DALYs Due to Eye Disease, by Specific Cause and Economic Status: Global Burden of Disease Study, 2004

	Worldwide			High-Income Countries			Middle- and Low-Income Countries		
	Gini Coefficient	Theil Index	Atkinson Index	Gini Coefficient	Theil Index	Atkinson Index	Gini Coefficient	Theil Index	Atkinson Index
Group I causes									
Trachoma	0.758	1.286	0.593	0.861	3.591	0.956	0.702	1.122	0.522
Vitamin A deficiency	0.824	2.063	0.736	0.828	2.549	0.919	0.781	1.900	0.691
Group II causes									
Glaucoma	0.255	0.119	0.057	0.150	0.069	0.031	0.215	0.096	0.046
Cataract	0.337	0.222	0.135	0.582	1.234	0.440	0.230	0.101	0.053
Refractive errors	0.312	0.126	0.064	0.166	0.082	0.040	0.304	0.118	0.061
Macular degeneration	0.115	0.021	0.010	0.061	0.006	0.003	0.124	0.023	0.011
All eye diseases	0.190	0.057	0.030	0.135	0.058	0.026	0.140	0.033	0.017

Note. DALY = Disability-Adjusted Life Year. The Gini coefficient ranges from zero (perfect evenness) to 1 (perfect unevenness). The Theil index (a generalized entropy index) ranges from zero (equal distribution) to infinity (a higher value is more uneven). The Atkinson index ranges from zero to 1, with zero meaning a state of evenness. For our analysis, the sensitivity parameter (ε) was set at 0.5.

whereas unnecessary cataract surgery (when the lens is relatively clear) is being performed in others to fulfill the demands of customers. In the year 2000, the WHO recommended a cataract surgical rate (defined as the number of cataract surgery procedures per million population per year) of 3000 as the minimum to eliminate blindness from cataract and a rate of 3500 in the established market economies.[26] Among high-income countries, however, the cataract surgical rate varies dramatically (e.g., 1200 in the United Arab Emirates, 1308 in Kuwait, 2175 in Bahrain, 6500 in the United States, and 8000 in Australia[27]).

The other reason is that several factors related to eye health disparity were not considered in this study. All high-income countries were not always equipped with sufficient universal insurance coverage, sufficient health care financing, and regular health care provision. If such confounding factors were adjusted, inequality in cataract across higher-income countries could be smaller.

Blinding eye diseases and conditions are strongly associated with poverty, and preventable or curable eye diseases and conditions are therefore believed to exist mainly in developing countries. However, our results indicated that we could not ignore the burden of refractive errors in high-income countries. Refractive errors have not received much attention because many definitions of blindness have been based on best-corrected visual distance acuity,[28] so that eye health planners probably have not comprehended the true magnitude of the problem due to refractive errors. The GBD study in 2004 used the presenting visual acuity to estimate the global burden of refractive errors. However, the burden of refractive errors was probably underestimated because it was based on epidemiological data from the presenting distance visual acuity. If the presenting near visual acuity was taken into consideration, the imbalance of refractive errors as well as its burden would be greater for females because females are less likely to be able to afford spectacles for presbyopia. Even high-income countries need to strengthen their refractive services, and also transfer knowledge, cost-effective techniques, and experience to the developing countries.

There are some limitations to this study. First, certain leading causes of blindness, such as diabetic retinopathy and onchocerciasis, were not included. It is true that the 2004 estimates of the GBD study included data on diabetes mellitus and onchocerciasis; however, the disease burden due to diabetic retinopathy and ocular onchocerciasis was not specified, and these data could lead to an underestimation of the global burden of eye disease. Assuming that 80% of the burden for onchocerciasis and one third of that for diabetes mellitus was due to visual impairment, the global burden of eye disease would increase to 4.5%. However, the distribution of DALYs for these diseases could not be derived from the data of the GBD study.

Second, the data of the GBD study were based on estimates. There have not been enough appropriate epidemiological studies performed around the world. Accordingly, the DALYs due to certain eye disease were estimated from epidemiological surveys focused on other eye diseases. This could also lead to underestimation of the prevalence and burden of some eye diseases, particularly if investigators missed ocular comorbidity.

Third, the use of aggregate data per country rather than provincial or district data might be a source of bias because it is apparent that there are geographic variations in the DALYs of various diseases or conditions. However, use of aggregate provincial or district data are unusual for international comparisons.

Our findings suggest that the major contribution to the global burden of eye disease was not caused by cataract but by refractive errors, regardless of the economic status. It is true that in Group II, the DALYs due to cataract were most unevenly distributed at the global level, but more uneven distribution was observed in high-income countries than in middle- and low-income countries. Most refractive errors are easily and cost-effectively managed with a basic eye examination and spectacles by trained eye care personnel, whereas other eye diseases such as cataract, glaucoma, and macular degeneration require specialized medical knowledge, advanced medical instruments, and expensive medicines. The institutions responsible for eye health should make efforts to reduce the burden of refractive errors, as well as to create cost-effective and universal service for refractive errors. In addition, the appropriate knowledge, skills, and experience should be spread around the world as soon as possible and given the highest priority for international public health services in eye care and eye health.

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Contributors

K. Ono conceptualized and designed the study and helped analyze and interpret the data and write and revise the article. Y. Hiratsuka helped analyze and interpret the data and write and revise the article. A. Murakami supervised the study and helped interpret the data and write and revise the article.

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Human Participant Protection

In accordance with Japanese law, Juntendo University School of Medicine concluded that this study was officially exempt from review because it employed publicly available data from international organizations.

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ORIGINAL RESEARCH

Influence of cataract surgery and blood pressure changes caused by sodium restriction on retinal vascular diameter

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Purpose: To investigate the impact of cataract surgery and blood pressure changes induced by one week of sodium restriction on retinal vascular diameter.

Methods: Fundus photographs of 200 patients were obtained before and one week after cataract surgery. For one week after admission, 100 patients received sodium restriction and 100 patients (ie, the control group) did not receive sodium restriction. The diameter of the retinal vessels and blood pressure were compared between the sodium restriction group and the control group. The vascular diameter was measured using an objective computer-based method.

Results: Neither group had a significant change in the diameter of the retinal vessels after cataract surgery. Although there was no significant change in retinal arterial and venular diameter in the sodium restriction group, one-week sodium restriction significantly reduced mean blood pressure. However, multiple linear regression analyses indicated that an increase in retinal arteriolar diameter was significantly associated with diabetes, hyperlipidemia, and alcohol intake.

Conclusion: Cataract surgery and blood pressure reduction induced by one week of sodium restriction resulted in no significant change in retinal arteriolar diameter.

Keywords: cataract surgery, hypertension, retinal blood vessel diameter, retinal fundus camera, sodium restriction.

Introduction

An excessive sodium intake raises blood pressure by changing arterial function and structure and by expanding intravascular volume and increasing vascular resistance.[1-3] In Japan, the guidelines for hypertension treatment recommend restricting sodium intake to 6 g or less per day. However, the mean daily sodium intake of Japanese people is as high as 11 g, which makes sodium restriction for patients with hypertension an important task.[4] Because hypertension is a major risk factor for cerebrovascular disorders, sodium restriction is clearly important.[5]

The fundus vessels are the only vessels in the human body that can be directly observed noninvasively. This permits evaluation of the retinal vessels. A retinal vascular abnormality is the most important factor in the early detection of hypertension and cerebrovascular disorders, and retinal vascular narrowing is the first fundus change caused by hypertension.[6] This has been used to determine the severity of arteriosclerosis and hypertension. However, the evaluation is subjective, and methods for more objective measurements are unavailable. Conventional methods using visual inspection to measure the diameter of retinal vessels also tend to overlook early-stage changes. This prevents the identification of cerebrovascular disorders at an early stage.

To address this problem, a method has been developed that uses computer software and digital processing to quantify retinal arteriolar narrowing.[7–9] In this method, a high-resolution scanner takes digitized fundus photographs, and a software program measures the diameter of retinal arterioles and venules. The software program measures with a greater accuracy and objectivity than is possible with conventional methods.

The cross-sectional Beaver Dam Eye Study used this method and demonstrated that retinal arteriolar diameter decreased by 4.0 µm with each 10 mmHg increase in mean arterial blood pressure. This indicates the potential of this method for evaluating small changes in the diameter of retinal vessels that are associated with blood pressure changes.[7] Using the same method, the Japanese epidemiologic Funagata study showed a relationship between increases in mean blood pressure and narrowing of retinal arteriolar diameter.[10] Previous epidemiologic studies have reported that age, gender, hypertension, systolic and diastolic blood pressures, diabetes mellitus, a history of smoking, total cholesterol level, body mass index (BMI), and a history of alcohol intake impact retinal vessel diameter.[11,12] Some research suggests that retinal arteriolar caliber may be narrower in people with hypertension and hyperlipidemia.[11] A large retinal venular caliber reportedly predicts the progression of retinopathy in people with diabetes. There is evidence that retinal venular caliber may be influenced by systemic inflammation.[12]

Many studies have shown a relationship between increased blood pressure and narrowing of retinal vascular diameter. However, only a few studies have examined the relationship between a decrease in blood pressure and a change in vascular diameter, including retinal vascular diameter.[13,14]

Unlike sclerotic changes, which are irreversible, the narrowing of retinal blood vessels appears to be reversible.[6] At a clinical site, it is essential to know the minimum dosing period for antihypertensive treatment that is needed to improve narrowing of retinal vascular diameter. Predicting this dose accurately will similarly ease the burden on arterioles in the brain and kidney, and therefore may be therapeutically important.

Cataract is the leading cause of blindness worldwide, and cataract surgery is the most frequent surgical procedure in people aged 65 years or older in the Western world, including Japan.[15–17] As the Japanese population ages, the prevalence of visual impairment is projected to increase from 1.35% in 2007 to 2.0% by 2050; hence, visual impairment due to cataract is on the increase.[18] Therefore, an important challenge is assessing the effect of cataract surgery on vascular changes because the increasing elderly population is directly linked with the rise in the number of cataract patients having systemic chronic diseases, including heart disease, stroke, and diabetes. The invasiveness of cataract surgery induces the production of prostaglandins and other inflammatory cytokines. However, the relationship between these proinflammatory markers and changes in retinal vascular diameter has not been examined.[19]

In the current study, patients were treated with sodium restriction for one week after admission. The impact of blood pressure changes induced by sodium restriction on retinal vascular diameter was assessed. Changes in diameter of the retinal vessels before and after cataract surgery were also examined. To our knowledge, this is the first clinical study in Japan to use computerized measurements of retinal vascular diameter.

Patients and methods

Retinal assessment

The subjects were 200 patients (92 males, 108 females, mean age ± standard deviation [SD] 76.4 ± 8.0 years) admitted between January 2009 and July 2009 to the Juntendo Tokyo Koto Geriatric Medical Center for cataract surgery. None had a history of renal dysfunction or abnormal blood biochemistry. Patients with renal dysfunction, including renal failure, were excluded because they are often undergoing dialysis, strict fluid restriction, and diet therapy, ie, factors that make them unsuitable for evaluation of the effect of sodium restriction. Patients who had retinal disease, including severe diabetic retinopathy, were considered unsuitable for evaluation of retinal vessel diameter and were therefore excluded.

The control group consisted of 100 patients who all gave informed consent. Before surgery and one week after surgery, the blood pressure of each patient was measured and posterior pole retina-centered fundus photographs were obtained. Diameter of the retinal vessels was measured quantitatively, and changes in mean blood pressure and in diameter of the retinal vessels were evaluated. During the week of the study, the control patients received a regular diet with no sodium restriction (ie, 10 g sodium per day).

For one week after admission, the remaining 100 patients received a sodium-restricted diet of 5 g sodium per day (ie, the sodium restriction group). At admission and one week after surgery, each patient's blood pressure was measured and posterior pole retina-centered fundus photographs were obtained. The diameter of the retinal vessels was measured quantitatively, and the extent of diffuse narrowing of the retinal vascular diameter was evaluated.

All patients underwent cataract surgery of both eyes. The procedure utilized phacoemulsification and intraocular lens implantation.

A nonstereoscopic 45° nonmydriatic fundus camera (Nonmyd7, Kowa Inc. Nagoya, Japan) obtained retinal photographs of both eyes for each patient. One field was centered between the macula and optic disc. A retinal photograph was ungradable if more than one arteriole or venule with a diameter greater than 40 μm could not be measured after three attempts. All retinal vessel measurements were obtained from the right eye. A trained grader graded the arteriolar and venular diameters. The grader used a standardized protocol with a computer-assisted method having high reproducibility. In these analyses, the fundus image covered a sufficient area in a zone lying 0.5 to 1 disc diameter away from the disc margin (referred to as zone B).

Details of image preparation and grading protocols have been described previously.[9] A digitized grid was placed over the image and centered on the optic disc. All vessels passing completely through zone B were measured using image analysis software (Retinal Analysis, Department of Ophthalmology and Visual Sciences, University of Wisconsin, Madison, WI). The grader identified each vessel as either an arteriole or venule. The software calculated the average width from five equidistant measurements of each vessel. The average retinal arteriolar or venular diameter for each eye was calculated using the Parr–Hubbard formula. They were then summarized as the central retinal arteriolar equivalent (CRAE) or the central retinal venular equivalent (CRVE).[20,21]

Each subject gave informed consent at the beginning of the examination. This study was conducted in accordance with the recommendations of the Declaration of Helsinki. The Institutional Review Board at Juntendo Tokyo Koto Geriatric Medical Center (Tokyo, Japan) approved the study.

Systemic assessment

Using a single mercury sphygmomanometer, the brachial systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured once at each examination with the patient in a sitting position after a five-minute rest period. Mean arterial blood pressure was calculated as (0.33 × SBP) + (0.67 × DBP).[7] The 2003 World Health Organization (WHO) guidelines were used to classify blood pressure as "normal" for an SBP of 120 mmHg or less and a DBP of 80 mmHg or less; as "high normal" for an SBP of 121 to 139 mmHg or a DBP of 81 to 89 mmHg, as "hypertension Stage I" for an SBP of 140 to 159 mmHg or a DBP of 90 to 99 mmHg; and as "hypertension Stage II" or above for an SBP of 160 mmHg or greater and a DBP of 100 mmHg or greater.[22] Hypertension was classified in patients who were at Stage I or II or in patients who had received treatment for hypertension.

Diabetes was defined according to WHO guidelines, ie, a fasting glucose level of 126 mg/dL (7.0 mmol/L) or greater, a nonfasting glucose level of 200 mg/dL (11.1 mmol/L) or greater, or a history of or current treatment for diabetes.[23]

A diagnosis of hyperlipidemia was based on the diagnostic criteria of the Japan Atherosclerosis Society and was defined as either a total cholesterol level of 220 mg/dL or greater, a low-density lipoprotein cholesterol (LDL-C) level of 140 mg/dL or greater in fasting blood samples; or a history of or current treatment for hyperlipidemia.[24] In the US, the National Cholesterol Education Program (NCEP) has defined hyperlipidemia as a total cholesterol level of 240 mg/dL or more and an LDL-C level of 160 mg/dL or more, based on the relationship between total cholesterol levels and rates of coronary death in the Multiple Risk Factor Intervention Trial.[25,26] In Japan, the criteria for hyperlipidemia, ie, a total cholesterol level of 220 mg/dL or greater and an LDL-C level of 140 mg/dL or greater, are based on an epidemiologic study (NIPPON DATA80).[27]

The Brinkman Index (ie, daily consumption of cigarettes × years of smoking) was used in the analysis of a patient's smoking status.[28] Based on an interview, a patient's alcohol intake (including consumption within the past year) was classified into one of two categories, ie, noncurrent or current intake.

A patient's BMI was calculated as weight in kilograms divided by the square of height in meters.

Statistical analysis

The extent of change in CRAE, CRVE, mean arterial blood pressure, SBP, and DBP in patients in the sodium restriction group and in patients in the control group was compared using paired *t*-tests. Within the sodium restriction group and the control group, the differences in the CRAE, CRVE, mean arterial blood pressure, SBP, and DBP after surgery were tested by unpaired *t*-tests. Simple regression analyses and multiple regression analyses were used to examine the association of the differences in CRAE and CRVE between the two groups and background factors (ie, age, gender, mean arterial blood pressure, diabetes mellitus, hyperlipidemia, Brinkman Index, alcohol intake, and BMI).

Three models were used in the multiregression analysis. In model 1, factors with significant differences in single regression analysis were added and analyzed. In model 2, the factors used in model 1 and the Brinkman Index (a factor showing no significant difference for retinal venular caliber in single regression analysis but with $0.05 < P < 0.10$) were added and analyzed. The Brinkman Index was added to the factors used in model 1 to make the analysis for model 2 because a relationship between smoking and retinal blood vessel diameter has been reported in an earlier epidemiologic study and because a causal relationship between smoking and arterial sclerosis is already proven. In model 3, an analysis was performed for all factors. Each model included age and gender as factors. The significance level was set at $P < 0.05$. Because patients with hypertension were on treatment and some had normal blood pressure, the mean arterial blood pressure, rather than hypertension itself, was used in the analysis.

All data were stored at Juntendo University and analyzed using SPSS16.0 J for Windows (SPSS Inc, Chicago, IL).

Results

None of the patients had complications after cataract surgery. Table 1 shows the age, gender, BMI, hypertension, mean arterial blood pressure, diabetes mellitus, hyperlipidemia, Brinkman Index, and alcohol intake for patients in the sodium restriction group and in the control group (n = 100 in each group). The association between age, BMI, mean arterial blood pressure, and Brinkman Index was analyzed by an unpaired t-test; all other characteristics were analyzed by the χ^2 test. Most background factors were similar in the two groups, but the age of the sodium restriction group (78.0 ± 4.9 years) was higher than that of the control group (74.9 ± 10 years). The rate of hypertension was also higher in the sodium restriction group. The rates of hyperlipidemia and Brinkman Index were higher in the control group.

In the sodium restriction group, CRAE values before and after surgery were 140.2 ± 13.1 μm and 140.5 ± 14.0 μm, respectively; and in the control group, 143.4 ± 17.5 μm and 144.2 ± 16.2 μm, respectively. The increase in CRAE after surgery was not significant in the sodium restriction and control groups (0.3 ± 9.3 μm and 0.8 ± 7.8 μm, respectively, Table 2).

CRVE values before and after surgery were 211.3 ± 27.6 μm and 214.1 ± 28.7 μm, respectively, in the sodium restriction group, and were 217.4 ± 23.4 μm and 218.4 ± 24.0 μm, respectively, in the control group. The 2.8 ± 12.9 μm increase in CRVE after surgery in the sodium restriction group was significant. The 0.9 ± 11.9 μm increase in CRVE after surgery in the control group was not significant.

Mean arterial blood pressure before and after surgery was 87.6 ± 6.9 and 83.1 ± 6.5 mmHg, respectively, in the sodium restriction group; the −4.4 ± 6.9 mmHg decrease after surgery was significant. In the control group, the mean arterial blood pressure values before and after surgery were

Table 1 Characteristics of the sodium restriction group and the control group

	Sodium restriction group (n = 100)	Control group (n = 100)	P value
Age (years)	78.0 ± 4.9	74.9 ± 10	0.006**
Gender			
Male	48 (48%)	44 (44%)	ns
Female	52 (52%)	56 (56%)	
BMI	24.0 ± 4.5	24.0 ± 4.1	ns
Hypertension			
+	86 (86%)	60 (60%)	<0.001**
−	14 (14%)	40 (40%)	%
MABP (before surgery)	87.6 ± 6.9	87.1 ± 9.5	0.674
Diabetes			
+	35 (35%)	36 (36%)	ns
−	65 (65%)	64 (64%)	
Hyperlipidemia			
+	46 (46%)	64 (64%)	0.016*
−	54 (54%)	36 (36%)	%
Current alcohol intake			
+	26 (26%)	28 (28%)	ns
−	74 (74%)	72 (72%)	%
Brinkman index	65.8 ± 206.9	139 ± 289.1	0.041*
median (25th–75th)	0 (0–0)	0 (0–200)	<0.001**

Notes: Data are shown as n (%) or as the mean ± standard deviation; *P based on the unpaired t-test (for age [Welch's t-test], BMI, MABP, and Brinkman Index), the Wilcoxon signed rank test (for the median Brinkman Index), and the χ^2 test (for all characteristics, except for age, BMI, MABP, and Brinkman Index *$P < 0.05$, **$P < 0.01$).
Abbreviations: BMI, body mass index; MABP, mean arterial blood pressure; ns, not significant.

Table 2 Change in blood pressure and retinal vessel caliber before and after cataract surgery in the sodium restriction group and in the control group

		Before surgery	After surgery	Change	Percentage change	P value
Retinal arteriolar caliber (μm)	Sodium restriction group (n = 100)	140.2 ± 13.1	140.5 ± 14.0	0.3 ± 9.3	0.2%	0.732
	Control group (n = 100)	143.4 ± 17.5	144.2 ± 16.2	0.8 ± 7.8	0.6%	0.296
		Change (sodium restriction group vs control group)				ns
Retinal venular caliber (μm)	Sodium restriction group (n = 100)	211.3 ± 27.6	214.1 ± 28.7	2.8 ± 12.9	1.3%	0.031*
	Control group (n = 100)	217.4 ± 23.4	218.4 ± 24.0	0.9 ± 11.9	0.4%	0.435
		Change (sodium restriction group vs control group)				ns
MABP (mmHg)	Sodium restriction group (n = 100)	87.6 ± 6.9	83.1 ± 6.5	−4.4 ± 6.9	−5.0%	<0.001**
	Control group (n = 100)	87.1 ± 9.5	86.5 ± 8.7	−0.6 ± 6.5	−0.6%	0.397
		Change (sodium restriction group vs control group)				<0.001**
SBP (mmHg)	Sodium restriction group (n = 100)	133.5 ± 12.7	123.3 ± 11.1	−10.2 ± 16.4	−7.6%	<0.001**
	Control group (n = 100)	121.5 ± 14.9	124.4 ± 12.7	2.9 ± 16.4	2.4%	<0.001**
		Change (sodium restriction group vs control group)				<0.001**
DBP (mmHg)	Sodium restriction group (n = 100)	70.7 ± 8.8	65.9 ± 6.8	−4.8 ± 10.9	−6.8%	0.081
	Control group (n = 100)	67.0 ± 6.6	67.0 ± 6.7	−0.1 ± 8.8	−0.1%	0.946
		Change (sodium restriction group vs control group)				0.001**

Notes: *P < 0.05; **P < 0.01. The before vs after cataract surgery association was analyzed by paired t-test. The sodium restriction group vs the control group association was analyzed by unpaired t-test; the amount of change was determined by the formula, change = after surgery − before surgery; percentage of change was determined by the formula, percentage change = (after surgery − before surgery) ÷ before surgery.

Abbreviations: DBP, diastolic blood pressure; MABP, mean arterial blood pressure; SBP, systolic blood pressure; ns, not significant.

87.1 ± 9.5 mmHg and 86.5 ± 8.7 mmHg, respectively; the −0.6 ± 6.5 mmHg decrease was not significant.

In the sodium restriction group, SBP before and after surgery was 133.5 ± 12.7 mmHg and 123.3 ± 11.1 mmHg, respectively; the −10.2 ± 16.4 mmHg decrease after surgery was significant. In the control group, the SBP before and after surgery was 121.5 ± 14.9 mmHg and 124.4 ± 12.7 mmHg, respectively; the 2.9 ± 16.4 mmHg increase after surgery was significant.

Both groups had no significant change in DBP before and after surgery. In the sodium restriction group, DBP decreased by −4.8 ± 10.9 mmHg after surgery, having been 70.7 ± 8.8 mmHg before surgery and 65.9 ± 6.8 mmHg after surgery. In the control group, the DBP decreased after surgery by 0.1 ± 8.8 mmHg, having been 67.0 ± 6.6 mmHg before surgery and 67.0 ± 6.7 mmHg after surgery. The changes in mean arterial blood pressure, SBP, and DBP in the sodium restriction group differed significantly from their respective changes in the control group.

Simple regression analyses were used to examine the association of differences in CRAE and in CRVE before and after cataract surgery (with a one-week hospitalization) in relation to age, gender, mean arterial blood pressure, diabetes mellitus, hyperlipidemia, Brinkman Index, alcohol intake, and BMI. The analyses demonstrated that an increase in CRAE was significantly associated with gender, diabetes mellitus, hyperlipidemia, alcohol intake, and BMI (Table 3), that an increase in CRVE was significantly associated with age, and that a decrease in CRVE was significantly associated with hyperlipidemia (Table 4).

Multiple regression analyses were used to examine the association of differences in CRAE and CRVE before and after cataract surgery and a one-week hospitalization with the factors listed earlier. The analyses revealed that an increase in CRAE was significantly associated with diabetes mellitus, hyperlipidemia, and alcohol intake (Table 3), that an increase in CRVE was significantly associated with age and Brinkman Index, and that a decrease in CRVE was significantly associated with hyperlipidemia (Table 4). In multiregression analysis, the analysis results in models 1 and 2 were the same as those in model 3 (a saturated model with all factors included). Furthermore, hyperlipidemia in this study was analyzed based on the Japanese diagnostic criteria. However, performing an analysis based on the criteria of the NCEP produced the same results (results not shown).

Discussion

Epidemiologic surveys and interventional trials have shown that an excessive intake of sodium causes hypertension and