# Changing patterns in cataract surgery indications, outcomes, and costs, 2012–2023: a retrospective study at Aravind Eye Hospitals, India

Sachin Gupta,[a] Ravindran D. Ravilla,[b] Haripriya Aravind,[c] Shivkumar Chandrashekharan,[d] and Thulasiraj D. Ravilla[e,*]

[a]Cornell SC Johnson College of Business, Ithaca, NY, USA
[b]Aravind Eye Care System, Madurai, India
[c]Aravind Eye Hospital, Chennai, India
[d]Aravind Eye Hospital, Tirunelveli, India
[e]LAICO- Aravind Eye Care System, Madurai, India

The Lancet Regional Health - Southeast Asia 2025;33: 100530

Published Online xxx
https://doi.org/10.1016/j.lansea.2025.100530

## Summary

**Background** Data on the evolving characteristics of patients seeking cataract surgery, surgical techniques used, preoperative vision, postoperative visual outcomes, and surgery costs provide critical insights for improving care delivery and making progress towards global eye care targets. We aimed to establish long-term trends in these factors.

**Methods** Retrospective analysis of all cataract surgeries performed at Aravind Eye Hospitals during 2012–2023.

**Findings** In 3.6 M cataract surgeries, the mean preoperative uncorrected visual acuity improved from 1.32 logMAR units (Snellen fraction ≈ 6/120) in 2012 to 1.15 (Snellen fraction ≈ 6/85) in 2023. The trend was observed in females and males, with females presenting with worse vision than males, in all age groups, and among outreach, subsidized and paying patients. Postoperative visual acuity outcomes steadily improved, with larger gains in Manual Small Incision Cataract Surgeries than in phacoemulsification. Mean prices for paying patients rose slightly faster than the Consumer Price Index for health. Surgeries supported by insurance and government assistance increased from 4.4% in 2012 to 28.7% in 2023. Male patients consistently paid about 10% higher prices than female patients because they chose more expensive intraocular lenses.

**Interpretation** Over this period, patients sought cataract surgery sooner, received better surgical outcomes, and were willing to pay more for the improvements. However, female patients continued to face inequities, presenting with worse vision, and receiving lower expenditures for surgery, indicating the need for targeted approaches to address sex inequity both on the demand generation and treatment provision sides.

**Funding** None.



**Keywords:** Cataract surgery; Preoperative vision; India; Postoperative vision; Sex inequity; Cost of cataract surgery

## Introduction

In 2020, South Asia had the highest number of vision impaired individuals among twenty-one global regions: 11.9 M with blindness, 96.2 M with moderate or severe vision impairment (VI), and 60.1 M with mild VI. Among adults aged 50 and older, South Asia experienced the largest percentage reductions in age-standardized prevalence of blindness and moderate to severe VI from 1990-2020.[1] Cataracts and refractive error are the leading causes of vision impairment globally and in this region. Given the magnitude and changing nature of VI in this region, understanding long-term trends in the incidence, prevalence, and treatment of cataracts is crucial.

Data on the evolving characteristics of patients seeking cataract surgery, the mix of surgical techniques, preoperative vision, postoperative visual outcomes, and costs, are critical for understanding both changing community preferences and progress towards global eye care targets.[2] For instance, recent guidelines by the

*Corresponding author.
*E-mail address:* thulsi@aravind.org (T.D. Ravilla).

## Research in context

### Evidence before this study

We searched PubMed with the terms ("Cataract Extraction" [Mesh] OR "Cataract" [Mesh]), "India" [Mesh], "Treatment Outcome" [Mesh], and "Health Care Costs" [Mesh] with different combinations of Booleans ("AND", "OR"), published anytime from 1990 to May 1, 2024. We found one directly relevant study that reported trends in cataract surgery indications and surgical outcomes based on seven years of retrospective data (2012–2018) from Aravind Eye Hospitals. The key differences in our current study are that it examines trends in patient sub-groups based on sex, age, and payment type, includes data on costs of surgery including third-party sources, and covers a longer and more recent period (2012–2023). Our search yielded other studies that were relevant to cataract surgery preoperative vision, postoperative outcomes, or cost-effectiveness. However, to our knowledge, there are no other studies that report on trends in these variables in the Indian context, at the national, subnational, or regional levels.

### Added value of this study

Data about the evolving characteristics of patients seeking cataract surgery, the mix of surgical techniques used, preoperative vision, postoperative visual outcomes, and the cost of cataract surgery, are critical to get insights on both changing surgical preferences in the community as well as progress towards global eye care targets. We find a persistent trend of better preoperative vision, overall and in subgroups by sex, age, and patient type. Female patients present with poorer preoperative vision than men and the sex gap in preoperative vision remained unchanged over the 12 years. Mean postoperative visual acuity improved steadily, and the quality gap between phacoemulsification and manual small incision cataract surgery shrunk. The cost of cataract surgery to paying patients increased at about the same rate as the overall healthcare price index, possibly reflecting a growing willingness to pay. An increasing proportion of surgeries was supported by the government and insurance. Spending per capita on female patients was about 10% lower than on male patients, and the sex gap declined only slightly.

### Implications of all the available evidence

The trends over 12 years imply that patients seek surgical treatment for cataracts sooner, receive better outcomes from surgery, and are willing to pay more for the improving benefits. At the same time, there are continuing inequities faced by female patients in both worse vision at presentation for treatment and lower expenditures for surgery, indicating the need for targeted approaches to address sex inequity, both on the demand generation and treatment provision sides. These insights on cataract surgical trends are critical as member states of the World Health Organization (WHO) strive to achieve the goal of increasing the effective Cataract Surgical Coverage (eCSC) by 30% by 2030. Further, the trends we show are likely useful for other institutions for planning, training, and equipment investments.

World Health Organization (WHO) have defined the population in need of cataract surgery as individuals with Best Corrected Visual Acuity (BCVA) < 6/12 with cataract as the main cause of VI[3]; this is a lower threshold than currently followed,[4] and the first time such a definitive threshold has been recommended. High income countries such as Australia,[5] Denmark,[6] England,[7] the Netherlands,[8] Sweden,[8,9] and the United States,[10] have reported a trend of improving preoperative vision; that is, the community is seeking care earlier. Since better visual acuity thresholds for cataract surgery are often accompanied with increasing Cataract Surgical Rates, (CSR: the annual number of cataract surgeries per million population[11]) such trends have key implications for the management of demand and supply of surgery, particularly in resource constrained settings.[12] However, most low and middle income countries (LMICs) around the world, including the five countries in South Asia–Bangladesh, Bhutan, India, Nepal, and Pakistan—lack administrative databases or population-based studies that report trends in such key measures at the national, sub-national, or regional level.

Improving preoperative vision over time is believed to be in part due to better postoperative outcomes of cataract surgery, resulting in increased patient benefits from surgery. In LMICs, an important driver of the uptake of cataract surgery is the cost of surgery to the patient.[13] Increases in third-party coverage of healthcare expenditures, both government- and insurance-provided, and consequent reduced out-of-pocket costs for patients, are important considerations that influence patient costs. It is also important to understand trends in these variables for subpopulations such as females, lower socio-economic groups, and older individuals, who face higher access barriers in LMICs.[14–17] Once again, population-level data that identify temporal patterns in postoperative outcomes or costs of cataract surgery in India, and more broadly in LMICs, are unavailable. Long-term data are essential to identify trends in these areas, as changes occur gradually.

Here we report on twelve-year trends (2012–2023) in patient demographics, preoperative vision, postoperative outcomes, and cataract surgery costs. Given the criticality of the research questions, and the paucity of population-based data, we use data from one major provider of eye care–the Aravind Eye Care System (Aravind)—which accounts for 40%–50% share of cataract surgeries in Tamil Nadu and a smaller share in Andhra Pradesh, India.[18]

## Methods

### Study design and participants

In this retrospective study, we extracted anonymized, cataract surgery-level data for 2012–2023 from two Aravind hospital databases: the cataract quality assurance platform (CatQA) for 2012–2015, and electronic medical records (EyeNotes) for 2016–2023. These data are captured as a part of patient flow and checked for completeness and accuracy. For each surgery we included unique patient identifier, patient sex (self-reported by patient at registration) and age, patient type (paying, subsidized, or outreach), hospital name, surgical technique, left or right eye, preoperative and postoperative vision, total surgical fee, and whether the patient received assistance from a government scheme or insurance. All surgeries except those where patient sex or age were missing were included in the analysis. Data were missing for some variables for some surgeries, and those observations were excluded in computing means or proportions. Data on preoperative BCVA were missing for a large percentage of surgeries on outreach patients, mainly in case of advanced cataracts. Consequently, for preoperative vision we only report Uncorrected Visual Acuity (UCVA).

### Ethical approval

The study protocol was approved by Aravind Eye Hospital's Institutional Review Board and adhered to the tenets of the Declaration of Helsinki. Patient confidentiality was maintained by adherence to privacy protocols.

### Cataract surgery at Aravind hospitals

All patients with visually significant cataract preoperatively undergo baseline Snellen visual acuity (VA) assessment, refraction (for all hospital patients), slit lamp examination, lacrimal duct patency, biometry, and systemic comorbidity evaluation. Surgical procedures at Aravind are performed by consultants, residents, and fellows. Patients choose one of three options to receive cataract surgical services based on affordability and access: paying, subsidized and outreach camp (free). Paying patients have the option to choose between phacoemulsification (PE) and Manual Small Incision Cataract Surgery (MSICS), whereas nearly all subsidized and outreach patients undergo MSICS.

The usual practice at Aravind hospitals is to discharge patients on the same day or the day following surgery, after checking VA with pinhole using Snellen chart and eye examination by slit lamp. During discharge, patients are advised to follow-up for a postoperative eye exam one month following surgery. During the one-month follow-up visit, all hospital patients receive VA testing, subjective refraction and detailed dilated eye examination using slit lamp.

### Statistical analyses

Visual acuity (VA) was initially measured using Snellen units. However, for most statistical analyses, VA was transformed to logarithm of the minimum angle of resolution (logMAR) units to facilitate parametric statistical testing, as logMAR provides a linear scale for measuring visual acuity, allowing for more accurate averaging and comparison of values. The conversion was performed using the standard formula: $\text{logMAR} = -\log_{10}(\text{Snellen fraction})$, where the Snellen fraction represents the test distance divided by the distance at which the smallest line read would be seen by a person with normal vision.[19] Counting fingers close to face, hand movement, light perception, and no light perception were assigned logMAR values of 2.3, 2.6, 2.9 and 3.2 respectively.[20] To assess trend in mean visual acuity expressed in logMAR units, for a single group we specify a simple linear regression of the outcome variable on year as the predictor, with year coded as 1 for 2012, 2 for 2013, ..., 12 for 2023, and use 12 annual observations to estimate the intercept and coefficient of year. For more than one patient group (e.g., male and female patients) we perform a multivariable linear regression with group dummy variables and year as predictors, and data pooled across groups. All reported p-values are 2-sided. Analyses were performed with SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) and Microsoft Excel.

### Role of the funding source

Not applicable.

## Results

### Sample description

Descriptive statistics of the 3.6 M operated eyes included in our study are in Table 1. During the 12-year period, the number of surgeries grew at a compound annual growth rate (CAGR) of 5.4%. Almost 55% of surgeries were on female eyes, and this proportion grew slightly over the time window. The mean age of male patients at the time of surgery was 62.4 years while that of female patients was 60.3 years ($p < 0.001$), and there was no discernable time trend. The median ages were 63 years for male patients and 60 years for female patients. In terms of surgical technique, the share of PE grew from 26.9% to 37.9%, and the number of PE surgeries increased at a CAGR of 8.5%. By contrast, the share of MSICS shrank from 73.1% to 62.1%, while the number of MSICS surgeries increased at a CAGR of 4.0%. Outreach patients accounted for 27.7% of all surgeries, subsidized patients 32.3%, and paying patients 40%. Outreach patients received free cataract surgery, post-op medicines, return transportation from campsite, and food during hospitalization; subsidized patients paid

| | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number of surgeries** | 241,194 | 238,968 | 257,129 | 260,929 | 277,764 | 291,994 | 308,650 | 316,222 | 173,520 | 324,052 | 447,629 | 455,579 | 3,593,630 |
| % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| **Patient sex** | | | | | | | | | | | | | |
| Female | 132,507 | 130,107 | 140,084 | 142,279 | 152,849 | 159,548 | 169,124 | 172,418 | 91,735 | 177,790 | 248,896 | 254,276 | 1,971,613 |
| % | 54.9 | 54.4 | 54.5 | 54.5 | 55.0 | 54.6 | 54.8 | 54.5 | 52.9 | 54.9 | 55.6 | 55.8 | 54.9 |
| Male | 108,684 | 108,836 | 117,011 | 118,622 | 124,908 | 132,432 | 139,512 | 143,782 | 81,779 | 146,256 | 198,721 | 201,296 | 1,621,839 |
| % | 45.1 | 45.5 | 45.5 | 45.5 | 45.0 | 45.4 | 45.2 | 45.5 | 47.1 | 45.1 | 44.4 | 44.2 | 45.1 |
| Transgender | 3 | 25 | 34 | 28 | 7 | 14 | 14 | 22 | 6 | 6 | 12 | 7 | 178 |
| % | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| **Patient age** | | | | | | | | | | | | | |
| Male–Mean (years) | 62.1 | 62.1 | 62.1 | 62.2 | 62.2 | 62.3 | 62.5 | 62.7 | 61.3 | 61.9 | 62.8 | 63.0 | 62.4 |
| Male–Std dev (years) | 10.8 | 10.7 | 10.6 | 10.7 | 10.5 | 10.4 | 10.3 | 10.0 | 10.7 | 10.2 | 10.0 | 10.0 | 10.4 |
| Female–Mean (years) | 59.9 | 59.9 | 59.9 | 60.0 | 60.0 | 60.2 | 60.2 | 60.5 | 59.3 | 59.9 | 60.8 | 61.1 | 60.3 |
| Female–Std dev (years) | 9.9 | 9.9 | 9.9 | 9.8 | 9.7 | 9.6 | 9.7 | 9.5 | 9.9 | 9.5 | 9.4 | 9.4 | 9.7 |
| **Surgery technique** | | | | | | | | | | | | | |
| Phacoemulsification | 64,764 | 69,417 | 76,577 | 81,846 | 92,219 | 95,242 | 106,201 | 114,533 | 80,667 | 137,057 | 169,419 | 172,652 | 1,260,594 |
| % | 26.9 | 29.0 | 29.8 | 31.4 | 33.2 | 32.6 | 34.4 | 36.2 | 46.5 | 42.3 | 37.8 | 37.9 | 35.1 |
| MSICS | 176,430 | 169,551 | 180,552 | 179,083 | 185,545 | 196,752 | 202,449 | 201,689 | 92,853 | 186,995 | 278,210 | 282,927 | 2,333,036 |
| % | 73.1 | 71.0 | 70.2 | 68.6 | 66.8 | 67.4 | 65.6 | 63.8 | 53.5 | 57.7 | 62.2 | 62.1 | 64.9 |
| **Patient type** | | | | | | | | | | | | | |
| Outreach | 87,456 | 83,840 | 88,075 | 86,048 | 83,980 | 91,845 | 92,635 | 89,216 | 19,192 | 50,510 | 107,193 | 114,578 | 994,568 |
| % | 36.3 | 35.1 | 34.3 | 33.0 | 30.2 | 31.5 | 30.0 | 28.2 | 11.1 | 15.6 | 23.9 | 25.1 | 27.7 |
| Subsidized | 69,774 | 68,850 | 75,721 | 77,825 | 85,165 | 88,077 | 91,655 | 95,694 | 62,936 | 124,340 | 158,598 | 162,306 | 1,160,941 |
| % | 28.9 | 28.8 | 29.4 | 29.8 | 30.7 | 30.2 | 29.7 | 30.3 | 36.3 | 38.4 | 35.4 | 35.6 | 32.3 |
| Paying | 83,964 | 86,278 | 93,333 | 97,056 | 108,619 | 112,072 | 124,360 | 131,312 | 91,392 | 149,202 | 181,838 | 178,695 | 1,438,121 |
| % | 34.8 | 36.1 | 36.3 | 37.2 | 39.1 | 38.4 | 40.3 | 41.5 | 52.7 | 46.0 | 40.6 | 39.2 | 40.0 |
| **Postop follow up** | | | | | | | | | | | | | |
| Number of Surgeries | 185,293 | 207,310 | 227,231 | 230,104 | 238,490 | 253,216 | 259,201 | 269,169 | 128,151 | 263,350 | 380,550 | 384,638 | 3,026,703 |
| % | 76.8 | 86.8 | 88.4 | 88.2 | 85.9 | 86.7 | 84.0 | 85.1 | 73.9 | 81.3 | 85.0 | 84.4 | 84.2 |

MSICS—Manual Small Incision Cataract Surgery.

***Table 1:*** **Sample description.**

INR 1000 (US$ 12) for the surgery and post-op medicines; and paying patients on average paid INR 23,000 (US$ 275) in 2023. The share of surgeries on outreach patients declined, while the share of subsidized and paying patients increased ($p < 0.01$). During the 12-year period, in 84.2% of surgeries patients followed up one month after surgery. The follow-up rate remained well above 80% in most years, with an exception in 2020, the first year of the Covid-19 pandemic, when it fell to 73.9%.

## Trends in preoperative vision

Fig. 1a shows that mean preoperative UCVA improved from 1.32 logMAR units (Snellen fraction ≈ 6/120) in 2012 to 1.15 logMAR units (Snellen fraction ≈ 6/85) in 2023 ($p < 0.01$), a linear rate of change of 0.011 per year (In logMAR units, better visual acuity is represented by lower values.) There is a noticeable decline in mean preoperative vision during 2020 and 2021, the Covid years. This is explained by a sharp drop in mean preoperative vision among subsidized and paying patients in both years (Fig. 1E), which is likely because patients with better vision postponed cataract surgery.[21] Fig. 1E shows that paying patients had the best preoperative vision on average ($p < 0.001$), followed by subsidized and outreach patients respectively, likely reflecting socio-economic differences in these patient groups. Fig. 1B shows that the percentage of operated eyes that were blind or severely vision impaired (UCVA<6/60) declined from 57.7% to 50.5% ($p = 0.14$), a linear rate of decline of 0.28% per year. Further, the percentage of operated eyes that were vision impaired (UCVA < 6/12) also declined from 94.8% to 93.1% ($p = 0.07$), a linear rate of decline of 0.14% per year.

Fig. 1C shows that the improving trend in preoperative vision based on mean UCVA in logMAR units ($p < 0.001$) was very similar in both female and male subgroups and resembled the trend in the overall sample seen in Fig. 1A. However, female patients had worse mean preoperative vision than male patients ($p < 0.01$), and the sex-gap was largely unchanged throughout the period. Fig. 1D shows the mean preoperative UCVA in

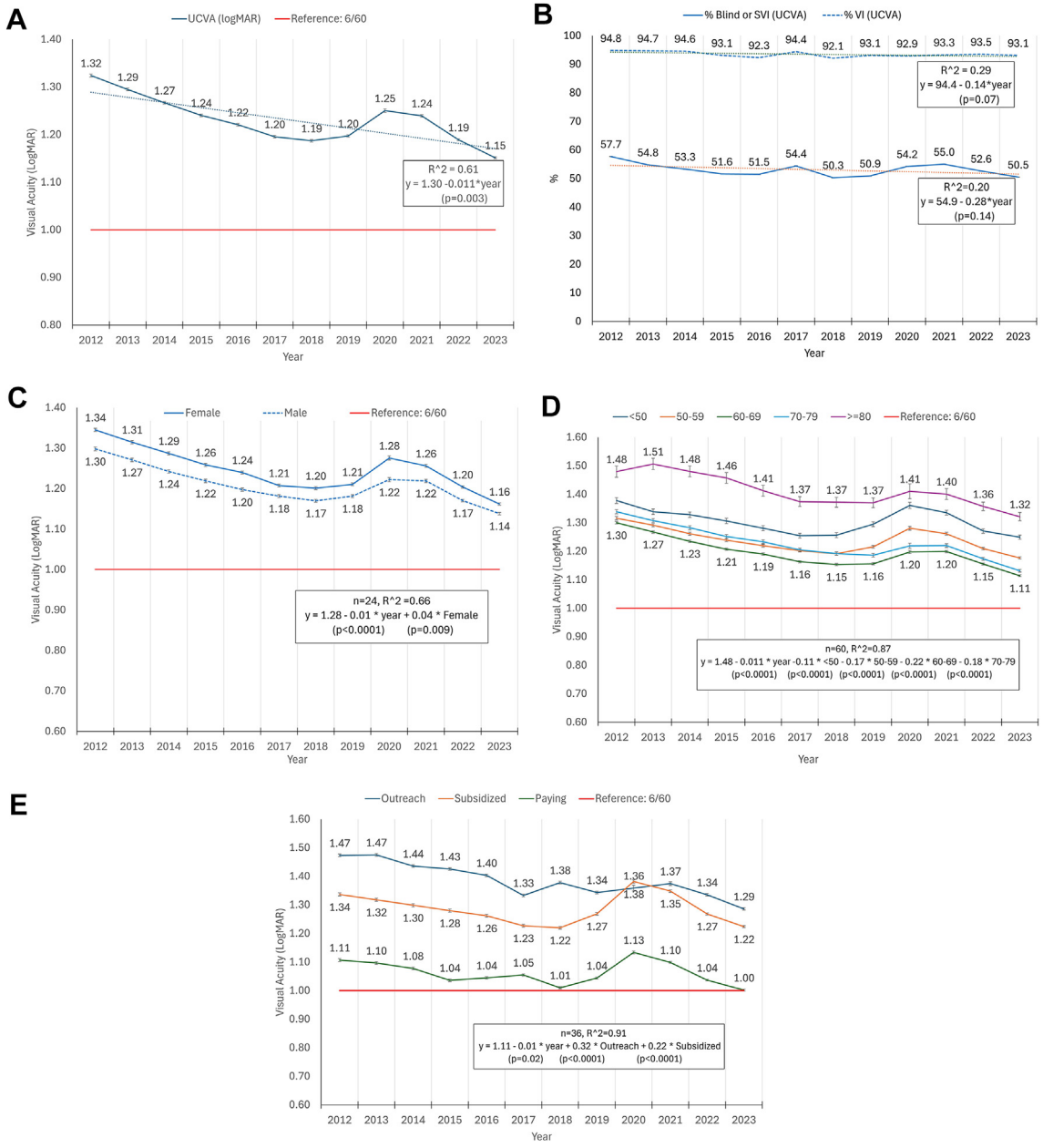


***Fig. 1:*** A: Preoperative mean uncorrected visual acuity (LogMAR) in operated eyes. Error bars show 95% CI. Dotted line is a linear trendline based on the regression equation shown. B: Percentage of operated eyes that are blind or severely vision impaired (<6/60) or vision impaired (<6/12) based on preoperative uncorrected visual acuity. Error bars show 95% CI. Dotted lines are linear trendlines based on the regression equations shown. C: Preoperative mean uncorrected visual acuity (LogMAR) in operated eyes by patient sex. Error bars show 95% CI. Box shows results of multivariable regression with year and group dummy variables as predictors. D: Preoperative mean uncorrected visual acuity (LogMAR) in operated eyes by patient age categories. error bars show 95% CI. Box shows results of multivariable regression with year and group dummy variables as predictors. E: Preoperative uncorrected mean visual acuity (LogMAR) in operated eyes by patient type. Error bars show 95% CI. Box shows results of multivariable regression with year and group dummy variables as predictors. Abbreviations: UCVA—Uncorrected Visual Acuity.

logMAR units for patients in five age categories. Patients in the ≥ 80-year age category had the worst mean vision, as expected. However, the group with the second-worst mean vision was <50 years old. The 60–69-year-old group had the best mean vision. The mean vision of each of the five age-groups was poorer than 6/60.

### Trends in postoperative vision

In Fig. 2 we show trends in postoperative vision. Fig. 2A shows a steady improvement ($p < 0.001$) in mean UCVA from 0.42 logMAR units (Snellen fraction ≈ 6/15) in 2012 to 0.29 logMAR units (Snellen fraction ≈ 6/12) in 2023, a linear rate of change of 0.012 logMAR units per year. There was rapid improvement in visual outcomes from 2012 to 2016, followed by four years of plateauing, with another marked growth in 2020. Mean BCVA measured in logMAR units also improved ($p = 0.03$), but the change was modest: 0.002 logMAR units per year. Fig. 2C shows that PE outcomes were better than MSICS outcomes in both UCVA ($p < 0.001$) and BCVA ($p < 0.001$) throughout. Notably, the UCVA gap between PE and MSICS shrank from 0.27 logMAR units (0.50 minus 0.23) in 2012 to 0.18 logMAR units (0.36 minus 0.18) in 2023 because of larger improvements in MSICS outcomes than in PE. The improvement in both MSICS and PE, combined with 65% of all surgeries being MSICS during this period, contributed to the overall improvement in mean UCVA seen in Fig. 2A. Fig. 2B shows that the percentage of operated eyes whose postoperative outcomes crossed the VI threshold of 6/12 grew steadily ($p < 0.001$ for UCVA and $p = 0.002$ for BCVA). In 2023, 69.9% and 93.4% of operated eyes achieved vision better than 6/12 based on UCVA and BCVA respectively.

### Trends in prices of cataract Surgery, Third party coverage, and sex gap

To analyze prices of cataract surgery, we consider only surgeries on paying patients since outreach patients are treated free and subsidized patients are charged a low fixed amount (currently and for several years INR1,000 or US$12), which is a fraction of the real cost. Fig. 3a shows that the mean fee paid by paying patients for surgery increased during the 2012–2023 ($p < 0.001$) period at a linear rate of about INR900 per year, which is slightly higher than the rate of increase in the Consumer Price Index for health. The rate of increase in

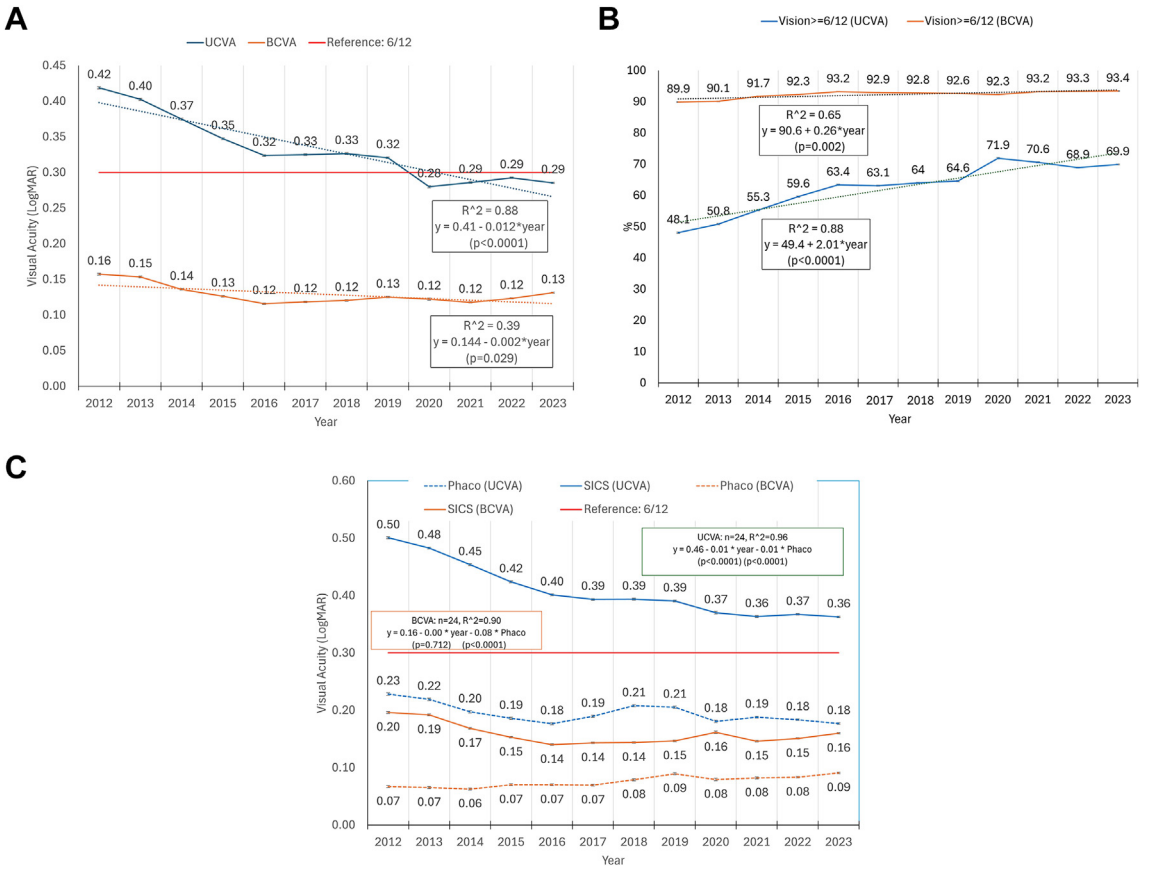


*Fig. 2:* A: Postoperative mean visual acuity (LogMAR) in operated eyes. Error bars show 95% CI. Dotted lines are linear trendlines based on the regression equations shown. B: Percentage of operated eye with postoperative vision ≥6/12. Error bars show 95% CI. Dotted lines are linear trendlines based on the regression equations shown. C: Postoperative mean visual acuity (LogMAR) in operated eyes by surgery type. Error bars show 95% CI. Boxes shows results of multivariable regressions with year and group dummy variables as predictors. Abbreviations: UCVA—Uncorrected Visual Acuity, BCVA—Best Corrected Visual Acuity.

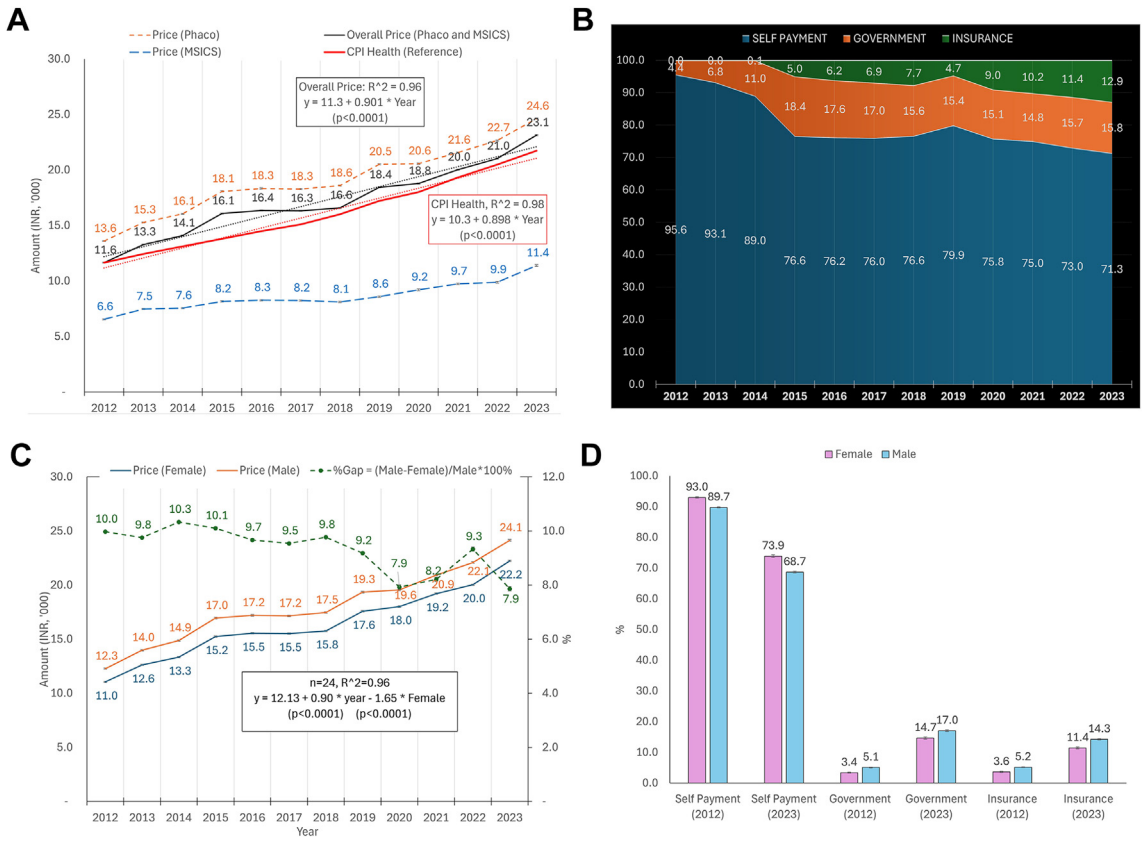


*Fig. 3:* A: Mean price of cataract surgery (INR: Indian Rupees) by surgery type for paying patients. Error bars show 95% CI. Dotted lines are linear trendlines based on the regression equations shown. B: Percentage of surgeries on paying patients by payment source. C: Mean price of cataract surgery (INR: Indian Rupees) for Paying patients by patient sex, and percentage gap between male and female patients (right vertical axis). Error bars show 95% CI. Box shows results of multivariable regression with year and group dummy variables as predictors. D: Percentage of surgeries on female and male paying patients by payment source, in 2012 and 2023. Error bars show 95% CI. Abbreviations: MSICS—Manual Small Incision Cataract Surgery, Phaco—Phacoemulsification. Note: For the CPI Health (Reference) line, monthly data for Consumer Price Index (CPI) Health were obtained from Ministry of Statistics and Programme Implementation, Government of India, 2012 = 100, averaged across months to convert to annual data, and applied to the overall cost of cataract surgery at Aravind.

prices of PE surgeries, which constituted 82.4% of surgeries on paying patients, was higher than on MSICS surgeries. As a result, the gap between the prices of the two types of surgeries grew over time. In 2023, the average price of a PE surgery was 116% more than an MSICS, largely because of the type of IOL that was implanted.

In Fig. 3B we examine trends in the share of surgeries in which third parties—government and insurance—contributed and therefore reduced the patient's self-payment. The share of surgeries in which paying patients paid entirely out-of-pocket (self-payment) dropped from 95.6% in 2012 to 71.3% in 2023 ($p < 0.001$ for linear trend). The share of surgeries in which insurance contributed grew almost steadily to 12.9% in 2023 ($p < 0.001$ for linear trend). While the number of surgeries that were supported by the government grew almost steadily (with an exception in 2020 due to Covid) during this period, the share of government-supported surgeries grew from 4.4% in 2012 to 18.4% in 2015 and then shrank to 15.8% in 2023, because of slower growth in such surgeries relative to the total number of paying surgeries. Notably, in 2023 the mean preoperative UCVA in logMAR units of paying patients was 0.84 (95% CI 0.83–0.84; Snellen fraction ≈ 6/40) for insurance-supported, 0.92 (95% CI 0.91 to 0.93; Snellen fraction ≈ 6/50) for government-supported, and 1.15 (95% CI 1.15–1.16; Snellen fraction ≈ 6/85) for self-supported surgeries. Further, the mean price paid by paying patients who paid entirely out of pocket (i.e., were not insurance- or government-supported) also rose steadily during this period, but at a linear rate of INR700 per year. This was lower than the increase for all paying patients, and also lower than the increase in the Consumer Price Index for health. Detailed data are not shown for reasons of space.

In Fig. 3C we show trends in the average price of a cataract surgery on female versus male paying patients, and the sex gap as a percentage of the male price. Prices of surgeries on male patients were about 10% higher than on female patients in 2012 ($p < 0.0001$), and the gap persisted till 2023 but showed a slight declining trend. Fig. 3D shows that more female surgeries (93.0%) than male surgeries (89.7%) were self-paid in 2012, and while both percentages declined in 2023, the gap grew from 3.3% to 5.2% in 2023 (73.9% versus 68.7%, $p < 0.05$).

## Discussion

Our analysis of 3.6 M cataract surgeries performed at Aravind eye hospitals during 2012–23 revealed important trends in demographic characteristics and eye-care seeking behaviors of patients, surgical techniques and outcomes, and prices of cataract surgery. Throughout the period of our data the mean age of female patients was two years younger than male patients (Table 1), the median age was three years younger, and the mean preoperative vision of female patients was poorer than male patients (Fig. 1C). Thus, even though female patients presented for surgery at a younger age than male patients, suggesting possible earlier onset, their vision at presentation was worse. The poorer vision at presentation may be explained in part by previous studies that females have higher rates of incidence and prevalence of cataract in India,[22,23] and lower uptake of eyecare services.[16,24] There is also a sex-gap in cataract surgical coverage in many low- and middle-income countries, including India, that disfavors female patients.[25] Patients under 50 showed worse vision for cataract surgery compared to older groups (Fig. 1D). Possible reasons include postponing surgery due to work or life commitments, fear of early operation, lack of awareness about correctability, and unilateral or disproportionate cataracts. Young patients may have cataracts due to trauma or uveitis, unlike older patients.

The persistent improving trend in preoperative vision for all patient groups (Fig. 1A–E) indicates a reducing threshold of vision impairment by surgeons and patient need. As noted previously, a similar trend has been observed and reported in several developed countries in other studies, and in one study in India.[18] We also found a decreasing proportion of patients with VI (UCVA < 6/12) and blindness and severe VI (UCVA < 6/60) in the operated eye. Decreasing proportions of surgeries with preoperative VI have been reported to be strongly related to higher levels of development at the country level and to higher cataract surgery rates (CSRs).[26] Reasons for increased demand from patients at lower impairment thresholds may include greater confidence of having good outcomes from surgery, which in turn leads to better quality of life,[12] and the growing proportion of government- and insurance-supported surgeries.

Recent literature has extensively covered postoperative outcomes in LMICs,[27] yet temporal trends remain unexplored. Contributing new findings to this literature, we found that postoperative outcomes steadily improved during this period.

Notably, from 2020 to 2023, mean postoperative UCVA surpassed the 6/12 VI threshold for the first time, with nearly 70.0% of surgeries achieving this level in 2023 (Fig. 2A). Additionally, 93.4% of surgeries reached this level based on best corrected vision (Fig. 2B). At Aravind hospitals, patients are prescribed spectacles at the four-week follow up visit post-surgery. Outreach patients are provided reading or distance correction spectacles free. Internally tracked compliance data show that across outreach, subsidized and paying patients, 85%–90% of those prescribed spectacles either buy them or get them free.

While PE outcomes consistently outperformed MSICS, the improvement over time was more significant for MSICS, reducing the quality gap between the two techniques (Fig. 2C). Given MSICS's cost-effectiveness[28,29] and its predominance in surgeries in LMICs, this trend is crucial. Factors contributing to these improved outcomes include advancements in IOL technology and techniques for determining IOL power. Between 2013 and 2018, for IOL power calculations for subsidized and outreach patients, all Aravind hospitals switched from applanation ultrasound biometry to immersion ultrasound biometry. This improvement in technology resulted in reduced prediction errors between target refraction and postoperative refraction achieved for MSICS, and a consequent increase in the proportion of patients achieving good postoperative vision outcomes.[30] Since optical biometry had been used for paying patients (most of whom receive phacoemulsification) since 2010, such an improvement was not observed for PE surgeries.

At Aravind eye hospitals about 40% of surgeries during 2012–2023 were performed on paying patients, and this proportion showed an increasing trend (Table 1). The overall average price of cataract surgery for these patients increased at a slightly higher rate than the Consumer Price Index (CPI) for Health for India (Fig. 3A). However, average spending by paying patients without access to insurance or government support rose more slowly. In a context in which individuals tend to largely pay out-of-pocket for healthcare, we see an increasing fraction of surgeries that are supported with government assistance or insurance. We interpret these trends as indicative of increasing willingness-to-pay for cataract surgery and patients choosing more expensive intraocular lens options, especially the growing proportion who are not dependent solely on self-payment.

We found a persistent sex gap in spending per cataract surgery of about 8–10% lower spending on female relative to male patients, with a small decline in the gap over time. To our knowledge this finding has

not been reported previously in the context of cataract surgery, although it is consistent with previous literature that in India health care expenditures per capita for adult females are lower than adult males, regardless of type of disease and for all socio-economic groups.[31] Since at Aravind all paying patients are offered the same price regardless of sex, we believe this price difference is largely due to differences in male versus female patients' choices of IOLs. This finding is consistent with the prioritization of men's health more than women's health in many settings.[31,32]

Our study is not without limitations. First, to ensure representativeness, the temporal trends related to utilization we have measured are best ascertained from comprehensive provider data. However, getting complete data over time from all providers is not feasible without mandated reporting being already in place. Second, the occurrence of the Covid-19 pandemic during 2020–2022 clouded the interpretation of long-term trends. Nevertheless, since we had several years of pre-pandemic data and at least one year of post-pandemic data, persistent trends were still detectable. Finally, we note that though the hospitals in our sample contribute to significant volume of cataract surgery in the region we study, findings of trends based on our data may not be readily generalizable to other regions. An important strength of our study is the use of standardized data collection and recording procedures across all hospitals over twelve years. Further, the availability of very large sample sizes each year allowed us to obtain precise estimates at both the overall and sub-group levels.

## Conclusion

In conclusion, our study has provided evidence of consequential and systematic changes over the last dozen years in the uptake, outcomes, and economics of cataract surgery in a large regional patient population in India. Overall, these trends paint a picture of patients who seek treatment sooner, receive better outcomes from surgery, and are willing to pay more for the improving benefits. At the same time, there are continuing inequities faced by female patients in both presentation for treatment with worse vision than male patients, and in receiving lower expenditures for surgery. This indicates the need for targeted approaches to address sex inequities, both on the demand generation and treatment provision sides, in line with the WHO's recommendation that countries should place focus on improving access and affordability of eyecare in traditionally underserved populations.[33]

**Contributors**

TDR and SG designed this study. TDR, RDR and SG collected and managed the data. SG analyzed the data. SG, TDR, RDR, HA, and SC prepared the manuscript and conducted revisions for important intellectual content. All authors read the final manuscript and approved submission.

**Data sharing statement**

Data from this study, including de-identified individual participant data and data dictionaries, will be shared by authors upon request to researchers who provide a methodologically sound proposal. Proposals should be directed to the corresponding author; to access the data, researchers will need to sign a data-access agreement. Statistical analysis plans might also be requested.

**Declaration of interests**

We declare no competing interests.

**Acknowledgements**

None.

**References**

1 Bourne R, Steinmetz JD, Flaxman S, et al. Trends in prevalence of blindness and distance and near vision impairment over 30 years: an analysis for the Global Burden of Disease Study. *Lancet Glob Health*. 2021;9:e130–e143.
2 Anon. Global eye care targets endorsed by member states at the 74th world health assembly. Available at: https://www.who.int/news/item/27-05-2021-global-eye-care-targets-endorsed-by-member-states-at-the-74th-world-health-assembly. Accessed May 13, 2024.
3 Keel S, Müller A, Block S, et al. Keeping an eye on eye care: monitoring progress towards effective coverage. *Lancet Glob Health*. 2021;9:e1460–e1464.
4 Ramke J, Gilbert CE, Lee AC, et al. Effective cataract surgical coverage: an indicator for measuring quality-of-care in the context of Universal Health Coverage. *PLoS One*. 2017;12:1–13.
5 Taylor HR, Vu HTV, Keeffe JE. Visual acuity thresholds for cataract surgery and the changing Australian population. *Arch Ophthalmol*. 2006;124:1750–1753.
6 Kessel L, Haargaard B, Boberg-Ans G, Henning V. Time trends in indication for cataract surgery. *J Clin Exp Ophthalmol*. 2011;2:7. Available at: https://www.omicsonline.org/time-trends-in-indication-for-cataract-surgery-2155-9570.1000174.php?aid=1547. Accessed April 4, 2024.
7 Keenan T, Rosen P, Yeates D, Goldacre M. Time trends and geographical variation in cataract surgery rates in England: study of surgical workload. *Br J Ophthalmol*. 2007;91:901–904.
8 Lundström M, Goh P-P, Henry Y, et al. The changing pattern of cataract surgery indications: a 5-year study of 2 cataract surgery databases. *Ophthalmology*. 2015;122:31–38.
9 Lundström M, Stenevi U, Thorburn W. The Swedish national cataract register: a 9-year review. *Acta Ophthalmol Scand*. 2002;80:248–257.
10 Gollogly HE, Hodge DO, St Sauver JL, Erie JC. Increasing incidence of cataract surgery: population-based study. *J Cataract Refract Surg*. 2013;39:1383–1389.
11 Foster A. A simple method for evaluating surgical cataract services in prevention of blindness programmes. *Community Eye Health*. 1992;10:2–5.
12 Erie JC. Rising cataract surgery rates: demand and supply. *Ophthalmology*. 2014;121:2–4.
13 Marques AP, Ramke J, Cairns J, et al. The economics of vision impairment and its leading causes: a systematic review. *EClinicalMedicine*. 2022;46:101354.
14 Desai N, Copeland RA. Socioeconomic disparities in cataract surgery. *Curr Opin Ophthalmol*. 2013;24:74–78.
15 Abou-Gareeb I, Lewallen S, Bassett K, Courtright P. Gender and blindness: a meta-analysis of population-based prevalence surveys. *Ophthalmic Epidemiol*. 2001;8:39–56.
16 Mailu EW, Virendrakumar B, Bechange S, et al. Factors associated with the uptake of cataract surgery and interventions to improve uptake in low- and middle-income countries: a systematic review. *PLoS One*. 2020;15:e0235699.
17 Radhakrishnan M, Venkatesh R, Valaguru V, Frick KD. Economic and social factors that influence households not willing to undergo cataract surgery. *Indian J Ophthalmol*. 2015;63:594–599.
18 Ravindran RD, Gupta S, Haripriya A, et al. Seven-year trends in cataract surgery indications and quality of outcomes at Aravind Eye Hospitals, India. *Eye*. 2021;35:1895–1903.
19 Holladay JT. Proper method for calculating average visual acuity. *J Refract Surg*. 1997;13:388–391. Thorofare NJ 1995.

20 Fletcher AE, Ellwein LB, Selvaraj S, et al. Measurements of vision function and quality of life in patients with cataracts in southern India. Report of instrument development. *Arch Ophthalmol*. 1997;115:767–774. Chic Ill 1960.
21 Muralikrishnan J, Christy JS, Srinivasan K, et al. Access to eye care during the COVID-19 pandemic, India. *Bull World Health Organ*. 2022;100:135–143.
22 Vashist P, Talwar B, Gogoi M, et al. Prevalence of cataract in an older population in India. *Ophthalmology*. 2011;118:272–278.e2.
23 Gupta S, Vardhan A, Ambalam V, et al. Cataract surgery workload estimates in Theni district, India. *Br J Ophthalmol*. 2024;108:915–920.
24 Joseph S, Ravilla T, Bassett K. Gender issues in a cataract surgical population in South India. *Ophthalmic Epidemiol*. 2013;20:96–101.
25 Gupta S, Ravindran RD, Vardhan A, Ravilla TD. Evaluation and model to achieve sex parity in cataract surgical coverage in Theni district, India. *Br J Ophthalmol*. 2024;108:1514–1520.
26 Shah SP, Gilbert CE, Razavi H, et al. Preoperative visual acuity among cataract surgery patients and countries' state of development: a global study. *Bull World Health Organ*. 2011;89:749–756.
27 Han X, Zhang J, Liu Z, et al. Real-world visual outcomes of cataract surgery based on population-based studies: a systematic review. *Br J Ophthalmol*. 2023;107:1056–1065.
28 Gogate P, Deshpande M, Nirmalan PK. Why do phacoemulsification? Manual small-incision cataract surgery is almost as effective, but less expensive. *Ophthalmology*. 2007;114:965–968.
29 Venkatesh R, Tan CSH, Sengupta S, et al. Phacoemulsification versus manual small-incision cataract surgery for white cataract. *J Cataract Refract Surg*. 2010;36:1849–1854.
30 Shivkumar C, Aravind H, Ravilla RD. Using a quality improvement process to improve cataract outcomes. *Community Eye Health J*. 2022;35:12–13.
31 Moradhvaj Saikia N. Gender disparities in health care expenditures and financing strategies (HCFS) for inpatient care in India. *SSM Popul Health*. 2019;9:100372.
32 Geneau R, Lewallen S, Bronsard A, et al. The social and family dynamics behind the uptake of cataract surgery: findings from Kilimanjaro region, Tanzania. *Br J Ophthalmol*. 2005;89:1399–1402.
33 Anon. Report of the 2030 targets on effective coverage of eye care. Available at: https://www.who.int/publications-detail-redirect/9789240058002. Accessed September 25, 2023.