Cataract Surgical Rate and Socioeconomics: A Global Study

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PURPOSE. Cataract is the leading cause of blindness and cataract surgical rate (CSR) is defined as number of cataract operations performed per million of population. CSR has been considered a more accurate estimate due to its comprehensive literature search methodology. The GBD showed that there were 10.8 million cataract blind people (1/3 of blind people worldwide) in 2010. The WHO has estimated that this number will increase to 40 million in 2025 as populations grow and age, with greater life expectancies.6 In 1999, the WHO and International Agency for the Prevention of Blindness (IAPB) launched the VISION 2020 global initiative to eliminate avoidable blindness by 2020. The World Health Assembly in 2013 endorsed a Global Action Plan (GAP) for Universal Eye Health, which has set a target to reduce the prevalence of avoidable blindness and visual impairment by 25% from the 2010 baseline to 2019, with cataract being considered a condition of priority.8

RESULTS. Over the study period, CSR data were available for 152 countries across both time periods. Most of the CSR data were obtained from nongovernment organization (NGO) reports, including WHO reports. A good linear correlation between CSR and GDP/P was found overall, nearest to 2009 (β = 0.162, Linear: y = 0.162x + 282.242; R² = 0.665, P < 0.001). Regression analysis of CSR nearest to 2014 produced similar findings, with significant correlations between CSR and GDP/P (Linear: y = 0.208x + 94.008; R² = 0.785, P < 0.001). When using GNI/P as an economic indicator, similarly excellent lines of fit were obtained. After adjusting for time and country, CSR was significantly associated with GDP/P (Coefficient = 0.147, R² = 0.759, P < 0.001), and GNI/P (Coefficient = 0.152, R² = 0.757, P < 0.001). Most countries had an increase in CSRs over time, with the greatest increases observed for Iran and Argentina.

CONCLUSION. Cataract surgical rate and economic indicators are closely associated, indicating the strong influence of resource availability on healthcare delivery. Considering this relationship, it is important to be innovative in delivery of low-cost services and invest strategically in capacity development to meet cataract surgical need in low-resource settings.

Keywords: cataract surgical rate, economics, systemic review, GDP, GNI
per million population in 1 year, and is used as a proxy indicator of access to cataract services in a country.\textsuperscript{7} In GAP, CSR is one of three core indicators. A number of factors may determine the CSR, including reduced uptake of available services due to patient anxiety over visual outcomes and the surgery itself, cultural barriers, and education. Supply-end determinants include numbers and accessibility of ophthalmologists, and the visual acuity cut-off or other indications on which the decision for cataract surgery depends. Cataract surgical rate varies greatly from country to country, and even within countries.\textsuperscript{10,11}

In economically developed countries (such as the United States, Europe, Australia, Japan) the general CSR ranges from 4000 to 10,000, and cataract blindness in the community is very rare. Comparatively, across developing countries in Latin America (such as Peru, Mexico, and Paraguay) and Asia (such as China and Vietnam), the CSR typically ranges from 500 to 2000. In many African countries such as Ethiopia and Kenya, the CSR was reported to be lower than 500.\textsuperscript{9,12,13} Over the past 10 years, CSRs have increased with the implementation of VISION 2020 and socioeconomic development.\textsuperscript{14,15} Although the CSR appears to be closely associated with the economic development of countries, this is not always true, as evidenced in the cases of India and China.\textsuperscript{15,16–18}

In many countries, cataract surgery remains one of the most commonly performed procedures, offering significant improvements to the quality of life for patients of all ages.\textsuperscript{19,20} The demand for cataract surgery has been expanding worldwide due to ageing populations and increased life expectancies. It follows that the increased numbers of necessary cataract surgeries poses significant economic challenges for countries with respect to health budgeting and the burden of disease.

Taylor\textsuperscript{21} has suggested that age of the population, visual acuity cut-off value indicating the need for surgery and cataract surgical output capacity are three factors that should determine CSR targets. However, one might also consider the economic development level of a country as a relevant context, taking into consideration the affordability of cataract surgery with respect to overall government health budgets.\textsuperscript{13,22,23} To understand and evaluate the possible relationships between the CSR and economic development, we require data from two variables: CSR and economic indicators in each country. The trend of CSR over time in some regions has been explored, for example, in the work of Lewallen et al.\textsuperscript{24–26} Although this is essential for informing health policy and strategies, global variations remain unclear.\textsuperscript{21}

To address this information deficit, this study uses available CSR and economic data globally over the past decade (2005–2014) to explore the trend of CSR in each region over time, and identify associations between a country’s economy (gross domestic product per capita [GDP/P]; gross national income per capita, [GNI/P]) and CSR.

**METHODS**

**Search Strategy and Selection Criteria**

Following PRISMA guidelines, eligible studies were retrieved from the literature by a two-step process: first, through comprehensively searching electronic databases (published literature); second, by obtaining additional data from unpublished reports (gray literature). The eligible data of CSR was restricted to reports on age-related cataract among adults using any cataract surgery method, including extracapsular cataract extraction (ECCE), small incision cataract surgery (SICS), and phacoemulsification with the implantation of an intraocular lens.

Eligible population-based studies were retrieved from OVID (Medline and Embase), Pubmed, Embase.com, ISI Web of Science, and Cochrane Library databases using standardized search terms (Supplementary Data S1). Reference lists of reviews and retrieved studies were also screened for suitable studies. Studies published from January 2000 to December 2015 were considered for inclusion into the review. There was no language restriction in the search, and any studies meeting the inclusion criteria were included for statistical analysis. The inclusion criteria for published studies were: (1) national or population-based samples, (2) cross-sectional studies, cohort studies, or surveys with a clear sampling methodology, (3) sufficient response rate (50% or greater), and (4) samples representative of populations in a country or region. Case series of hospital and clinic data were excluded.


**WHO Regions, Economical, and Population Data**

Countries were divided into six regions according to WHO classification (in the public domain, http://www.who.int/about/regions/en/): Africa, the Americas, South-East Asia, Europe, the Eastern Mediterranean, and the Western Pacific. The World Bank (in the public domain, http://data.worldbank.org/) provides data of GDP/P and United Nations Human Development (in the public domain, http://hdr.undp.org/en/data) provides data of GNI/P.\textsuperscript{27} We retrieved the relevant economic data in international dollar units of 2011. The Organization for Economic Co-operation and Development Policy (ESCAP) Statistical Database (in the public domain, http://www.unescap.org/stat/data/) and government websites were used to verify the economic data. Information of the total population was obtained from World Population Prospects: the 2015 revision by the United Nations.\textsuperscript{28}

**Data Extraction**

Data extraction was performed using a standardized data extraction form. The extracted fields included the region and country in which the study was conducted, year of publication, year of data collection, age, number of people examined and CSRs with 95% confidence intervals (CI). The data on GDP/P and GNI/P in each country from 2005 to 2014 were extracted in a similar fashion. National CSRs were calculated with the numerator being total number of surgeries performed in a particular year in a country. There was a mix of information sources for many countries. For each country, the data was verified by several means; the data from NGOs reports, peer-reviewed papers and government reports were cross checked, where multiple sources were available. If more than one national CSR measure in the same year were available, we used the following hierarchy in selecting national CSR data for analysis: WHO reports, national reporting systems reports, Ministry of Health in the country, National Society of
Ophthalmology, national population-based survey, other NGO (such as IAPB) reports, insurance database reports, conference reports, communications, population-based studies in a sub-population, and estimated reports based on numbers of intraocular lenses sold per year in the country. When there were two CSR figures available for a country for each year, approximately 6 months apart, we averaged them for each year to obtain the mean CSR. When there were at least two national CSRs from the same type source were available, the CSRs were averaged. If the CSRs of several regions and provinces in a country were reported, the mean CSR for the country was determined by calculating a summative total, and dividing it by the total population for the regions and provinces combined. If only one published paper focused on a subpopulation in the country was available, the CSR data was used as a surrogate for national CSR.

Statistical Analyses
All statistical analyses were conducted using the SPSS software package (version 20.0; SPSS, Inc., Chicago IL, USA). Cataract surgical rate data were arbitrarily analyzed in two time frames, 2005 to 2009 and 2010 to 2014. Cataract surgical rate data for the nearest year to 2009 were used to represent the period 2005 to 2009, and similarly, CSR data for the nearest year to 2014 were used to represent the period 2010 to 2014. The corresponding GDP/P data for the same period of time in each country were used for statistical analysis. By population size, the regression analysis of the 50 most populous countries with available CSR data were used to develop a regression analysis and scatter plots. Regression curve estimation procedures were used to assess the association between CSR and GDP/P (linear, power, quadratic, exponential selected). A regression curve was fitted for CSR versus GDP/P for 2005 to 2009 and 2010 to 2014, respectively. We used longitudinal data for each country with at least 3 years of CSR data and pooled this information across countries to model the association between CSR and GDP/P using a mixed-effects model. Regression-curve estimation was used to calculate the economic-adjusted CSR for 2015. A P value of less than 0.05 was considered statistically significant. The scatter plots were produced for GDP per capita versus CSR using GraphPad Prism 5.0 software (La Jolla, CA, USA).

RESULTS
Among a total of 198 independent countries in the world, CSR data were retrieved successfully for 152 countries (Supplementary Data S2) between 2005 and 2014. While some CSR data were extracted from published papers,12,16–18,29–52 the majority of the data were extracted from WHO and NGO reports, although further details of how these data were extracted from published papers,12,16–18,29–52 the majority of the data were extracted from WHO and NGO established national/district reporting systems such as the Medical Information System (Medisave Database, Singapore), Medical registers in Togo (Togo, Africa), Medicare beneficiaries system and National Eye Outcomes Network in the United States, although most countries did not report CSR from an established reporting system.67–74 France and Sweden were the only two countries to publish registry CSR data systematically. Furthermore, there were very few reports available for 2013 and 2014.

The CSRs reported between countries varied greatly, with the lowest being the Democratic Republic of Congo (76 per million) and the highest being France (11080 per million) (Supplementary Data S2). Using United Nations population estimations, the 50 countries with the largest populations and available CSR and GDP/P data between 2005 and 2009 were included in the regression analysis (Supplementary Data S3). The regression analysis of the 50 most populous countries with CSR data showed that CSRs were significantly correlated with GDP/P (β = 0.173, Linear: y = 0.173x + 250.551; R² = 0.670, P < 0.001). Figure 1 shows the distribution of CSR and GDP/P. The regression line indicated that countries such as Iran, India, and Nepal had CSRs that was greater than their GDP/P model estimates, while China and Saudi Arabia tended to have lower than expected CSRs when measured against the model estimates.

Similar results were obtained for the period between 2010 and 2014 (Fig. 2). Data from the 50 largest countries by population size were chosen for statistical analysis (Supplementary Data S4). A line of best fit was created for the association between CSR and GDP/P with R² = 0.8, suggesting that the linear regression accounted for 80% of the variance (Linear: y = 0.208x + 94.008; R² = 0.785, P < 0.001). Between 2005 and 2014, India and Argentina maintained CSRs that were consistent with economy-based projection using the GDP/P regression model; however China, Saudi Arabia, and Mexico, and the Republic of Korea were all positioned below their economy-projected CSRs using this model. The regression line suggests that in China for example, the CSR should be at a minimum of 2721 (95% CI: 2305–3137) to maintain this consistent relationship with GDP/P.

When using GNI/P as the economic indicator, similar excellent lines of fit were obtained. For the period between 2005 and 2009, the regression analysis of the 50 most populous countries with CSR data showed that CSRs were significantly correlated with GNI/P (β = 0.172, Linear: y = 0.172x + 283.132; R² = 0.656, P < 0.001; Figure 3). For the period between 2010 and 2014, the regression analysis of the 50 most populous countries with CSR data showed that CSRs were significantly correlated with GNI/P (β = 0.215, Linear: y = 0.215x + 68.452; R² = 0.813, P < 0.001; Figure 4).

Over the study period, most countries experienced an increase in CSR (such as China, India, United States, Brazil), with greatest increases for medium to large populations and a moderate increase observed for China (Fig. 5; Supplementary Data S2). The mean CSRs for 2005, 2009, 2011, 2012, 2013, and 2014 for China were 440, 796, 684, 822, 882, and 1067 per million population, respectively. The growth rate over the study period was 143%, together with an increase of 704.48 million (5%) in the population, and an increase of 86933 (122%) in the GDP/P suggesting the growth rate of CSR tended to be consistent with GDP growth. The CSR in 13 countries decreased as GDP/P increased (Uganda, Botswana, Sierra Leone, Togo, South Africa, Congo, Vanuatu, Guatemala, Philippines, Nigeria, Lao People’s Democratic Republic, Kenya, Zambia), though it is worth noting that these countries were all relatively small by population size.

Twenty-eight countries provided at least 3 years data on CSR, GDP/P and GNI/P, and were included in our linear mixed-model. After adjusting for time and country, CSR was significantly associated with GDP/P (Coefficient = 0.147, R² = 0.759, P < 0.001). After adjusting time and country, CSR was also significantly correlated with GNI/P (Coefficient = 0.152, R² = 0.757, P < 0.001). These results indicate that GDP/P and GNI/P are significant variables for CSR in mixed-models.
According to the World Bank Atlas method, countries were categorized by GNI/P into low-income economies ($\leq$1045), middle-income economies ($1045 - 12,736$), and high-income economies ($\geq 12,736$) in 2014. In the high-income countries, such as France, the Netherlands, the United States, Sweden, Japan, Australia, Argentina, Singapore, New Zealand, the CSR in 2014 ranged from 4001 to 11080. This provides a picture of cataract surgery rates in high-resource settings and further

**Figure 1.** Correlation between CSR and GDP/P-based (purchasing power parity, or GNI/P method) data nearest to 2009.

**Figure 2.** Correlation between CSR and GDP/P-based (purchasing power parity, or GDP/P method) data nearest to 2014.
indicates an inequity in access to cataract surgery in high-income countries.

**DISCUSSION**

Cataract blindness accounts for more than 50% of blindness globally, but this proportion varies considerably between countries and districts. For developing countries in the Sub-Saharan African, Latin American, Caribbean regions, and for minority groups in high-income countries, cataract remains the main cause of blindness. The proportions of cataract blindness were found to be 44% and 66% in Paraguay and Panama, respectively, 50% in the African and Eastern Mediterranean region, and 27% of all African Americans living in the United States.6,9,75

Overall, there is a paucity of standardized data depicting CSRs across countries in different regions owing to a lack of standardized registry systems. In this study, we report the CSR data for 152 countries over a 10-year period. We also explored the possible relationship between CSR and GDP/P. The results demonstrated that CSRs were closely associated with GDP/P in a linear fashion.

Our model satisfactorily answered the question “how many cataract surgeries are being performed in a given country,” but answering, “how many cataract surgeries need to be performed” is more complex and falls beyond the scope of this research. Several other considerations are needed for determining CSR targets in a given country. Our analysis aims to primarily explore the association between CSR and economic indicators and help health policy planners appreciate how economy size and wealth influences CSR, and does not reflect the appropriateness of CSRs in individual country contexts. It would be fallacious to conclude from this model directly that countries are performing fewer or excessive numbers of cataract surgeries than what is ideal. We propose that the CSR required addressing cataract blindness, and the CSR that is most affordable for a country’s economy are independent questions requiring separate consideration, to best guide the optimal CSR targets.

It has been recognized there are three main determinants of CSRs were the age structure of the community, visual acuity cut-off for cataract surgery, and the cataract surgical coverage (CSC) from need-based estimates.23 A mathematical model to estimate the ideal CSR has been previously produced based on population and age structure.21,22,26 With a burgeoning private surgery sector and improved access to insurance the number of cataract surgeries performed may increase dramatically, but the optimal numbers of cataract surgeries in countries can still remain unclear.76–78

Although wealthier countries appear to have higher rates of cataract surgery, provision of surgical services is frequently deferred to the private sector, with costs passed onto patients. Furthermore the inconsistent access to surgical services within high-income countries highlights that healthcare inequities can persist despite increases in GDP and observed CSR overall. The highest concentration of Brazilian ophthalmologists for example was found in areas with the highest GDP.76 Therefore, the correlations between higher GDP/P and higher CSR may not uncover the true distribution of ophthalmologists and accessibility to services, particularly for patients in lower socioeconomic areas.

Cost-effectiveness studies can further validate that increased resource expenditure on cataract surgeries produces a proportional return in terms of Quality-of-Life Years (QALYs) gained. The cost-effectiveness of cataract surgery in several countries was estimated in previous studies (Table).77–83 In Japan, cataract surgery was associated with incremental costs of (¥) 551,513 (US$6920) and an incremental effectiveness of 3.38 QALYs per single cataract patient.80 In the United Kingdom, a meta-analysis showed that second-eye surgery generated an additional 0.08 QALY with an incremental cost-
The effectiveness ratio of £1964 per QALY gained.\textsuperscript{79,81} In the United States, it was reported that cataract surgery greatly improved quality of life, and the incremental costs per QALY gained for cataract surgery were US$259. Furthermore, initial cataract surgery yielded an extraordinary \(4567\%\) financial return on investment (ROI) over a 13-year period.\textsuperscript{78,82} Brown et al.\textsuperscript{84} have also demonstrated that the financial ROI for direct ophthalmic expenditures for cataract surgery to be approximately \(4500\%.\) This data suggests that significant benefits and returns can be derived from increased spending on cataract surgery. In Latin America, the most recent surveys identified cost of the surgery as one of the main barriers to cataract surgery. In Latin America, the most recent surveys identified cost of the surgery as one of the main barriers to cataract surgery.\textsuperscript{50} Eckert et al.\textsuperscript{85} estimated the cost of blindness (COB) in nine sample countries and demonstrated that the loss of productivity ranged from \$0.1\ billion in Honduras to \$2.5\ billion in the United States based on minimum wage. Alternatively, this ranged from \$0.1\ billion in Honduras to \$7.8\ billion in the United States, based on GNI/P. Both suggest that more rigorous eye care would improve economic productivity across the globe.\textsuperscript{85}

The strengths of this study include the systematic search protocol and data extraction methodology, of published and unpublished CSR data in each country. The study also investigated the trends in CSR over a relatively long period of time. However, this study also contains several limitations. Firstly, the missing data for several countries over the study period may lead to incomplete reporting and inaccurate estimations of CSR to GDP/P associations. Secondly, the CSR included all surgeries performed in the total population irrespective of visual acuity or degree of visual impairment prior to the surgery, and therefore increasing CSR does not necessarily reflect a needs-based provision of services. The CSR data does not incorporate other significant outcomes such as sight restoration rate, as well as the cataract surgical coverage among the cataract blind. Furthermore, CSR data in 2013 or 2014 were not available for the majority of NGO reports, and most data from NGO or government reports did not specify the

<table>
<thead>
<tr>
<th>Study (y)</th>
<th>Location</th>
<th>Cost per Outcome</th>
<th>Unit of Outcome</th>
<th>Currency</th>
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<tbody>
<tr>
<td>Baltussen and Smith.\textsuperscript{77} (2012)</td>
<td>Sub-Saharan Africa (AFR-E); South Asia (SEA-D)</td>
<td>$116 AFR-E; $97 SEA-D</td>
<td>DALY averted</td>
<td>2005 I$</td>
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<td>Griffiths et al.\textsuperscript{82} (2014)</td>
<td>Zambia</td>
<td>$259</td>
<td>QALY gained</td>
<td>2010 USD</td>
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<td>Brown et al.\textsuperscript{78} (2013)</td>
<td>USA</td>
<td>$1636</td>
<td>QALY gained</td>
<td>2012 USD</td>
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<tr>
<td>Cooper et al.\textsuperscript{79} (2015)</td>
<td>UK (second eye cataract)</td>
<td>$1964</td>
<td>QALY gained</td>
<td>2012 UK Pound</td>
</tr>
<tr>
<td>Eye Care Comparative Effectiveness Research\textsuperscript{80} (2013)</td>
<td>Japan</td>
<td>$1486</td>
<td>QALY gained</td>
<td>2011 USD</td>
</tr>
<tr>
<td>Frampton et al.\textsuperscript{81} (2014)</td>
<td>UK, USA, Finland (second eye cataract)</td>
<td>$1964</td>
<td>QALY gained</td>
<td>2012 UK Pound</td>
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AFR-E, the WHO subregion in Africa with the highest mortality rates; DALY, disability-adjusted life year; QALY, quality-adjusted life year; I$, international dollar; SEA-D, the WHO subregion in Southeast Asia (including South Asia) with the highest mortality rates.
methodology for data collection. Although we identified established cataract surgery registry systems in Sweden, France, the Netherlands, Malaysia, China, India, the United Kingdom, Singapore, Togo, and the United States, most of these did not publish their data collection procedures. As a result of this, the accuracy of CSR data from these sources cannot be verified.

To meet the target set by the GAP, a system for more effective data collection at an international level is needed. The development of a system, as in the WHO prevention of blindness framework, that allows for countries to report annual CSR data using standardized methods (i.e., data collection from lens manufacturers) would facilitate further research and inquiry in this area.

As demonstrated in our study, the CSR were closely associated with GDP/P, which suggests that CSR as an indicator for the effectiveness of eye care delivery is strongly related to the size of the economy and economic development. This may be helpful for understanding the relationship between CSR and economic development in each country, using other economies as comparison standards.

For developing countries without reliable cataract prevalence data, or comprehensive collection systems in place, our model may be useful supplementary information to guide preliminary budgets and planning. However, economic indicators should not be used in isolation to project CSR targets, and we recommend that health planners take into account their country’s cataract prevalence data to complement this assessment. It should be noted that our analysis was based on cross-sectional data from various countries without controlling for the differences between the country characteristics, which may produce bias in the results. Cataract surgery rate is associated with many factors, such as cataract prevalence, accessibility to services, the racial and genetic make-up, as well as density of ophthalmologists. A country with high economic level but low prevalence of cataract is unlikely to produce a high CSR. However, linear mixed-effect modeling using longitudinal data also found significant associations between economic indicators and CSR, and indicates the robustness and reliability of our model.

CONCLUSIONS

In summary, CSR and economic indicators (GDP/P, GNI/P) appear to be closely associated, indicating the strong influence of resource availability on healthcare delivery. The model may be helpful for understanding the relationship between CSR and economic development. Considering this relationship, it is important to innovatively deliver low-cost services and invest strategically in capacity development to meet the cataract surgical need in low-resource settings. Regression modeling in this study illuminates the relationship between CSR and economic data worldwide. Furthermore, establishing an international standardized CSR registry may improve accurate reporting of CSR, to better inform government health policy and budgeting. In addition, the thresholds for CSR are often modeled on rate to address “blinding cataract,” where, by definition, the vision is less than 3/60. We recognize that increasingly cataract surgery is performed for less advanced cataract that affects vision and reduces the economic capacity of the individual but that has not yet caused profound vision loss. The information from this model may be useful in conjunction with a country’s cataract prevalence and surgical demand data, but should not justify a reduction in cataract surgery spending where there is need and scope to improve delivery.

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