

A Global View on Output and Outcomes of Cataract Surgery With National Indices of Socioeconomic Development

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PURPOSE. Cataract blindness accounts for a substantial proportion of blindness worldwide. Understanding the correlations between national levels of socioeconomic development with the quantity and quality of cataract surgery may provide insight for the prioritization and resource allocation for blindness prevention programs.

METHODS. The relationships between human development index (HDI), gross domestic product (GDP) per capita, and cataract surgical coverage (CSC) and visual outcome of cataract surgery were examined in a multinational study utilizing secondary data from the repository for Rapid Assessment of Avoidable Blindness (RAAB), World Health Organization, Global Burden of Disease, United Nations, and the World Bank.

RESULTS. A total of 266 RAAB studies across 73 countries/territories were retrieved. Linear regression model results revealed strong associations of HDI with prevalence of cataract blindness ($\beta = -7.056$, $P < 0.001$), CSC ($\beta = 60.808$, $P = 0.004$), proportion of intraocular lens (IOL) implantation ($\beta = 87.040$, $P = 0.001$), and proportion of cases with good vision outcomes among operated eyes ($\beta = 73.351$, $P < 0.001$) in studies performed between 1995 and 2009. Similar associations were observed for studies performed between 2010 and 2015. In addition, countries with lower GDP per capita showed a higher rate of cataract blindness ($\beta = -0.527$, $P = 0.001$), lower CSC ($\beta = 9.800$, $P < 0.001$), lower percentage of IOL implantation ($\beta = 6.871$, $P = 0.001$), and fewer patients with good vision outcomes after surgery ($\beta = 7.959$, $P < 0.001$). After controlling survey year, country, and other factors, GDP per capita and HDI were also found to be significantly associated with CSC and visual outcomes after cataract surgery (all $P < 0.05$).

CONCLUSIONS. We documented the strong associations of socioeconomic indices with quantity and quality of cataract surgery. These socioeconomic indicators should be considered as important factors for developing strategies aimed to improve worldwide cataract surgery service delivery.

Keywords: cataract surgical coverage, outcome, human development index, socioeconomic, gross domestic product

The current World Health Organization (WHO) global action plan (GAP), “Universal eye health: a global action plan 2014–2019,” requests countries to strengthen national initiatives for the elimination of avoidable visual impairment. The global target is a reduction in the prevalence of avoidable visual impairment by 25% in 2020, compared to 2010.¹ Globally, unoperated cataract remains the leading cause of blindness (51% in 2010), even though cataract surgery is one of the most cost-effective medical procedures.^{2,3} Cataract surgical rate (CSR) and coverage (CSC) are recommended in the GAP as key indicators for delivering eye care. The visual outcome after cataract surgery is an indicator of the quality of cataract surgery, which is just as important as output indicators.⁴ At a population level, low socioeconomic status is likely to be correlated with

care inequality.^{5,6} The gross domestic product (GDP) per capita is a single indicator of economic wealth, while the human development index (HDI) is a composite indicator appraising both social and economic status. Both indicators were commonly used for the comparisons of development across countries.⁷

In our previous analysis, we found a close correlation between CSR and GDP per capita globally.⁸ Socioeconomic factors play a key role in the access to high-quality health care, but also as a determinant of long-term health outcomes following treatment.⁸⁻¹⁴ When evaluated against the output and quality of cataract surgery, socioeconomic indicators such as the HDI and GDP present considerations for health policy and implications for target setting in public health. Although it



was previously reported that 90% of blindness was in developing countries, and that access and quality of health services may be closely linked to socioeconomic factors.^{2,3,15} no standard socioeconomic indicators were specifically investigated. At present, the nature of these associations is not well understood. The aim of this study was to quantify the correlations of levels of socioeconomic development with the quantity and quality of cataract surgery performed in countries of interest.

METHODS

Sources of Data

The Rapid Assessment of Avoidable Blindness (RAAB) is a standardized, population-based methodology and was designed to assess the prevalence of blindness and its main causes in a population aged 50 years and above, living in a district environment. The study provides further information about CSC, cataract surgical outcomes, and barriers to cataract surgery access.¹⁶ An online repository for RAABs (<http://raab.data.info/repository/>; in the public domain) has documented the salient findings of all RAAB studies completed to date. Information fields including survey year, location, prevalence and cause of blindness, rate of cataract blindness, CSC, and outcomes of cataract surgery were extracted from this repository for the present study.

The HDIs of countries were obtained from the Human Development Reports Database (<http://hdr.undp.org/en/data/>; in the public domain). HDI is a product informed by social and economic factors across three domains (health, education, living standard) released by the United Nations Development Programme (UNDP). Before 2010, it was calculated by values of life expectancy, education attainment, and GDP per capita. In 2010, the UNDP changed the formula for calculating HDI to four indicators (life expectancy, mean years of schooling, expected year of schooling, and gross national income [GNI] per capita). The HDI is scored between 0 and 1 based on quartiles, with the lowest, second-lowest, second-highest, and highest quartiles considered as low, medium, high, and very high human development for specific years. The values of GDP per capita in the corresponding year and country were obtained from the World Bank repository (<http://data.worldbank.org/>; in the public domain). To minimize effects of economic inflation, the GDP per capita was calculated based on 2011 constant international dollars using the purchasing power parity (PPP) method. The levels of solar ultraviolet (UV) radiation and age-standardized mean body mass index were obtained from the WHO Global Health Observatory data repository (<http://apps.who.int/gho/data/node.imr>; in the public domain). The age-standardized prevalence of cataract was retrieved from the Global Burden of Diseases, Injuries and Risk Factors Study 2015 (GBD 2015) Results Tool (<http://ghdx.healthdata.org/gbd-results-tool>; in the public domain).^{17,18} The proportion of people aged 50 years or older was obtained from the United Nations World Population Prospects, the 2015 Revision (<https://esa.un.org/unpd/wpp/Download/Standard/Population/>; in the public domain).

Definition of Variables

The prevalence of blindness and low vision (% in persons 50 years and older) in the sample was calculated based on bilateral presenting visual acuity of less than 3/60 and ranging from 3/60 to 6/18 (20/60), respectively. The rate of cataract blindness was defined as a percentage of all blindness caused

by cataract, and prevalence of cataract blindness was defined as the percentage of cataract blindness in a population. CSC is usually reported both by eye and by person, and at different levels of presenting visual acuity. Previous research has presented a strong association with various measures of CSC among RAAB studies. Only the CSC by person at the 3/60 level (blindness) was used for all analyses in this study because this variable was available for all RAAB studies. Visual outcome after cataract surgery measured in RAAB studies was expressed as the percentage of all operated eyes with “good outcomes,” “poor outcomes,” or “borderline outcomes.” A good outcome was defined as ability to see 6/18 and better following surgery. Proportion of intraocular lens (IOL %) was defined as the percent of eyes with IOL correction among all operated eyes. The mean UV radiation was defined as the average daily ambient UV levels in J/m². Furthermore, GDP per capita was defined as the total market value of all recognized final goods and services produced within a country, in a given period of time, divided by the population at annual measurement.

Statistical Analysis

All statistical analyses were performed using the STATA 12.0SE statistical software package (Stata Corp., College Station, TX, USA). Scattergrams were constructed to explore the relationship between HDI, GDP per capita, and cataract surgery indices. Because changes were made to the definition of HDI before and after 2010, two sets of analyses were performed independently over two periods (1995–2009, 2010–2016) for HDI. GDP per capita was transformed to logarithmic value due to an evidently exponential relationship in scattergrams. Simple linear regression was used to evaluate the correlations between HDI, logarithm scale of GDP per capita, and cataract surgical metrics. Comparisons of cataract surgery indices among different quartiles of GDP per capita were assessed by ANOVA test, followed by post hoc Turkey test. The association of percent of IOL implantation with proportion of good outcome was assessed as well. The generalized estimation equation (GEE) linear regression model with an exchangeable working correlation matrix was used to assess the effect of HDI or GDP per capita on CSC and proportion of good surgical outcome after accounting for survey year, country, the mean UV radiation, prevalence of cataract, the proportion of people aged 50 years or older, and mean body mass index for each country. These regressions modeled CSC/outcome as a function of HDI/per capita GDP via a linear link, and robustly accounted for the above factors within each country. A *P* value <0.05 was considered to be statistically significant.

RESULTS

There were 266 RAAB studies performed in 73 countries/territories (Fig. 1). Among these, 135 (50.8%) were conducted from 1995 to 2009, and 131 (49.2%) were conducted after 2010. The majority of studies were performed in East Asian and Pacific countries. Most studies were conducted in middle- and low-income countries (97.0%), while high-income areas were underrepresented (3.0%). Table 1 presents the characteristics of the sample population from these studies, including a total of 612,000 people aged 50 and older. The mean prevalence rates of blindness and low vision in the examined population were 3.8% and 13.6%, respectively. The majority of cases of blindness were attributed to cataract, ranging from 21.2% to 91.1% of all blindness. For persons with cataract blindness, the

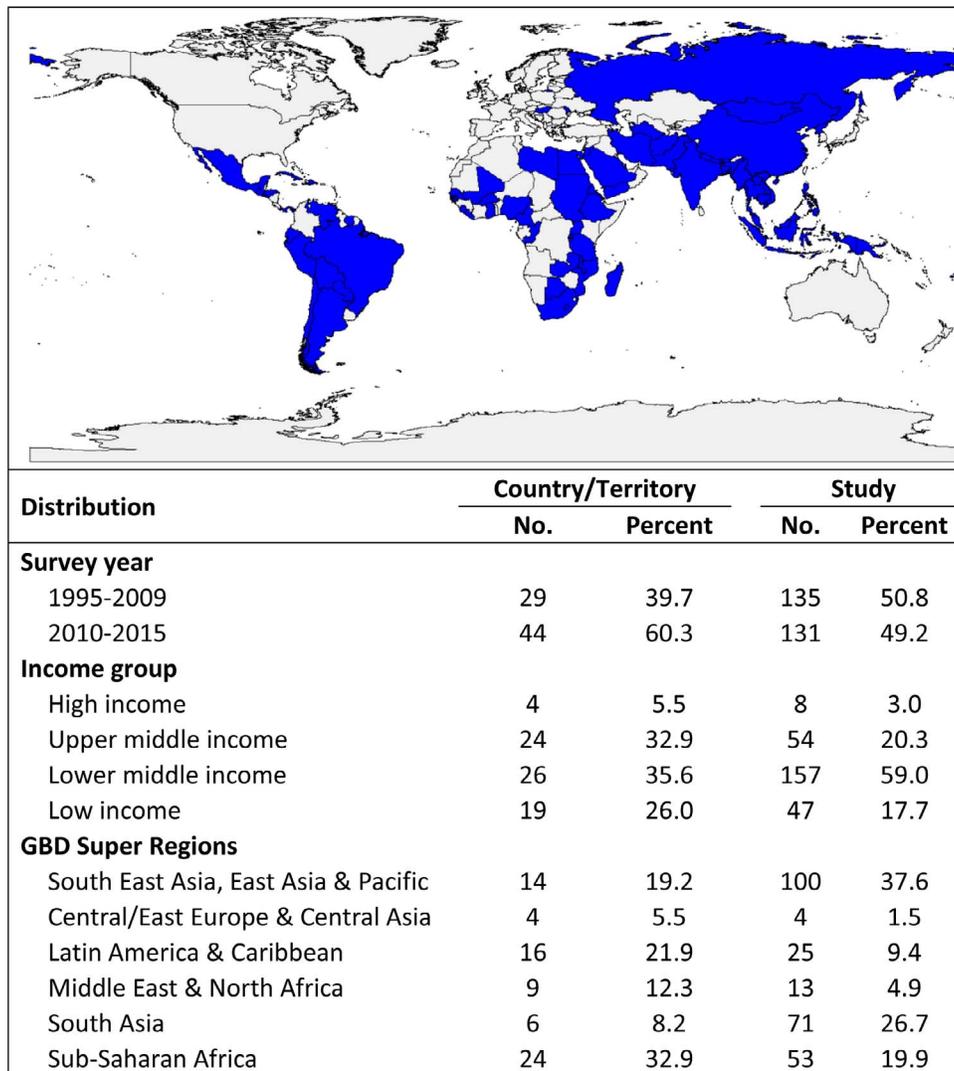


FIGURE 1. Distribution of studies using methodology of assessment of avoidable blindness (RAAB).

CSC values ranged from 10% to 100%. Among the operated eyes, 7.0% to 100% were corrected by IOL implantation. Approximately half of the operated eyes (range from 6.0% to 86%) had good vision outcomes.

For studies performed between 1995 and 2009, linear regression model results revealed a strong direct correlation between HDI and CSC ($\beta = 60.808, P = 0.004$; Fig. 2) as well as a direct correlation between HDI and good vision outcomes in

operated eyes ($\beta = 73.351, P < 0.001$; Fig. 2). Similar associations were seen for studies performed from 2010 to present (Fig. 2). Table 2 summarizes the linear regression analyses of cataract surgical indices with HDI. For studies performed between 1995 and 2009, HDI was found to be closely related to the rate of cataract blindness ($\beta = -7.506, P < 0.001$) and proportion of IOL implantation ($\beta = 87.040, P = 0.001$). For studies performed in 2010 or later, the same trends were detected, with lower-HDI countries having higher odds of small CSC and poor visual outcomes compared to higher-HDI countries.

Cataract surgery indices differed significantly among countries with different quartiles of GDP per capita (Fig. 3). Countries with lower GDP per capita showed a higher rate of cataract blindness ($\beta = -0.527, P = 0.001$), lower CSC ($\beta = 9.800, P < 0.001$), and lower percentage of IOL implantation ($\beta = 6.871, P = 0.001$), with fewer patients with good vision outcomes ($\beta = 7.959, P < 0.001$) (Table 3). Among the included studies, the proportion of patients with good vision outcomes was lowest in Pakistan (6%) and highest in Malaysia (86%). Higher rates of IOL implantation were associated with a significant increase in the odds of good visual outcomes after cataract surgery ($\beta = 0.825, P < 0.001$).

TABLE 1. Characteristics of Sample Population of Included Studies

Characteristic	Mean	Median	Min	Max
Sample size	2758	2500	1150	7500
Coverage, %	94.4	96.1	69.6	100.0
Rate of blindness, %	3.8	3.2	0.4	11.1
Rate of low vision, %	13.6	13.1	2.3	40.9
Rate of functional low vision, %	2.2	2.0	0.0	5.7
Cataract as cause, % of all blindness	62.7	65.3	21.2	91.1
Rate of cataract blindness, %	2.3	1.9	0.2	8.2
CSC at blind level, %, person	63.5	64.5	10.0	100.0
Rate of IOL implantation, %	79.1	86.0	7.0	100.0
Good outcome after surgery, %	53.2	55.0	6.0	86.0

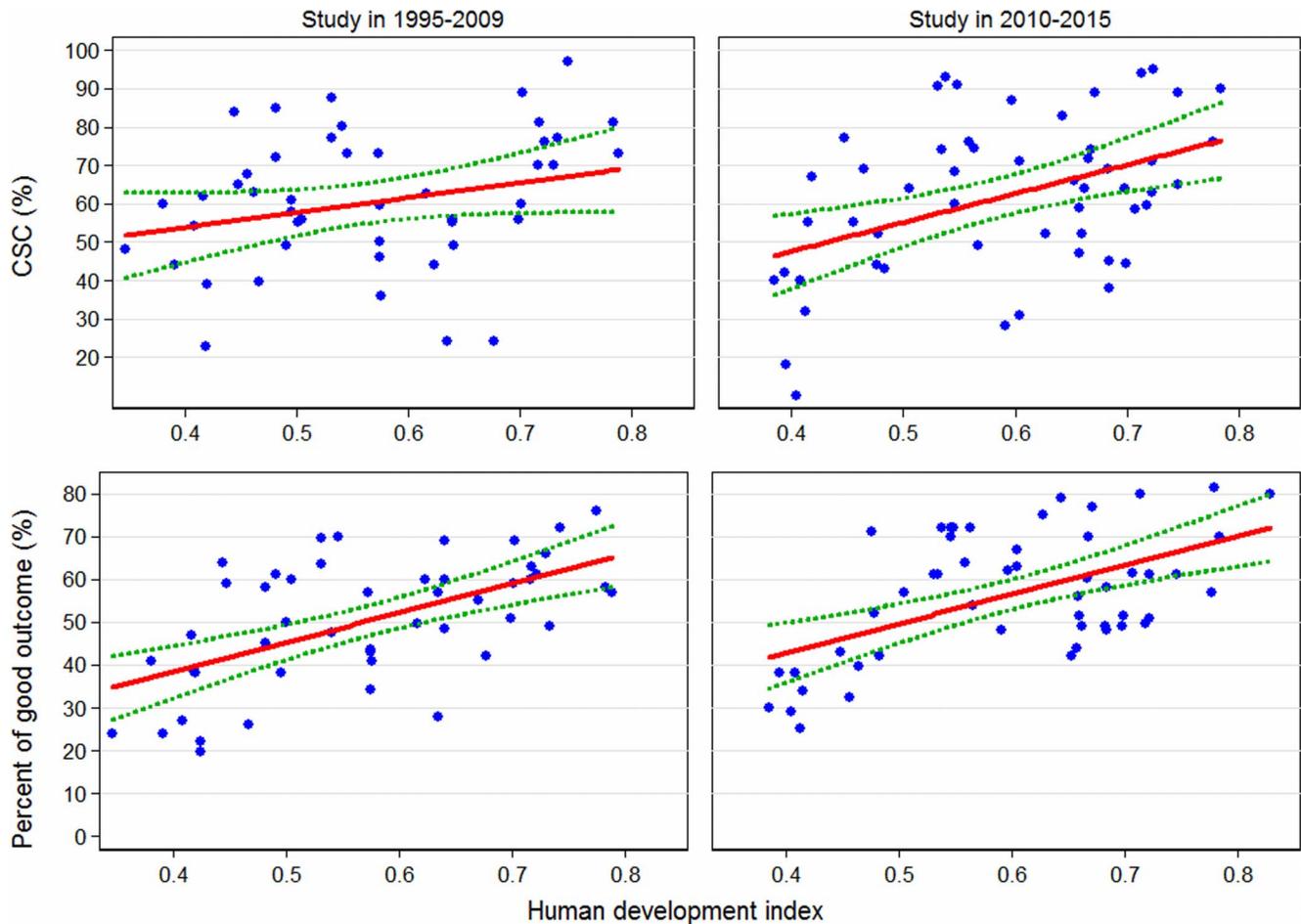


FIGURE 2. Scatter plots illustrating the correlations of national level of human development index with cataract surgical coverage (CSC) and percent of good visual outcome (PVA of 6/18 or more) after cataract surgery. Red line: linear regression model; green dashed line: 95% confidence interval.

Table 4 shows the results of GEE linear regression controlling for survey year, country, and other factors. The results showed that the higher CSC was significantly associated with the increase in HDI (coefficient = 60.307, $R^2 = 0.270$, $P = 0.047$) after adjusting other factors. The CSC was also significantly associated with logarithm value of GDP per capita (coefficient = 10.558, $R^2 = 0.210$, $P = 0.004$). With regard to the proportion of good visual outcome, the HDI (coefficient = 117.441, $R^2 = 0.356$, $P < 0.001$) and GDP per capita

(coefficient = 14.186, $R^2 = 0.315$, $P < 0.001$) were also significantly correlated after controlling year, country, and other factors.

DISCUSSION

The information on output and quality of cataract surgery is essential for monitoring the progress of surgical services, and

TABLE 2. Association of Quantity and Quality of Cataract Surgery With Human Development Index

Indices	Regression Coefficient, 95%CI			P Value	R ²
	β	Low	Up		
Year 1995-2009					
Rate of cataract blindness, %	-7.506	-11.155	-3.857	<0.001	0.272
CSC at blind level, %	60.808	20.792	100.823	0.004	0.157
Rate of IOL implantation, %	87.040	39.212	134.868	0.001	0.230
Good outcome after surgery, %	73.351	42.012	104.690	<0.001	0.321
Year 2010-2015					
Rate of cataract blindness, %	-4.249	-6.891	-1.606	0.002	0.161
CSC at blind level, %	88.309	50.771	125.847	<0.001	0.284
Rate of IOL implantation, %	44.882	19.813	69.951	0.001	0.209
Good outcome after surgery, %	60.519	30.140	90.898	<0.001	0.243

95%CI, 95% confidence interval.

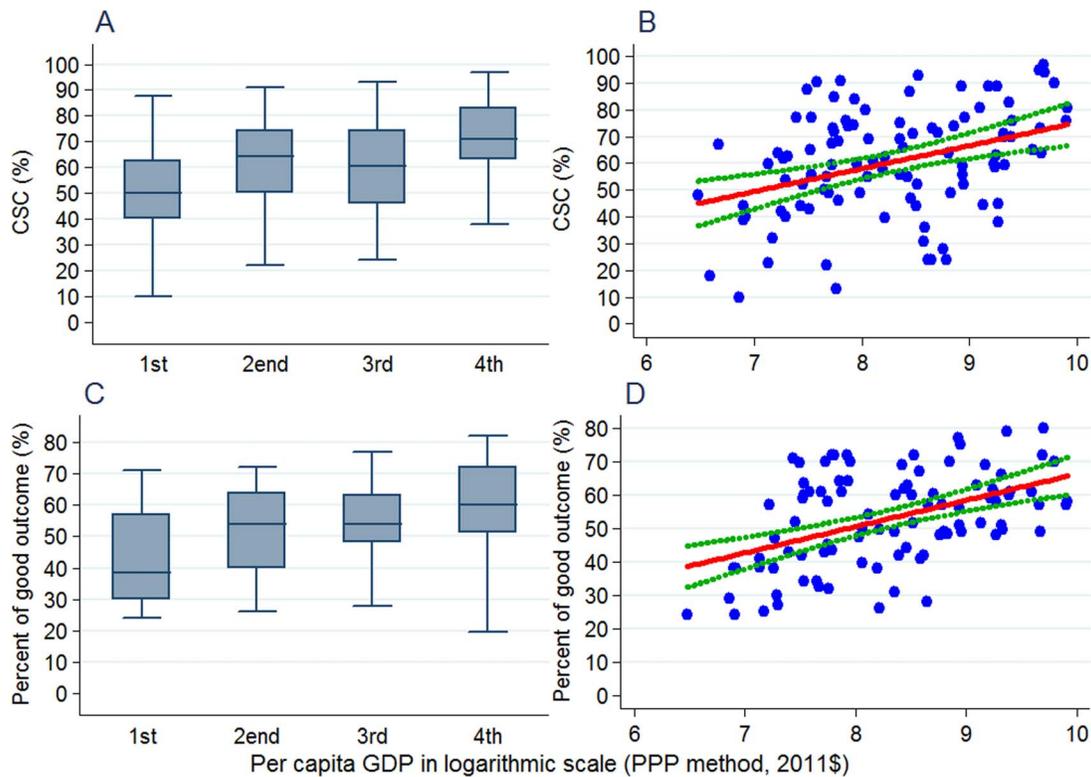


FIGURE 3. Associations of the levels of national gross domestic product (GDP) per capita with cataract surgical coverage (A, B) and percent of good visual outcome (PVA of 6/18 or more) after cataract surgery (C, D). 1st, 2nd, 3rd, and 4th indicate the lowest, second-lowest, second-highest, and highest quartiles of the levels of gross domestic product (GDP) per capita. *Red line:* linear regression model; *green dashed line:* 95% confidence interval.

provides a valuable proxy measure of eye care and burden of blindness. This study documented statistically significant associations of HDI and GDP per capita with quantity and quality of cataract surgery. The countries with highest HDI had the best cataract surgery outcomes, which should be reached by a large number of countries, and identification of the key determinant of these variations was essential. The proportion of good visual outcomes following cataract surgery was higher in Latin America and the Caribbean than in Sub-Saharan Africa (63.0% vs. 43.1%, respectively), which may be partly explained by different proportions of IOL implantation (90.5% vs. 75.6%, respectively). We also confirmed the statistically significant associations between IOL implantation and proportion with good vision outcomes following surgery.

Economic factors have been linked to resource availability for eye health and its service delivery. We found that CSC increases when GDP per capita grows, raising the possibility that important factors such as increased resources for health care, improved infrastructure and technology, efficiency of

providers, and better affordability of patients may accompany increasing wealth.⁵ In China, only 35.7% of patients with cataract blindness received cataract extraction, and lower CSC was correlated with older age, being female, lower educational level, and geographic rurality.¹⁹ Of 21 countries in Sub-Saharan Africa and in Brazil, a higher density of ophthalmologists was located in areas with higher GDP per capita.^{20,21} In China, a study of the GDP for 13 cities in Jiangsu Province also found a positive correlation between GDP and CSR.²²

Socioeconomic level is a multidimensional concept with several indicators. Although GDP per capita is the most commonly used indicator, it has been criticized for overemphasizing economic factors. HDI is a more comprehensive indicator, reflecting social and economic domains. Comparing between countries with similar economic size and wealth by GDP per capita, there are differences in standard of living, education, and health, which are reflected by HDI. Our findings are consistent with previous questionnaire and descriptive studies, which demonstrated that lower HDI was

TABLE 3. Association of Quantity and Quality of Cataract Surgery With Gross Domestic Product per Capita

Indices	Regression Coefficient, 95%CI			P Value	R ²
	β	Low	Up		
Rate of cataract blindness, %	-0.527	-0.822	-0.231	0.001	0.110
CSC at blind level, %	9.800	6.329	13.272	<0.001	0.226
Rate of IOL implantation, %	6.871	2.734	11.007	0.001	0.105
Good outcome after surgery, %	7.959	4.844	11.074	<0.001	0.210

95%CI, 95% confidence interval.

TABLE 4. Generalized Estimating Equations Using Linear Regression Model for Assessing Relationship Between Socioeconomic Factors and Cataract Surgical Indices

	Model 1*			Model 2†		
	Coefficient (95%CI)	P	R ²	Coefficient (95%CI)	P	R ²
CSC						
HDI	79.957 (47.996-111.917)	<0.001	0.198	60.307 (0.753-119.861)	0.047	0.270
Per capita GDP‡	11.737 (7.370-16.105)	<0.001	0.148	10.558 (3.314-17.802)	0.004	0.210
Proportion of good visual outcome						
HDI	114.381 (97.955-130.807)	<0.001	0.250	117.441 (87.442-147.441)	<0.001	0.356
Per capita GDP‡	18.352 (16.017-20.688)	<0.001	0.028	14.186 (10.346-18.025)	<0.001	0.315

95%CI, 95% confidence interval.

* Model 1 controlled for the country and survey year.

† Model 2 further adjusted for the prevalence of cataract vision loss, proportion of people aged 50 years and older, mean body mass index, and the daily ambient ultraviolet radiation.

‡ Logarithmic scale.

correlated with a low preoperative visual acuity and increased prevalence of cataract blindness.^{23,24} Lou et al.²⁵ recently demonstrated that socioeconomic disparity in cataract burden has been deteriorated even global health progress in cataract, with heavier burden in less developed countries. These results indicate that health policymakers should pay more attention to socioeconomic-related inequality in quantity and quality of cataract surgery.

The WHO recommends that at least 80% of patients have good visual outcomes following surgery as an indication of adequate quality of service.²⁶ Unfortunately, outcomes of cataract surgery in many countries do not meet this recommended level. For example, the China Nine-Province Survey revealed that only 46.5% of postoperative cataract eyes had presenting visual acuity of 20/63 and better, and 23.5% remain blind after cataract surgery in rural China.¹⁹ Our findings of positive associations between cataract surgical outcomes and HDI were also consistent with other ecologic analyses for noncommunicable diseases. HDI was found to be significantly associated with survival and metastasis of retinoblastoma in less developed countries after controlling for other factors.²⁷ Furthermore, HDI was significantly correlated with rates and outcomes of hematopoietic stem cell transplantation, outcomes of acute coronary syndrome, *Helicobacter pylori* eradication therapy, and outcomes of various types of cancer.^{9-11,13,14,28} Younger patients, better screening programs, reduced rate and effective management of complications, increased IOL implantation, and comprehensive follow-up may explain the better postoperative cataract outcomes in countries with higher HDI.²⁹

This study presented a window to improve surgical output and quality through HDI-sensitive strategies. Policies should be made in countries with less human development, which are more likely to obtain worse outcomes after cataract surgery, in order to improve their compressive capacity and optimize performance of the health system. The SHARP study demonstrated that government and NGO investment in screening may enhance the quantity of cataract surgeries in rural China.³⁰ Furthermore, the monitoring of cataract surgical quality is valuable, especially in countries with low HDI, despite many barriers. In these countries, there are often small proportions of patients returning after surgery. It has been reported that both early vision assessment (at 3 days or less postoperatively) and follow-up examinations for those returning for follow-up examination are valid measures of surgical outcomes in countries where follow-up is poor.³¹ Therefore, a rigorous and straightforward approach to follow-up after cataract surgery is helpful in low-HDI countries

where inadequate quality of postoperative care is highly prevalent.³²

The limitations of this study should not be ignored. Firstly, the accuracy of each RAAB study depends on sample sizes at a given time. The RAAB studies include only the population 50 years and older; thus cataract indices in people under 50 cannot be estimated. Some RAAB studies were performed in subnational regions or single provinces, which leads to unequal distribution of the data. Secondly, the RAAB studies examined individuals who had had surgery recently and many years prior to the date of the study, which may introduce bias especially for visual outcomes. Thirdly, most data were derived from middle- and low-income countries; thus the conclusions should not apply directly to other areas. Fourthly, using HDI and GDP per capita has limitations in that HDI is an average value of socioeconomic development for a country, and significant variations in development levels may exist within a country. Fifthly, subgroup analyses were not performed by sex, ethnicity, and education because corresponding data for these fields were inadequate. Reassessment of the relationship between cataract indices and socioeconomic factors in specific populations may produce more comprehensive findings in the future. Finally, only data at country level were available; for example, exposure is the average HDI/per capita GDP of a country, outcome is CSC/proportion of good visual outcome in that country. Because no individual data were available, ecologic fallacy and bias may arise from aggregation of data.³³⁻³⁵ For example, different provinces in China have significantly different development levels. Different populations in a region might have different prevalence of cataract, educational level, and awareness of cataract surgery. Even in the United States, high geographic variations in the rate and timing of cataract surgery were observed in recent years.³⁶ However, we could not perform subgroup analysis according to sex, ethnicity, or region because of inadequate data. Furthermore, the aggregated data did not take into account inequalities within countries. Future prospective study examining the individual characteristics of patients and cataract surgery outcomes could provide better insight into the impact of socioeconomic development on the progress of blindness prevention. In addition, longitudinal studies could provide better insight into the return on investment in cataract surgical programs.

In conclusion, this ecologic analysis provides a worldwide overview of the quantity and quality of cataract services according to socioeconomic development indices. We demonstrated a strong association between HDI, GDP per capita, and the quantity and quality of cataract surgery. These socioeco-

conomic indicators should be considered when developing strategies aimed to enhance cataract surgical services worldwide.

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