Ophthalmology Care in Ethiopia: a Health Economic Evaluation

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Foreword

Ethiopia is a low-income country with an estimated population of 115 million, were 84% live in rural areas. The annual economic growth was 6.1% in 2020 and total health expenditure per capita was $26.74. Eye health care is an important component of the sustainable development goal target 3.8- to achieve universal health coverage (UHC). This includes financial risk protection, access to quality essential health care services, safe, effective, affordable essential medicines, and vaccines for all. Ethiopia has adapted the global plan “VISION 2020 the Right to Sight” to eliminate avoidable blindness, which was established by the World Health Organization (WHO) to achieve universal eye health care by 2020. However, the current extreme scarcity of eye care practitioners suggests that Ethiopia will not achieve this target [1].

Vision impairment reduces quality of life and has wide impact on the welfare of affected households. The prevalence of untreated vision impairment in Ethiopia is high, where 1.8 million individuals are estimated to be blind and 4.1 million with poor vision. Cataract is a major cause for both blindness and poor vision, where uncorrected refractive error is a major contributor to poor vision. There are highly effective interventions like cataract surgery, laser photocoagulation of retinopathy, surgery of trachomatous trichiasis, and glasses for refractive errors. However, coverage of these services is very low in many low- and low-middle-income countries. In Ethiopia, the coverage of: (1) cataract surgery was around 50% with less than 500 operations per million population per year; (2) surgery of trachomatous trichiasis 41%; (3) diabetic retinopathy screening and photocoagulation 10%; and (4) spectacles or refractive error 28% (Source: data from latest revision of Ethiopian Health Service Package (2019), One health Tool (OHT)). Access to vision improvement services is far behind the planned targets in VISION 2020.

The evidence presented in this thesis could inform policy and identify best buy vision improvement services, which could contribute to an increased focus on eye health and improve the health and productivity of the Ethiopian population by expanding such services.

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Objective and rationale of this study

The objective of this study is to conduct a cost-effectiveness analysis of essential eye health interventions in Ethiopia. To my knowledge, this is the first economic evaluation of eye health in Ethiopia and one of few comprehensive cost-effectiveness analyses on eye health conducted in any LMIC setting. The results will play a key role regarding priority setting, planning and decision making. Evidence on best-buy ophthalmology services is extremely important in resource constrained settings due to the high opportunity cost and a very long list of competing essential health care interventions.

In this mantle I will focus on providing a more extensive background and literature review than is possible in the paper. Standard methodology for cost-effectiveness analysis is used in this thesis. A thorough description of the methods is provided in the paper of this thesis.

Background

Being blind or having severe vision impairment is catastrophic. Vision impairment causes severe loss in quality of life and even affects the welfare of households. Few services are available, and societies in Sub-Saharan Africa seem poorly prepared to tackle such disabilities. Interventions targeting vision impairment has until now been neglected in global health. Cataract, glaucoma, uncorrected refractive error, age-related macular degeneration, trachoma, and diabetic retinopathy are the most common causes of vision impairment globally [5]. Other causes of vision impairment include accidents, trauma and burns, complications of surgery, birth defects, uveitis, and retinal break [6, 7]. Vision impairment can affect all age groups, but it is more frequent in adult and productive populations older than 50 years of age [4] [8].

Around 90% of individuals with vision impairment live in low- and low-middle-income countries (LMICs) (see Figure 1) [12]. The highest overall prevalence of vision impairment is in South Asia (22%) and Sub-Saharan Africa (18%) [12] [3]. For adults, the most common causes of vision impairment are cataract in LMICs; diabetic retinopathy in middle-income countries; and diabetic retinopathy, glaucoma, and age-related macular degeneration in high-income countries. For children, uncorrected refractive error is the main cause of vision impairment across all countries. Congenital cataract is a common cause for child vision impairment in LMICs and retinopathy due to prematurity is more common in MICs [4] [8].

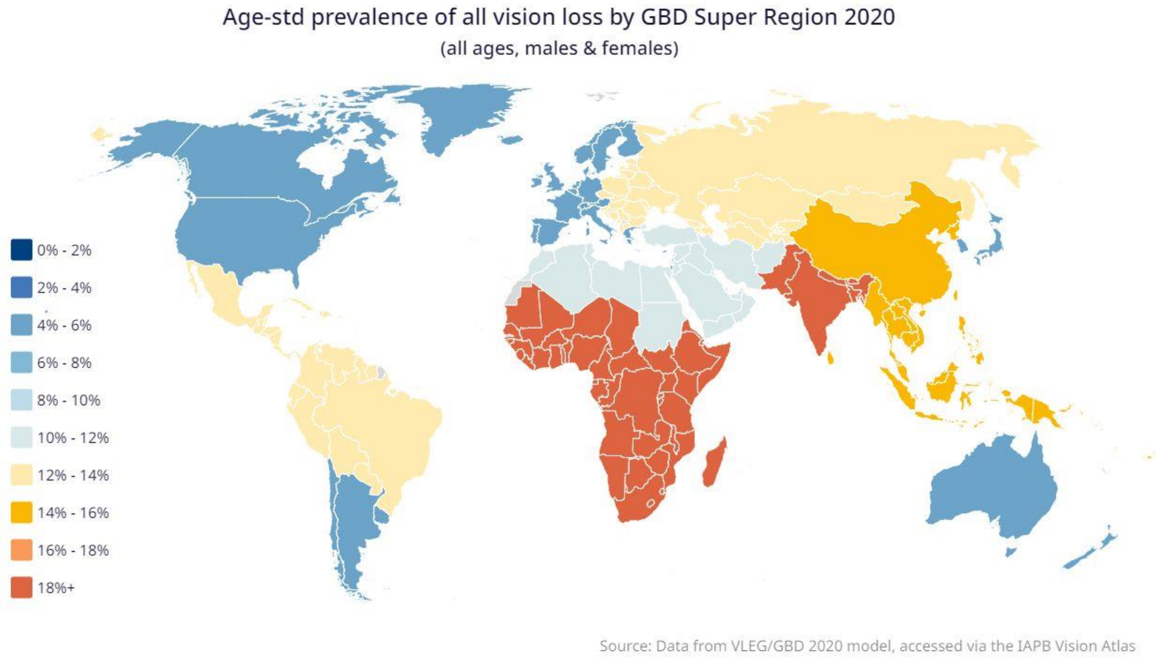

Figure 1: Age-standardized prevalence of all vision loss in 2020 (all age, males, and females).

Vision impairment describes any kind of vision loss, including blindness (see Table 1 for a more detailed classification of vision impairment). Ophthalmology is specialized health care that deals with diagnosis, treatment, and prevention of eye diseases [2]. In Sub-Saharan Africa, cataract, trachoma, uncorrected refractive errors, childhood blindness, glaucoma, corneal opacities, and onchocerciasis are common causes of visual impairments [3]. In Ethiopia, the most common cause of visual impairments are cataract, uncorrected refractive errors, trachomatous corneal opacities, and diabetic retinopathy [9] [10, 11].

Ageing, gender, inaccessibility of eye services and socio-economic status are important drivers of the burden of vision impairment in Sub-Saharan Africa [12]. Women are more affected than men for all causes of visual impairment [12]. Higher level of poverty, more responsibility in the household and cultural issues are some of the factors limiting access to eye care of women [12]. Additionally, women have an increased lifetime risk of developing some eye conditions due to higher life expectancy as compared to men. Smoking cessation, physical activity, ultraviolet light exposure optimal nutrition, ophthalmology care (e.g., timely laser photocoagulation, screening, surgery), and provision of glasses with affordable price are some of the most cost-effective interventions to reduce the burden of eye health problems [4] [12-16]. However, effective coverage of such eye care is poor in LMICs.

Type of disease	Classifications
Near vision impairment	Near visual acuity $< N6$ or < M.08 at $40cm$
Normal eyesight	Visual acuity $6/6$
Mild vision impairment	Distance visual acuity 6/12 to 6/18
Moderate vision impairment	Distance visual acuity 6/18 to 6/60
Severe vision impairment	Distance visual acuity 6/60 to 3/60
Blindness	Distance visual acuity $< 3/60$ or $< 10^0$around central fixation

Table 1: International classifications of visual impairment (sources [3],[4]). The above information indicates the distance that the patient can see the Snellen chart or figures as compared to the average population. For example, <6/18 means that the patient can see at 6 meter what people normally can see at 18 meter. And $< N6$ or $< M.08$ at $40cm$ is the occurrence of $\geq 6/12$ best-corrected or worse in both eyes distance acuity.

Ophthalmology care in Ethiopia and Globally

Blindness or vision impairment is highly prevalent globally. The number of people with blindness increased from 36 million people in 2015 to 43.3 million in 2020 [12, 15]. Around 2.2 billion individuals suffered from vision impairment in 2020 globally [17]. Cataract is the most common cause of blindness globally, and 13.5 million suffered from cataract in 2020 and it increased by 1.5 million between 2015 to 2020 [15, 16]. Glaucoma is the second most prevalent cause with 3.6 million cases in 2020, followed by 2.3 million with uncorrected refractive error, 1.8 million with age-related macular degeneration, and 0.9 million with diabetic retinopathy [15, 16].

Globally, around 160 million people do not receive glasses for uncorrected refractive error and cataract surgery per year [16]. About 19 million do not have access to management of glaucoma, diabetic retinopathy, and age-related macular degeneration which causes blindness and visual impairment among people aged 50 and older, can be easily treated or prevented [16].

The burden of vision impairment accounted for 342 DALYs per 100 000 population in LMICs, of which 124 are due to cataract, 98 are due to refractive errors, and 3 are due to trachoma [18]. In 2019, Vision impairment caused about 404 DALYs per 100 000 population in South Asia and 171 DALYs per 100 000 population in Sub-Saharan Africa [18]. Cataract was responsible for around 507 000 DALYs, trachoma 75 000 DALYs and refractive errors 410 000 DALYs in Sub-Saharan Africa [18]. In Sub-Saharan Africa, the prevalence of blindness increased from

4.3 million to 4.7 million in between 2015 to 2020, whereas the vision impairment increased from 17.4 million to 19.7 million [3].

Both the crude and age-standardized prevalence of blindness among both genders aged 50 years and above were slightly higher in Ethiopia when compared to other African countries [3]. However, the vision impairment was lower in Ethiopia compared to Eritrea among both genders [3].

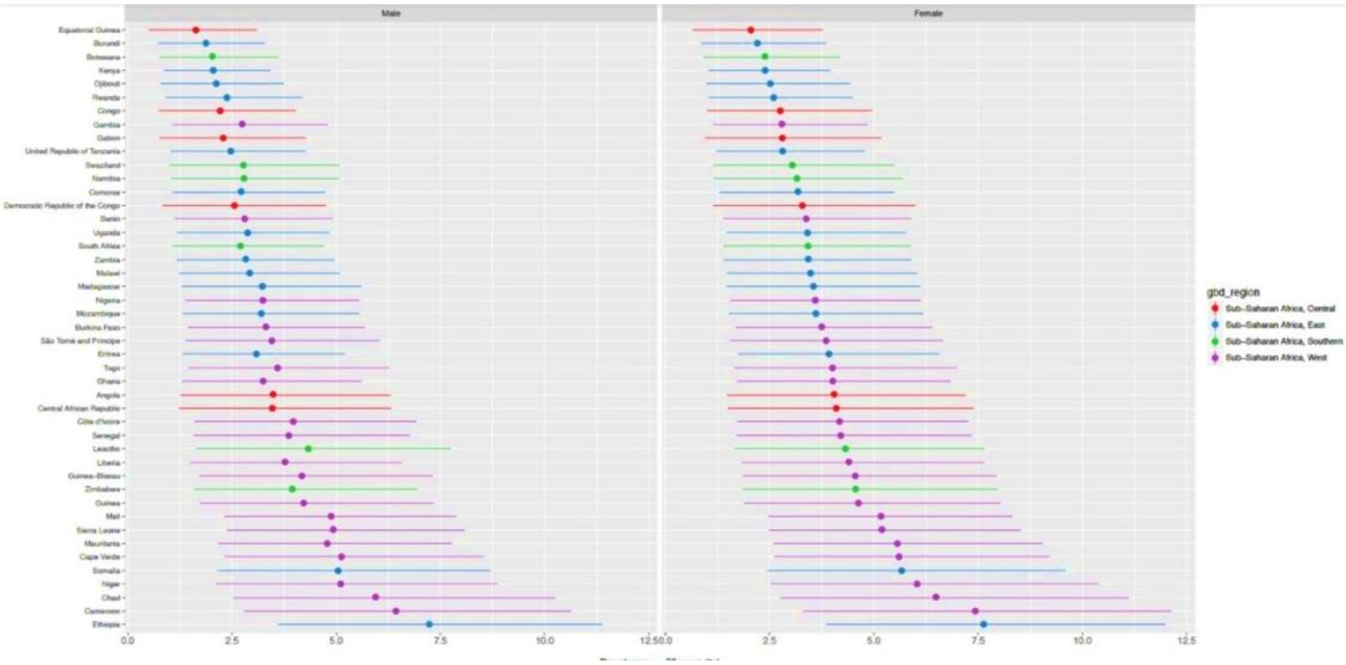

Figure 2: Age-standardized prevalence of blindness among both genders aged 50 years and older in 2015 in Sub-Saharan African countries (source:[19]).

The conducted national survey on prevalence of vision impairment in Ethiopia indicated that 1.6% of Ethiopian population suffered from blindness and 3.7% with low vision [9, 10]. The prevalence is higher among the rural populations with both blindness (1.6% rural, 1.1% urban) and low vision (3.8% rural and 2.6% urban) [10]. The geographical setting is one of the main barriers to universal health coverage of eye care in Ethiopia. Around 84% of the population in Ethiopia live in rural or hard to reach areas [20]. Furthermore, poverty or inability to pay for eye services and shortage of trained eye care specialists are key limiting factors [4]. Childhood blindness caused around 6% of the total blindness burden in Ethiopia [21] [22, 23]. See Figure 3 for an overview of blindness causes in Ethiopia. Interestingly, 90% of the causes of blindness can be prevented or treated in Ethiopia [24].

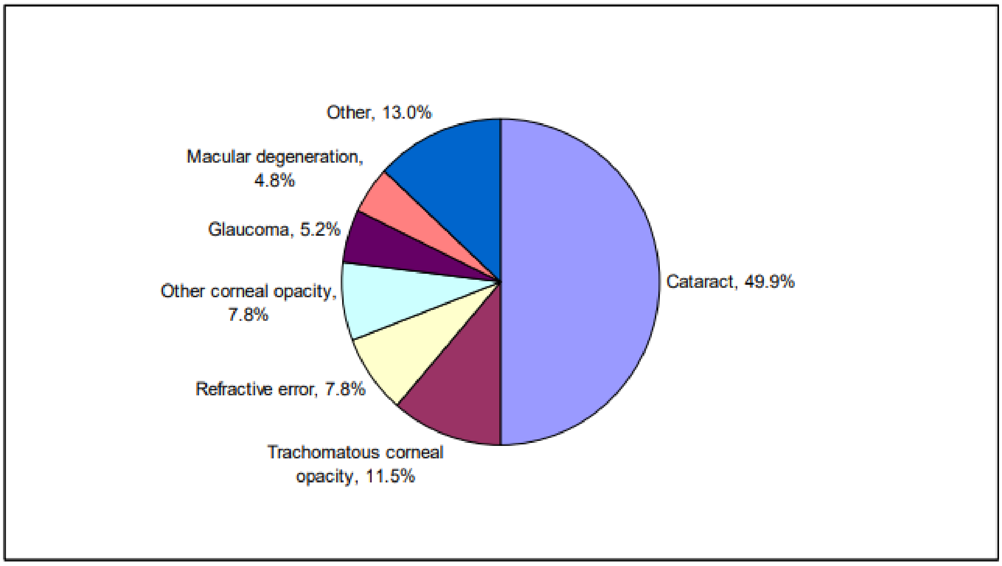

Figure 3: Causes of blindness in Ethiopia: National survey on blindness and low vision: (source:[9, 11]).

Economic impact of ophthalmology care

Blindness or vision impairment has a significant impact on quality of life of individuals and productivity loss. Poor vision increase the chances of social isolation and financial dependency, and narrows job opportunities [26].Around 161 million people among the working age groups between 15-64 years were affected by vision impairment in 2020, out of these about 18 million individuals were blind and 143 million had impaired vision in 2020 [25]. The global annual

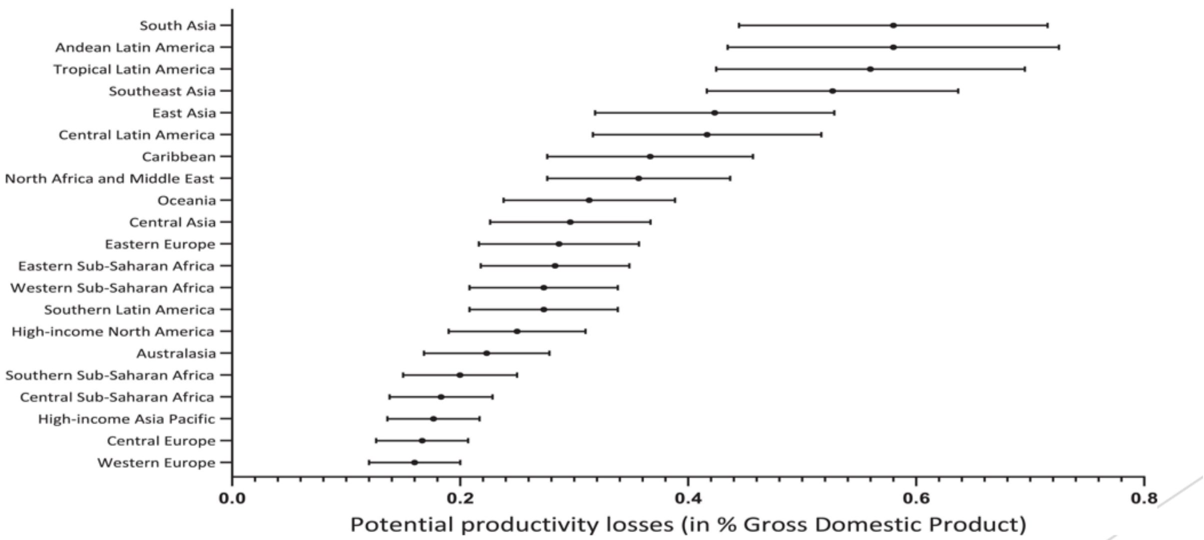

Figure 4: Productivity loss estimates using Gross Domestic Product due to blindness and vision impairment in the 21 Global Burden of Disease regions in 2018: (source:[25]).

cost of potential productivity losses due to vision impairment was estimated to be $410.7 billion (purchasing power parity adjusted) or 0.3% of the global GDP in 2018 [25] (see Figure 4 regional impact).

The global productivity losses due to trachomatous trichiasis in total is estimated to be $8 billion annually [27]. The average lifetime cost of lost productivity due to trachomatous trichiasis was estimated to be $89 per person in Gambia [28].
There is a lack of separate evidence on the economic impact of diabetic retinopathy and cataract either globally or LMICs. However, economic burden of diabetes mellitus in total was estimated to be $760 billion in 2019 globally [29]. In this estimate, the contribution of diabetic retinopathy was aggregated with the total economic impact of diabetes mellitus. In the United States of America, the performed cataract surgeries has been estimated to save $123.4 billion over 13 years with 36% improvement in quality of life [30]. People who had restored their eyesight by using cataract surgery had long term improvements in quality of life, economic related issues, and social happiness [31, 32]. After cataract surgery in Ghana, the average number of working hours or productivity of patients increased by 121%, and hours spent by caregivers on cataract patients declined by 62% in total [33].

The prevalence of blindness and vision impairment have been found to be higher among poor populations or socially disadvantageous groups as compared to wealthier groups. For instance, the prevalence of blindness was 0.3% among the richest population and 1% or more in the poorest population in Sub-Saharan Africa [22].

Ophthalmology care from Ethiopian health system perspective

Improving equity, efficiency and effectiveness is one of the strategic objectives on Ethiopia health care financing strategy to be achieved by 2025 [34]. Eye health interventions are the less prioritized compared to other interventions in Ethiopia. In the recently revised essential health service package (2019), 1018 interventions were considered high or medium priority. Only 240 of these were targeting non-communicable diseases and only 8 eye health interventions were included on, which is insufficient [35]. The eye care services in Ethiopia are delivered either in government facilities, private for profit or non-governmental organizations (NGOs) [36, 37] (see Figure 5). Lack of sufficient human resources, infrastructure, equipment, and supplies are the major barriers for scaling up of effective care of visual impairment [1, 3]. In Ethiopiqa (2919) there were 250 general surgeons, 300 optometrists and 100 ophthalmologists. This is on average less than one eye specialist per million population, where 48% of them are practicing in the capital city of the country Addis Ababa [37, 38]. Due to this, the eye services are often delivered by non-physicians, clinical officers, and nurses. Also, the waiting time for ophthalmologic surgery is up to four years [1, 38].

In Ethiopia, 47 public secondary eye units and four tertiary centers are currently available, which is insufficient to provide universal eye health care to all 115 million people in the country [39]. Additionally, out of thirty-three universities only five of them are conducting training for eye health workers, and only 224 optometrists will graduate by 2023 [20].

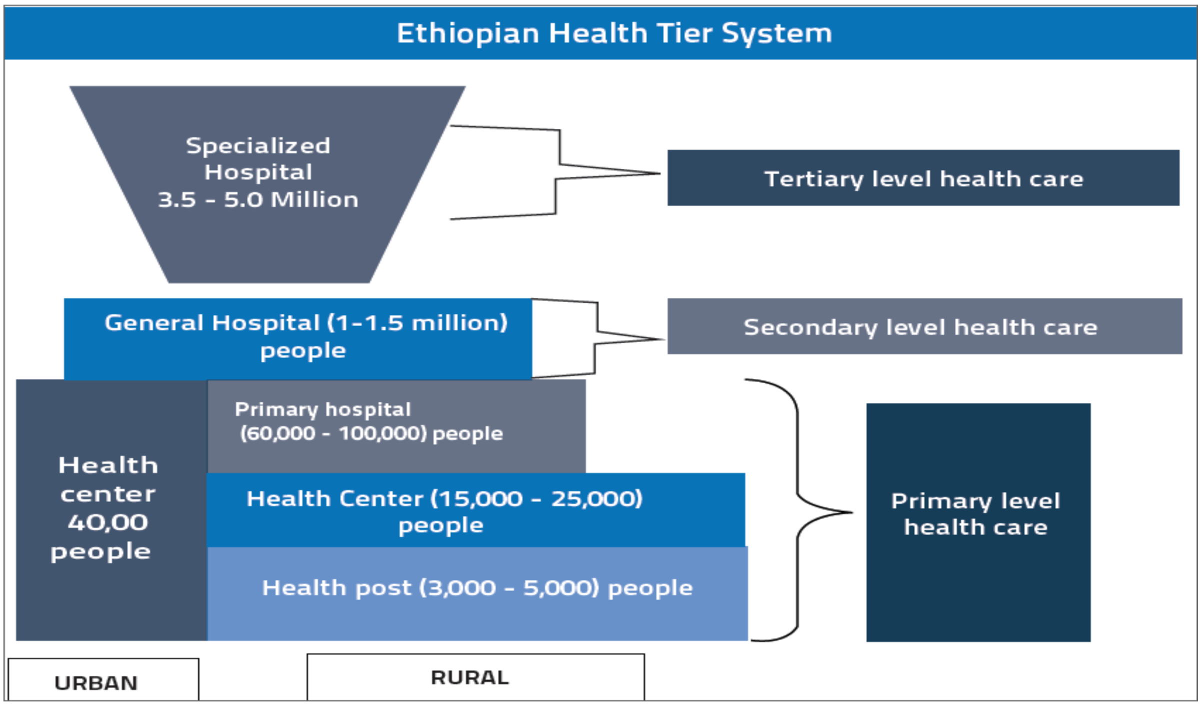

Figure 5: Ethiopian Health service delivery system: (source: [34]).

Cataract surgery, school-based vision screening, provision of glasses and surgery of trachomatous trichiasis are often provided by NGOs at a community level and outreach programs with affordable cost or free of charge [20, 37]. NGOs typically provide such ophthalmologic care due to failed government systems. However, the sustainability of such programs, after the termination of the NGOs, is fragile [20, 37]. For example, about 70% to 100% of cataract surgery were provided by the NGO in Southern region of Ethiopia in 2012 [36].

Cost-effectiveness analysis evidence of ophthalmology care

Laser photocoagulation, eye surgery, and provision of glasses all to some degree require advanced health care. Health economic evaluations provide important evidence when considering which interventions to prioritize within a health care system. A study conducted in South India estimated the cost of screening and laser photocoagulation of people with diabetic retinopathy to be between $394 and $578 [29]. In South Africa, retinopathy screening costs were estimated to be $22 and laser photocoagulation $144 per person [40].

Average cost per procedure of cataract surgery was estimated to be £31.55 in India, £399.34 in New Zealand and $183 in South Africa [40] [42]. One study found that the average willingness to pay (WTP) per cataract surgery in Africa ranges between $2.3 and $18.5 [43]. In Southern Ethiopia, the average cost of cataract surgery was estimated to be $142 (ranges $37.6 to $312.6), with an average WTP per surgery to be $18 ($10.9 - $28.8) [36, 43]. Costs that were included in this study were: consultation, investigations, intravitreal injections, medical equipment (i.e., laser, IOL), staff salaries, vitreoretinal surgeries, transportation, accommodation, rent, capital, recurrent, vehicles, total materials, maintenance, drug and supplies, patient food and other support [29] [36, 40].

The cost per surgery of trachomatous trichiasis in Gambia was estimated to be $6.1, where the average WTP per surgery was $1.4 [28]. The average WTP cost for refractive error services ranges in between $12 and $15, where about 70% of the respondents were not willing to pay for this service in the Mozambique market [44]. The average cost of glasses was $37 in Asia, $142 in Latin America, and $194 in Africa, with an average WTP per pair of glasses of $11.6 in Asia, $65.8 in Latin America and $99.9 in Africa [45]. In Africa the cost of glasses was very expensive in market value. Custom-made spectacles for children cost $6 per pair in Cambodia, and $25 in Ghana, $17.9 in Ethiopia [46, 47].

In Ghana, the average cost per child in school-based vision screening was estimated to be $1.8, and the cost of corrected refractive disorder was $238 per child. In Cambodia the corresponding numbers were $1.33 and $230 [46]. Providing training for the teachers costed in average $76 per participant per day in Cambodia, and $396 in Ghana [46]. In rural China, a study on vision screening among preschool children found that the cost per detected case by teachers was $37.5, whereas the cost was $59.1 for vision prescreening at the local optometrist and $52.2 when done by volunteers [48]. Studies from rural China and Malaysia concluded that vision screening by teachers was the most cost-effective when compared with screening by optometrist if the proper training was provided to the teachers; validity was high and costs were reduced [48, 49].

Table 2 summarizes cost-effectiveness studies on cataract surgery, surgery for trachomatous trichiasis, glasses for vision problems, vision prescreening by teachers and retinopathy screening and laser photocoagulation [50] [40] [29] [51] [41, 44] [52][28] [53] [54] [46]. All studies reported that all the interventions are cost-effective compared to the comparator interventions [50] [40] [29] [51] [41, 44] [52][28] [53] [54] [46]. For example, the incremental cost-effectiveness ratio (ICER) of retinopathy was $1 206 per blindness case averted in South Africa, which less than the threshold $1 393 [40]. The use of telemedicine screening would reduce the transportation and accommodation costs for patients in rural settings in low-income countries. Three systematic reviews shown that surgery for trachomatous trichiasis ICER between $13 to $998 per DALY averted, while cataract surgery had an ICER $90 to $370 per DALY averted in developing countries [28] [53] [52].

Type of intervention	**ICER ($^{IC}/_{IE}$)**	**Outcomes**	**Country**	**Year**	**Source**
Cataract surgery: - Cataract extraction and insertion of intraocular lens	$730 to $2 400	Cost per DALY averted	Developed countries	2007 and 2012	[52],[28].
	$245 to $22 000	Cost per QALY gained			
	$90 to $370	Cost per DALY averted	Developing countries		
	$9 to $1 600	Cost per QALY gained			
	£1 964	Cost per QALY gained	United Kingdom	2017	[51].
	$259		United States		
Surgery for trachomatous trichiasis	$83 to $222	Cost per DALY averted	Sub-Saharan Africa	2014	[53].
	$335 to $998		Southeast Asia		
	$13 to $78		Seven regions of the world	2012	[28].
	$13 to $17		Africa		
Retinopathy screening through laser Photocoagulation: - Retinopathy screening through	$1 206	Cost per blindness case averted	South Africa	2013	[40].
	$1 320	Cost per QALY gained	India	2013	[54].

telemedicine which followed by treatment using laser photocoagulation	$15 000	Cost 67 sight years saved per QALY	LMICs	2015	[41].
	$37 000	Cost 56 sight years saved per QALY			
Glasses for vision problems	$1 075	Cost per DALY averted	India	2014	[44].
	$2 759				
	$5 775		Rural India		
Vision prescreening by teachers: - Vision prescreening by teachers; vision tests and provision of ready-made glasses on site by eye specialists	I$67 to I$130	Cost per DALY averted	South-east Asia	2018	[46].
	I$165 to I$443		Africa		
	I$178 to I$258		South America		
	I$458 to I$734		Europe		
	$574		India	2014	[44].
	$221				
	$1 211		Rural India		

Table 2: Summary of cost-effectiveness analysis evidence

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Article:

Economic evaluation of ophthalmology care in Ethiopia: findings from a cost-effectiveness analysis

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Abstract

Background
Blindness and visual impairment are major global health problems, with about 43 million individuals blind and 2.2 billion visually impaired worldwide. Ethiopia has the highest disease burden due to blindness and visual impairment in Sub-Saharan Africa (1.6% blind and 3.7% low vision). Evidence on the cost-effectiveness of eye health interventions is important to inform decision makers. In this study we aim to estimate cost per healthy life year (HLY) gained from five eye health interventions in Ethiopia.

Methods
This cost-effectiveness analysis was conducted in an Ethiopian setting from 2020 to 2021 with different target populations for five eye health interventions. We took a health care provider perspective regarding input on human resources, equipment, drugs, and supplies used to estimate the direct costs. Security, laundry, and cleaning costs were defined as overhead costs. The efficacy, prevalence, baseline, and target coverage of the interventions are extracted from the best available evidence, expert opinion, and publicly available data bases. FairChoices-Analytics Tool version 2.1 was used to conduct the main analyses and one-way sensitivity analyses. We did not discount costs or effect, and all costs were converted to US$ 2020.

Results
We found ICERs from $19.7 per HLY gained (retinopathy screening and laser photocoagulation) to $240.8 per HLY gained (cataract surgery). The overall ICER of the full eye health package was $143.9 per HLYs gained. The ICERs were $240.8 ($144.5 to $541.7) HLYs gained for cataract surgery, $87.3 ($52.4 to $196.4) HLYs gained for surgery for trachomatous trichiasis, $19.7 ($8.7 to $44.4) HLYs gained for retinopathy screening and laser photocoagulation, $165.8 ($104.8 to $374.9) HLYs gained for glasses for vision problems, and $185.6 ($110.7 to $417.5) HLYs gained for vision prescreening by teachers.

Conclusions
The full eye health package were very cost-effective in an Ethiopia setting. The evidence on cost-effectiveness will inform decision makers on the health impact of implementing or scaling up these interventions. This is relevant in other low- and lower middle-income settings.

Key words: Cost-effectiveness analysis, ophthalmology care, eye health interventions, FairChoices, DCP Tool, ICER, HLY.

Introduction

Blindness and visual impairment are major problems in global health. In 2019, about 43 million were blind and about 2.2 billion people had near or distance vision impairment [1]. Out of these, 1 billion could have been prevented or treated [1]. In many low-and lower middle-income countries (LLMICs), an increase in life expectancy and growth in population with poor access to eye health care results in an increased prevalence of blindness and vision impaired [2].

Blindness or visual impairment contributed to 0.98% of total disability adjusted life years (DALYs) in lower middle-income countries (LMICs) and 0.36% in low-income countries (LICs) in 2019[3]. Leading causes of blindness or visual impairment in LMICs are uncorrected refractive error, cataract, corneal opacity, trachoma, and congenital cataract [1]. Interventions on conditions causing blindness and visual impairment are often considered cost-effective in LLMIC settings [4] [5] [6]. Typically, the cost effectiveness for this group of interventions is between $38 and $3328 in LLMICs, and the willingness to pay is between $6 and $1393 [4] [5] [7] [8] [9] [6] [6, 10]. Sub-Saharan Africa has one of the highest prevalence of blindness and low vision in the world, where 1.6% individuals are blind and 3.7% with low vision in Ethiopia [11]. Cataract accounts for 40% of preventable or treatable causes of blindness, and uncorrected refractive errors account for 49% of preventable moderate and sever visual impairment in sub-Saharan Africa [12].

Ethiopia is a LIC at the horn of Africa with an estimated population of 115 million and a life expectancy at birth of 67 years [13] [14, 15]. About 682 000 disability-adjusted life years (DALYs) were due to blindness and visual impairment (180 DALYs per 100 000) in Ethiopia in 2019[3], with cataract (96 000 DALYs; 89 per 100 000), trachoma (40 000 DALYs; 38 per 100 000), diabetes mellitus (449 000 DALYs; 417 per 100 000), and refraction disorders (36 000 DALYs; 33 per 100 000) being the four most common causes [3].

In LLMICs the economic burden of blindness and visual impairment is massive, especially for those living below the international poverty line of $1.9 per day per person (i.e. 27% of the people in Ethiopia [16]) and members of socially disadvantaged groups. It has a huge impact on the quality of life of individuals as well as families, mostly because of a reduced ability to work and contribute to society in other ways [17] [18]. For example, a randomized controlled study on the productivity of tea workers with age-related decline in near vision (i.e., presbyopia) in India found that productivity increased from 25.0kg per day to 34.8kg per day by providing near glasses to the workers, at low cost and with high intervention uptake [7].

Still, health economic evaluations of eye health interventions studies remain limited in LLMIC settings, both regarding efficacy, prevalence, incidence, and indirect and direct costs. Therefore, to conduct an analysis for one country, one may have to rely on knowledge from settings that are similar regarding economic growth, culture, life expectancy, disease burden and health system.

Information on the cost-effectiveness of eye health interventions is important so that policy makers can make informed decisions regarding health impact. Currently, retinopathy screening through telemedicine and vision prescreening by teachers are not implemented at all in Ethiopia, and glasses for vision problems, cataract surgery, and surgery for trachomatous trichiasis are not provided at full coverage and have been implemented without evidence on cost effectiveness.

The main objective of this study is to estimate cost per healthy life year (HLY) gained for cataract surgery, surgery for trachomatous trichiasis, glasses for vision problems, retinopathy screening through telemedicine followed by photocoagulation treatment, and vision prescreening by teachers in Ethiopia.

Methods

Cataract occurs due to opaque or clouding of eye lens and ageing. The affected lens can be removed by surgery and replaced by plastic intraocular lens to restore sight. Trachomatous trichiasis happens when repeated infections of the inner part affect the upper eyelid and leads to scarring of the front cornea [19]. Surgery, antibiotics and facial cleanings are the methods to treat this disease [19]. Diabetic retinopathy is caused when high blood sugar levels damages the back of the eye (retina) and it can be treated by laser photocoagulation treatment, screening, injection and surgery [20] [20]. Refractive errors make it hard to see clearly and can be corrected by eyeglasses, contact lens or surgery [21].

General approach

This cost-effectiveness study focusses on five curative eye health interventions in Ethiopia (see Table 1). The interventions were selected from a list of 218 interventions from the essential health care package of the Disease Control Priorities, 3^{rd} edition (DCP3). For example, the school-based vison screening and glasses for vision problem intervention can improve the social benefits and educational outcomes.

Study setting and data

The study was conducted in Ethiopia during 2020 and 2021. As seen in Table 1, the target populations were people aged 15 and older for surgery for trachomatous trichiasis and retinopathy screening, children aged 5 to 14 for vision prescreening by teachers, people aged 35 and older for vision screening and provision of glasses to adults, and people aged 40 and older for cataract surgery. The salaries of health professionals, user fee data were extracted from Ministry of Health (MoH) in Ethiopia, unit costs of drugs and supplies from the Ethiopian pharmaceutical and supply agency (EPSA), number of patients per year, monthly working hour of the professionals, costs, and life years of the medical equipment from the World Health Organization (WHO-Choice), and other sources (i.e., available websites). We collaborated with experts from the African Leprosy Rehabilitation and Training Center (ALERT) Hospital on data collection (see next sections for details). ALERT is one of the largest public hospitals in Ethiopia and multiple health service types are provided, including annual eye examinations, diabetes screening, glaucoma screening, and macular degeneration screening, cataract surgery, allergy treatment, glaucoma medical, surgical therapy, laser vision correction, retina, vitreous treatment, lens implementations, neuro-ophthalmology, and uveitis treatment.

Table 1: Description and Epidemiology information of eye health interventions examined in the cost-effectiveness analysis.

Interventions	**Description of the interventions**	**Primary cause addressed**	**Affected population**	**Population treated**	**Delivery platform**
Cataract surgery	Cataract extraction and insertion of intraocular lens	Cataract	Individuals with condition	Both genders, prevalence based, aged 40-99 years	Referral and specialty hospital
Surgery of trachomatous trichiasis	Surgery for trachomatous trichiasis	Trachoma	Individuals with condition	Both genders, prevalence based, aged 15-99 years	
Retinopathy screening and laser photocoagulation*	Retinopathy screening	Diabetes mellitus	Individuals with condition	Both genders, incidence based, aged 15-99 years	
	Laser photocoagulation treatment			Both genders, prevalence based, aged 15-99 years	
	Telemedicine follow-up			Both genders, incidence based, aged 15-99 years	
Glasses for vision problems	Vision screening	Refraction disorders	Individuals with condition	Both genders, all groups, aged 35-35 years	
	Provision of glasses			Both genders, prevalence based, aged 35-99 years	
Vision prescreening by teachers	Vision prescreening by teachers; and test		Children	Both genders, all groups, aged 5-5 years	Community based
	Provision of ready-made glasses on site by eye specialists			Both genders, Prevalence based, aged 5-14 years	

Costing

Regarding costs, we used a health care provider perspective and excluded costs like transportation, food, and accommodation expenses, infrastructure, maintenance, telephone, and vehicles etc. For each intervention, ophthalmologists in the ALERT hospital filled the detailed information of the items to be costed like human resources, medical equipment, drugs, overhead costs (e.g., laundry, security, and cleaning), and supplies. This was used to calculate the unit cost of each intervention. The unit cost of drugs and supplies was calculated as unit price×quantity (an overview of the data available here: Additional File 1). All costs were adjusted for inflation by using the consumer price index of the year 2020 as base year cost, and costs in Ethiopian birr (ETB) were converted to 2020 United States Dollars (US$).

We assumed an implementation period of ten years, where interventions were linearly scaled up from baseline coverage to a target coverage. For each intervention, we considered three scenarios: easy, medium, and hard. In the easy, baseline coverage was scaled up by 10 percentage points, in the medium, it was scaled up by 25 percentage points, and in the hard, it was scaled up by 40 percentage points. These scenarios were chosen because scaling up by 1 percentage point per year was considered well within the capacity of the health care system in an LLMIC whereas scaling up by more than 4 percentage points per year was considered infeasible.

Health impacts and effectiveness

The effectiveness of the selected interventions were analysed using FairChoices – DCP Analytics Tool version 2.1 (FairChoices) [34]. The effectiveness of an intervention was defined as the reduction of disability, mortality, prevalence, and incidence of the eye conditions in Ethiopia.

Health outcomes were measured using undiscounted healthy life years (HLYs) gained as baseline scenario. Because eye health interventions do not directly affect mortality, HLYs gained due to an intervention is just the total population-wide reduction in the disability caused by conditions targeted by the intervention. This reduction is calculated using condition-specific disability weights. For an individual, the disability weight is a measure of health-related quality of life, where 0 means full health and 1 means zero health (typically death). Hence, HLYs gained due to an intervention is the sum of the reduction in the disability weights of all individuals affected by the targeted conditions for as long as the effect of the intervention lasts (e.g., until glasses break or an individual dies).

Conceptually, HLYs gained for an intervention is calculated using standard life-table methodology: First, we calculate age- and sex- specific healthy life expectancy (HLE) based on a population with the current coverage of the intervention. Next, we calculate age- and sex-specific HLE based on a population where coverage of the intervention is scaled up to the target coverage in 10 years. The scale-up is linear in the sense that a scale-up of, e.g., 25 percentage points in ten years would yield a scale-up of 2.5 percentage points each year. For an individual, HLYs gained is calculated as the difference between HLE with intervention and HLE without intervention. For a population, HLYs gained is the sum of HLYs gained for all individuals. The age-, sex-, and intervention-specific parameters used to calculate HLYs gained are as follows:

1. Population size (from GBD 2019 [3]).
2. Prevalence and incidence of target conditions [3]. GBD does not provide the specific prevalence values for trachomatous trichiasis (TT) or diabetic retinopathy (DR). Therefore, we used 3.1% times the overall prevalence of trachoma [26] as our age- and sex-specific prevalence for TT, and 19.5% times the overall age- and sex-specific prevalence of diabetes mellitus [27] as the prevalence for DR.
3. Disability weights (general population) [3]
4. Disability weights (condition-specific); the disability weight of blindness was 0.19 [3]
5. Mortality rates (general population) [3]
6. Effect on condition-specific disability, prevalence, and incidence
7. Duration of effect on condition-specific disability, prevalence, and incidence
8. Baseline coverage of interventions in Ethiopia [22] [23] [24, 25]
9. Estimated costs of interventions in Ethiopia.

The effect of an intervention on condition-specific disability was estimated from relative risk (RR) values of the reviewed published papers. For example, the disability effect of laser photocoagulation for people with the diabetic retinopathy compared to no treatment was estimated as 1-RR= 1-0.49=0.51 or 51% (from RR: 0.49, 95% CI: 0.37 to 0.64) [28]. This means that the disability weight would be reduced by 51% for an individual receiving the treatment.

Studies directly comparing the intervention with the null intervention were not available for cataract surgery, surgery for trachomatous trichiasis, vision prescreening by teachers and glasses for vision problems, so the effectiveness was assumed based on the best available evidence ((i.e., randomized control trials (RCTs), meta-analyses or systematic reviews, and observational studies; accessible here: Additional File 2)), coverage, and prevalence in Ethiopia. In the cost-effectiveness analysis estimates of health gains and cost of an intervention was compared with the null intervention of no treatment. Interventions were assumed independent in the sense that the implementation of one intervention did not affect the implementation of the other interventions (neither costs nor effects).

Cost effectiveness analysis

We summarized the cost-effectiveness of the selected five eye health interventions by calculating the incremental cost-effectiveness ratio (ICER). The ICER is the cost per HLY gained when comparing two interventions (ICER $= \frac{\text{cost intervention 1} - \text{cost intervention 0}}{\text{effect intervention 1} - \text{effect intervention 0}} = \Delta C / \Delta E$)[29]. Because we assume that both cost and effect of the null intervention is zero, the ICER simply becomes cost of intervention divided by HLY gained from intervention. Interventions are often ranked from low to high priority based on their ICERs.

Our population model was static in the sense that we assumed that the parameters 1 through 9 listed above including the estimated costs of interventions did not change during a 10-year implementation period. The baseline coverages for the interventions were 48% or 500 surgeries per million people [30] [31] for cataract surgery, 41% [32] for surgery for trachomatous trichiasis, 28% [33] for glasses for vision problems, 10% for retinopathy screening and laser photocoagulation, and 0% for retinopathy screening through telemedicine and vision prescreening by teachers. The population in need of treatment was assumed to be everybody with the targeted condition for all the interventions.

Cost-effectiveness analyses were also conducted using FairChoices. One-way sensitivity analyses were performed to determine how model output changed when varying input values. In a “worst-case” scenario, costs were increased by 50% and effects were decreased by 33%, and in “best-case” scenario costs were reduced by 33% and effects were increased by 50%. We do not discount costs nor effects in the main nor sensitivity analyses.

Results

An overview of costs and effects of the selected five eye health interventions is shown in Table 2. All the interventions are delivered at referral and specialty hospitals, except vision prescreening by teachers, which is delivered at the community level. All five interventions have a unit cost of less than $35 per procedure. Surgery for trachomatous trichiasis has the lowest unit cost $8.67 per patient per surgery while cataract surgery has the highest unit cost $33.18 per patient per surgery. The overhead cost for glasses for vision problems, and retinopathy screening and laser photocoagulation were at $0.32, for cataract surgery $1.12, surgery for trachomatous trichiasis at $0.98 and $0.18 for vision prescreening by teachers.

Table 2: The estimated interventions cost

Eye health Interventions					
Inputs	**Cataract surgery**	**Surgery for trachomatous trichiasis**	**Retinopathy screening and laser photocoagulation**	**Glasses for vision problems**	**Vision prescreening by teachers**
Total unit cost (US$)	**34.30**	**9.65**	**20.99**	**11.57**	**9.88**
Cost (excluding overhead, US$)	33.18	8.67	20.67	11.25	9.70
Screening*	-	-	8.86	2.24	0.68
Laser photo-Coagulation	-	-	11.75	-	-
Telemedicine	-	-	0.06	-	-
Provision of Glasses	-	-	-	9.02	9.02
HR	4.83	1.51	2.49	1.05	0.63
Drug and Supply	26.82	7.08	0.75	9.93	9.02
Equipment	1.53	0.08	14.14	0.27	0.05
Retinopathy screening	-	-	5.62	-	-
Laser photo-coagulation	-	-	8.52	-	-
Overhead cost (US$)	**1.12**	**0.98**	**0.32**	**0.32**	**0.18**
Disability reduction	90%	90%	51%	95%	90%

The cost for telemedicine follow-up only included the internet cost, we assumed that the patient could use the health extension workers phones or other options to consult the ophthalmologist.
*Retinopathy screening equipment price was $5.62, where $8.86 (2.49+0.75+5.62) was cost per screening.
*Equipment price for laser photocoagulation and telemedicine was $8.52, where $11.75 (2.49+0.75+8.52) was cost per procedure.

The effectiveness (disability reduction) of three interventions were assumed as 90%, one intervention as 95% (glasses for vision problem), and retinopathy screening and laser photocoagulation was estimated to reduce disability by 51%. To avoid double counting of the disability reduction, we did not consider reduction of prevalence or incidence.

Cost analysis

The total annual costs after ten years (i.e., 2031) of scaling all interventions by 10, 25, and 40 percentage points are $579 667, $1 449 155, and $2 318 648 (see Table 3). Scaling up retinopathy screening and laser photocoagulation would be the least costly ($20 540 at 10%, $51 350 at 25%, and $82 159 at 40%), whereas scaling up cataract surgery would be the most costly ($278 972 at 10%, $697 431 at 25%, and $1 115 889 at 40%). Detailed disaggregated results are available in: Additional File 3.

Cost-effectiveness analysis

This study generated cost-effectiveness analyses evidence for five eye health interventions. Table 3 shows the estimated costs and HLYs gained over 10 years at different target coverages of all interventions. The ICERs remain the same as both costs and HLY gained increases with the target coverages. The full eye health package costs estimated to be $1.3 million over the 10 years duration with the target coverages of 40% points. The overall ICER of the full eye health package was $143.9 per HLYs gained. The ICERs ranging between $19.7 per HLY gained (retinopathy screening and laser photocoagulation) to $240.8 per HLY gained (cataract surgery). Two interventions had an ICERs less than $100 per HLY gained (i.e., Surgery for trachomatous trichiasis, and retinopathy screening and laser photocoagulation), two interventions had an ICERs less than $200 per HLY gained (i.e., vision prescreening by teachers and glasses for vision problem), and one intervention have an ICER above $200 per HLY gained ($240.8 per HLYs gained). The result file available here: Additional File 4.

Table 3. Estimated costs and HLYs gained with different target coverages.

Interventions	Baseline coverages	Target coverages											
		10%				25%				40%			
		ICER ($/HLY gained)	Cost ($, end year)	Cost ($, 10 years)	HLY Gained (10 years)	ICER ($/HLY gained)	Cost ($, end year)	Cost (10 years)	HLY gained (10 years)	ICER ($/HLY gained)	Cost ($, end year)	Cost ($, 10 years)	HLY gained
Cataract surgery	48%	240.8	278,972	1,534,348	6,373	240.8	697,431	3,835,870	15 932	240.8	1,115,889	6,137, 391	25, 491
Surgery for trachomatous trichiasis	41%	87.3	49,076	269,920	3,092	87.3	122,691	674,799	7 730	87.3	196,305	1,079,679	12 368
*Retinopathy screening and laser photocoagulation**	10%	19.7	20,540	112,969	5,727	19.7	51,350	282,423	14 316	19.7	82,159	451,876	22, 906
Glasses for vision problems	28%	165.8	31,364	172,500	1,041	165.8	78,409	431,251	2 602	165.8	125,455	690,001	4,163
Vision prescreening by teachers	0%	185.6	199,710	1,098 404	5,919	185.6	499,275	2,746,010	14 798	185.6	798,839	4,393,616	23,678
All eye health interventions		143.9	579,662	3,188,141	22,151	143.9	1,449,155	7,970,353	55,378	143.9	2,318,648	12,752,564	88,606
Costs (US$) and effects are based on a linear scale-up across 10 years from baseline coverage to target coverage + 10, 25, and 40 percentage points. Additional result for end-year HLYs gained refer additional file 3.													

Sensitivity analysis

Table 4 shows one-way sensitivity analyses result by increasing or decreasing the costs and effects of five eye health interventions. In the worst-case scenario we increased the cost by 50% and decreased the effect by 33% which implies more costly-less effective intervention, whereas the best-case scenario (less costly-more effective intervention) we decreased the costs by 33% and increased effects by 50%. The ICERs remain the same to scaling up the interventions by 10, 25 and 40 percentage points of target coverages, where both costs and effects increases (as mentioned somewhere else: see Table 4). One-way sensitivity analyses result shown that the ICER for full eye health package were ranging between $79 per HLYs gained and $323.9 per HLYs gained. We found the ICERs between $144.5 per HLY gained and $541.7 per HLY gained for cataract surgery, between $52.4 per HLY gained and $196.4 per HLY gained for surgery for trachomatous trichiasis, between $8.7 per HLY gained and $44.4 per HLY gained for retinopathy screening and laser photocoagulation, between $104.8 per HLY gained and $374.9 per HLY gained for glasses for vision problems, and vision prescreening by teachers between $110.7 per HLY gained and $417.5 per HLY gained (results available here: Additional File 5.

Table 4: One-way sensitivity analysis ICER results with different baseline and target coverages for selected eye health interventions.

Interventions	**Baseline coverages**	**ICERs**	
		Best case	**Worst case**
Cataract surgery	48%	144.5	541.7
Surgery for trachomatous trichiasis	41%	52.4	196.4
Retinopathy screening and laser photocoagulation	10%	8.7	44.4
Glasses for vision problems	28%	104.8	374.9
Vision prescreening by teachers	0%	110.7	417.5
All eye health interventions		79	323.9

Discussion

This is the first cost-effectiveness analysis study conducted in Ethiopia on eye health interventions, cataract surgery, surgery for trachomatous trichiasis, retinopathy screening and photocoagulation, glasses for vision problems, and vision prescreening by teachers. The selected interventions have low coverage and target prevalent conditions. Especially, cataract and refractive disorders are major causes of blindness and vision impairment in Ethiopia. As seen in Table 3, the cost of linearly scaling all interventions up by 40 percentage points in a ten-year period was estimated to be $12.8 million and yield 89 thousand HLYs gained, whereas scaling up by 25 and 10 percentage points would cost $8 million for 55 thousand HLYs gained and $3.2 million for 22 thousand HLYs gained, respectively. The ICER was estimated at $143.9 per HLY gained (best-case $79 per HLY gained; worst case $323.9 per HLY gained) (Table 4).

Retinopathy screening and laser photocoagulation as well as surgery for trachomatous trichiasis both had ICERs less than $100 per HLY gained, although the worst-case scenario for the latter was $196.4 per HLY gained (Table 4). Vision prescreening by teachers and glasses for vision problems both had ICERs between $100 and $200 per HLY gained, and cataract surgery had an ICER above $200 per HLY gained, but all three had worst-case ICERs above $350 per HLY gained (Table 4). Still, all five best-case ICERs were less than $150 per HLY gained.

Our cost estimates for cataract surgery are in the lower range of that reported in the literature. We found that the cost of cataract surgery was $34.30 per surgery, whereas the average cost of cataract surgery per person has been estimated at £32 in India, $183 in South Africa, and between $38 and $313 in Southern Ethiopia [36] [37, 38]. However, the study from Southern Ethiopia considered expenses to, e.g., patient food and transportation, house rent, equipment transportation and non-governmental organizations (NGOs). Two systematic reviews on cost effectiveness analysis have showed that cataract surgery had an ICER between $90 to $370 per DALY averted, and between $9 to $1600 per quality-adjusted life year (QALY) gained in developing countries [39, 40]. We found an ICER $240.8 per HLY gained for cataract surgery which is in the rage of the findings in the reviews.

In the Gambia, the cost per surgery of trachomatous trichiasis was $6.13 in 2012 [39], which fits well with our estimate of $9.65, especially when considering the time since the Gambian estimate. A systematic review on the cost-effectiveness of surgery of trachomatous trichiasis in lower middle-income countries showed that cost per DALY averted was between $83 and $222 in Sub-Saharan Africa and $335 and $998 in Southeast Asia [9]. Our analysis estimate of $87.3 per HLY gained was in the lower range of the numbers for Sub-Saharan Africa.

Our estimate of $21 for retinopathy screening and laser photocoagulation for patients with diabetic retinopathy was lower than what has previously reported for LMICs in the literature. Two studies estimated costs to be between $394 and $578 in South India, and the estimated cost for screening per patient $22 and $144 for laser treatment in South Africa [37, 41]. However, the South African study included the transportation cost of the medical equipment, capital costs, vehicles, and so on, whereas we did not. Three systematic reviews on the cost effectiveness of telemedicine for retinal screening in diabetes management found that the incremental cost–effectiveness ratio was between $113.5 and $3,328.5 per QALY gained, and about $1206 per blindness case averted in South Africa [4] [5] [6]. In our study the retinopathy screening and laser photocoagulation has an of ICER $19.7 per HLY gained. The discrepancy could be due to differences in how the cost of the intervention was calculated in the other studies.

We estimated the cost of screening at $2.24 for individuals older than 35 years, which was almost the same as the cost in a study from Ghana on screening of children ($1.84) [42] Two studies found that the cost of glasses per person was $10.20 in rural India and $194 in Africa [7] [6]. The Indian estimate fits well with our estimate of $9.02 but is about one eight of the market value estimation $74 by ophthalmologist in Ethiopia. We based our estimate on the price of glasses estimated by the UN Population Division, which takes into consideration that the purchase and distribution of large quanta drives down prices. Using market prices in our analyses increased the ICER from $165.80 to more than $1300 per HLY gained, which is in line with an Indian study, reporting between $1075 and $5775 per DALY averted for primary eye screening [42].

A study on school-based interventions found that cost of spectacles per children was $6 in Cambodia, and $25 in Ghana [42], which again leaves our estimate of $9.02 per children in the lower range of what has been reported in the literature. We estimated cost per child screened to $0.68 in Ethiopia, which was comparable with the finding in Cambodia ($1.33) and Ghana ($1.84). ICERs for school-based screening among children ranges between $221 and $1211 in India per DALY averted, and I$165 (international dollar) to I$1443 per DALY averted in Africa

[42]. We found an ICER $185.6 per HLY gained which is low, but not unreasonable considering that our cost estimates are also in the lower end of the reported spectrum.

This study has some limitations. First, disability weights for the eye health conditions were very low (0.19), indicating that the disability loss of blindness vision impairment is lower than other conditions, e.g., schizophrenia. We used the GBD 2019 disability weights, and this value has been criticized for being too low. Nevertheless, the consequence of using a low disability weight in our effectiveness analysis is that we may underestimate the effects of eye care interventions. Second, the market unit price for spectacles were not available in the MoH catalogue of procurements. Ophthalmologists at ALERT hospital and people in the MoH suggested to use the private market value of glasses in Addis ($74). However, this seemed too high, and we therefore decided to use the global market price (UNDP estimate, $7 per spectacle). Third, data on baseline coverage was not available in MoH Ethiopia since there was not established a health information system reporting utilization of eye care services. Therefore, we made assumptions on baseline coverage based on expert input and from the literature. The starting point for the incremental cost and effect in the model may therefore deviate from the true starting point. Since marginal benefits are assessed in this analysis, the starting point may not have too much impact on results. Fourth, GBD did not report the disability fraction of trachoma and diabetes mellitus that were due to trachomatous trichiasis and diabetic retinopathy respectively. Therefore, we made expert based assumptions on the treated and affected fractions for these conditions. Fifth, overhead costs were added to a unit cost per treated patient and a linear correlation between scale up in utilization and overhead costs were assumed. This may cause overestimated total costs.

A health care provider perspective was used in our analysis. Around 40% of the total health budget is out-of-pocket expenditure in Ethiopia, and we know less how this is in particular for ophthalmology care [35]. A societal costing analysis considering the patient perspective could add more detailed understand of the financial risk protection of scaling up public finance of ophthalmology in Ethiopia.

Conclusion

This health economic evaluation puts eye health on the agenda and facilitates efficiency comparisons by investments in eye health care as compared to other types of standard health care in Ethiopia. The eye health package assessed in this study seems to be good value for money in an Ethiopia setting as compared to other types of health services. Surgery of cataract and trachomatous trichiasis, laser photocoagulation of diabetic retinopathy and glasses for poor vision has a potential to improve population health at a low cost. Blindness and vision impairment is too severe to continue being neglected disorders in LMICs.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Authors' contributions

HGM, ØAH, KAJ and AH worked on study protocol. HGM collected all the required costs data. HGM, ØAH, JMØ and KAJ analyzes the result. HGM, GK, ØAH and KAJ worked on effectiveness. HGM, ØAH and KAJ interpreted the result and wrote the first manuscript. ØAH, KAJ, VS and HN provided the feedback on the first draft manuscript. All the authors read and approved the final manuscript.

Availability of data and materials

All the required data is available in the article.

Acronyms

ALERT: African leprosy rehabilitation and training center; BCEPS: Bergen Centre for Ethics and priority Setting; CEA: Cost-effectiveness analysis; DALYs: Disability-adjusted life years; DR: Diabetic retinopathy; ECCE: Extracapsular cataract extraction; ETB: Ethiopian Birr; EPSA: Ethiopian pharmaceutical and supply agency; DCP-FC: Disease Control Priorities- Fair choices; DR: Diabetic retinopathy; GBD: Global burden of diseases; HLY: Healthy life years; HReH: Human Resources for eye Health; ICERs: Incremental cost-effectiveness ratios; LLMIC: Low- and lower middle-income countries; LIC: Low-income countries; LMICs: Lower middle-income countries; MoH: Ministry of Health; NB: nota bene (note well); NGO: Non-governmental organizations; OHT: One health tool; PEA: Phacoemulsification; QALY: Quality-adjusted life years; RR: Relative risk; TT: Trachomatous trichiasis; UHC: Universal Health Coverage; USD: United states dollar; WHO: World Health Organization

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