plus other financial and nonfinancial costs from their vision loss in that year Understanding cost components is crucial for appropriate allocation of health care resources.[4]

All costs were originally calculated in Japanese yen (¥) and are presented with United States dollar equivalents based on the Organization for Economic Cooperation and Development's purchasing parity 2007 rate of ¥120 66 per US dollar

PREVALENCE

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

Prevalence rates by age were based on data from the Japanese Ministry of Health, Labour and Welfare, presented by the National Committee of Welfare for the Blind in Japan,[7] and a major epidemiological study [8] Sex and severity splits were based on epidemiological data sets by cause of visual impairment [9-19] Prevalence rates were multiplied by Japanese census data to estimate the number of people with visual impairment.

DIRECT HEALTH COSTS

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

OTHER FINANCIAL COSTS

Other financial costs are composed of productivity losses, costs of care outside the health system, vision aids, and efficiency losses from government transfers and expenditure People with visual impairment may work less than otherwise, retire early, or die prematurely, representing real productivity losses to the economy A human capital approach was used to measure productivity losses, as is appropriate in countries with low unemployment like Japan [21] Age- and sex-standardized employment rates, absenteeism, and mortality rates were estimated for people with visual impairment using official estimates and government survey data [7,22] Productivity costs were estimated, assuming that in the absence of visual impairment, people would have worked at the same rate as the general population Productivity costs from increased absenteeism were calculated as the average number of days absent per year owing to visual impairment × the total number of people employed with visual impairment × average annual wages Production losses arising from premature mortality from falls and depression associated with visual impairment were calculated as a net present value using World Health Organization data for Japan on retirement age, average life expectancy, average age of death, and an estimated discount rate of 1 5%, calculated as long-term nominal bond rates minus expected inflation and growth in productivity

Additionally, any taxation foregone requires equivalent revenue raising, imposing real efficiency costs on the economy, known as deadweight losses (DWLs) Internationally, DWLs are estimated to be in the range of 9, 16, and 50 cents (9%, 16%, and 50%, respectively)[23] for every additional tax dollar raised by the government The parameter estimate of 16% was used, since no Japanese studies were found to provide a local estimate

To estimate the cost of community care services, an opportunity cost method valued time devoted to care giving responsibilities that cannot be spent in the paid workforce This was calculated as the estimated number of people with visual impairment who require some level of care × the average number of hours of care required[20] × by an average hourly rate for the wage forgone by the caregiver,[21] and weighted by age, sex, and the probability of alternative employment [22]

LOSS OF WELL-BEING

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

Years of healthy life lost as a result of disability from visual impairment were calculated by multiplying prevalent cases by disability weights for mild, moderate, and severe visual impairment (0 02, 0 17, and 0 43, respectively) based on the global burden of disease study [24] These disability weights represent losing 2%, 17%, and 43%, respectively, of a year of healthy life Years of life lost were calculated from the age when a person dies from comorbid conditions attributable to visual impairment and the life expectancy for people of that age and sex. To calculate the burden of disease, Japanese prevalence rates for low vision were subdivided into mild and moderate visual impairment using weights from Australian prevalence data [25]

The loss of well-being in DALYs was converted into a monetary value using an estimate of the value of a statistical life The value of a statistical life in Japan has been valued between ¥675 9 million (US $5 6 million) and ¥1783 5 billion (US $14 8 million) [26] The lower bound of US $5 6 million was used with a discount rate of 3 0% during 40 years to generate an estimate for the value of a statistical life year (VSLY) of ¥28 3 million (US $234 552)

SENSITIVITY ANALYSIS

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

RESULTS

PREVALENCE

There were 1 64 million people with visual impairment in Japan in 2007, almost 188 000 were blind Of those with visual impairment, 93 2% were aged 40 years or older, 61 2% were aged 65 years or older, and 33 5% were aged 75 years or older (**Table 1**)

DIRECT HEALTH COSTS

The direct financial costs in Japan for the treatment of all disorders of the eye and adnexa were estimated to total ¥1338 2 billion (US $11.1 billion) in 2007 (**Table 2**) and may include some conditions that are not visually impairing. However, the cost overestimation is expected to be slight as a result of this data constraint and is countered in that costs of screening programs and eye health promotion are not included, so health cost coverage was not exhaustive. The largest component of health costs for visual impairment related to general medical expenditure (¥977.5 billion [US $8.1 billion]), of which outpatients represented 77.7% (¥759.4 billion [US $6.3 billion]).

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

Age, y	No. × 1000 (%) Men	Women	Total
Total visual impairment			
<40	58 (0.20)	53 (0.19)	111 (0.19)
≥40	792 (2.40)	733 (1.96)	1526 (2.17)
≥65	519 (4.44)	482 (3.06)	1001 (3.65)
≥75	281 (5.90)	267 (3.37)	548 (4.32)
Total	850 (1.37)	787 (1.20)	1637 (1.28)
Low vision			
<40	51 (0.17)	47 (0.17)	98 (0.17)
≥40	701 (2.12)	649 (1.74)	1351 (1.92)
≥65	459 (3.93)	427 (2.71)	886 (3.23)
≥75	249 (5.22)	236 (2.98)	485 (3.82)
Total	752 (1.21)	696 (1.06)	1449 (1.13)
Blindness			
<40	7 (0.02)	6 (0.02)	13 (0.02)
≥40	91 (0.28)	84 (0.23)	175 (0.25)
≥65	60 (0.51)	55 (0.35)	115 (0.42)
≥75	32 (0.68)	31 (0.39)	63 (0.50)
Total	98 (0.16)	90 (0.14)	188 (0.15)

OTHER FINANCIAL COSTS

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

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

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

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

Cost Item	¥ in Billions	US $ in Billions	% of Total Health Costs	% of Total Economic Costs
General medical expenditure	977.5	8.102	73.0	11.1
Inpatient	218.2	1.808	16.3	2.5
Outpatient	759.4	6.294	56.7	8.6
Drugs	168.3	1.395	12.6	1.9
Meal service on admission	18.0	0.149	1.3	0.2
Home-visit nursing	1.6	0.013	0.1	0.0
Health care administration	57.3	0.475	4.3	0.6
Long-term care insurance	19.6	0.162	1.5	0.2
Eye care research	96.0	0.795	7.2	1.1
Total Health Care Costs	**1338.2**	**11.091**	**100.0**	**15.1**

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

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

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

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

taxation (¥33 8 billion [US $280 million]), welfare payments (¥24 8 billion [US $205 million]), and other costs associated with providing institutional care and vision aids (¥4 6 billion [US $38 4 million])

Expenditure on other institutional care and rehabilitation for people with visual impairment in Japan was based on the average cost of institutional care per person per year (derived from long-term care insurance facilities, estimated at ¥7 445 863 [US $61 711 63]) and multiplied by the number of people admitted (3857 people, minus the adjustment to account for the 30% overlap in the data with long-term care insurance facilities) In total, it was estimated that expenditure for institutional services (over and above that provided by long-term care insurance facilities) for the visually impaired was ¥28 7 billion (US $238 million) in 2007

LOSS OF WELL-BEING

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

The gross value of the burden of disease (DALYs multiplied by the VSLY) was ¥6503 1 billion (US $53.9 billion) However, the gross value includes some costs borne by the individual—notably, lost earnings and out-of-pocket health expenditures, for example, which have already been captured As such, these costs were subtracted and the net cost of the loss of well-being in Japan was calculated as ¥5863 6 billion (US $48 6 billion) for 2007. Costs by item and bearer are summarized in **Table 4**

INTERNATIONAL COMPARISONS

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

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

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

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

SENSITIVITY ANALYSIS

Varying direct health costs, the number of people requiring informal care in the community, and male and female average earnings ±20% produced a variation in the baseline of total visual impairment costs of ±2 9%, ±1 9%, and ±2 2%, respectively Our results did not vary significantly when the assumption used for the DWL parameter estimates was dropped from 16% to 9%, resulting in a fall of total costs of 1 0% The value of a statistical life used for Japan to estimate the burden of disease was varied by 20% resulting in changes of ±15 1% of total costs, the sensitivity of this result is discussed subsequently The distribution of low vision (between mild and moderate vision) was altered by 20% resulting in changes of ±1 5% of total costs

COMMENT

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

In the present study, we have shown that in 2007 visual impairment affected more than 1 64 million people in Japan, or 1 3% of the population, and cost an estimated ¥8785 4 billion [US $72 8 billion], or 1 7% of the gross domestic product of Japan These findings are consistent with other studies that also found substantial expenditures to be associated with visual impairment [27,28]

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

Our analysis suggests that community care costs account for 50% of indirect costs of visual impairment in Japan. This suggests that substantial resources are dedicated to care for individuals with visual impairment at home through informal care Community care costs were composed of both paid and unpaid home care. Official usage data were available for paid home care[20] and used as a proxy for unpaid care. Usage data ranged from all-day care to care only when required. A weighted average of 17.1 hours per week based on the percentage distribution of the usage data was applied to those with visual impairment most likely to require some form of community care. It was assumed that those with mild visual impairment would not require any form of community care and those in institutional care were accounted for in other financial costs

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

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

Owing to good access to high-quality cataract surgery, the prevalence of visual impairment from cataract is low in Japan On the other hand, glaucoma is the leading cause of visual impairment.[8,19] Compared with the United States and Australia, the rate of undiagnosed glaucoma is very high in Japan,[15] and this may partially explain the high prevalence of visual impairment from glaucoma in Japan Diabetic retinopathy is the second most common cause of visual impairment The prevalence of diabetes is relatively high in Japan and this would contribute to a high prevalence of diabetic retinopathy and visual impairment.[8] Access to good medical services in Japan through its universal health care system enables people with diabetes to have better systemic control However, the high proportion of visual impairment due to diabetic retinopathy also raises questions about the adequacy of coverage of screening and close coordination with general physicians and ophthalmologists and the use of photocoagulation and vitreous surgery, which are readily available in Japan.

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

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

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

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

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

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CLINICAL INVESTIGATION

Cost-effectiveness of cataract surgery in Japan

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Abstract

Purpose To evaluate the cost-effectiveness of cataract surgery through measurement of the cost per quality-adjusted life-year (QALY) in Japan.

Methods A total of 549 patients scheduled for cataract surgery at 12 clinical sites from November 2008 through February 2010 were included in the study. Prospective assessment of patient preference-based quality of life (utility) was performed before and after the surgery using the time tradeoff method, EuroQol, and Health Utilities Index Mark 3. Multiple regression analysis was used to determine the correlation between utility and visual acuity. The QALYs gained through cataract surgery were estimated, and cost-utility analysis was performed.

Results The utilities significantly correlated with the visual acuity in the better seeing eye. In all the subgroups (first eye surgery, second eye surgery, and bilateral surgery), mean utility improvement was statistically significant. Average QALYs for unilateral cataract surgery and bilateral cataract surgery were 2.40 and 3.40, respectively. The cost per QALY gained from surgery was estimated at ¥122,472 (US $1,307) for unilateral surgery and ¥145,562 (US $1,553) for bilateral surgery.

Conclusions Routine cataract surgery in Japan is highly cost-effective. Factors that contribute to this are the high clinical effectiveness of the surgery, the substantial improvement in patient-perceived quality of life, and the reasonable cost of the surgery.

Keywords Cataract surgery · Cost-effectiveness · Cost-utility · QALYs · Time tradeoff

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Introduction

Just as the resources in the world to satisfy human wants are always limited, so too the resources available for health care are limited. The issue of how health services should be provided and the extent of the resources required for such a provision is obviously one of the most important and contentious political issues of the day. An effort has to be made to match the health-care service needs of the population to the health-care goods and services that are allocated within the delivery system. Because health-care spending is rising, it is necessary to choose those health-care interventions that produce the greatest health gains for the greatest number of people at the lowest cost.

Although there is no single correct answer or solution to this problem, the concept of cost-effectiveness has become increasingly common, and Britain, Australia, and Canada have already used cost-effectiveness findings in the process of introducing innovative drugs in their national health-care systems [1]. In the United States, the federal government last year authorized the expenditure of $1.1 billion to conduct research comparing "clinical outcomes, effectiveness, and appropriateness of items, service, and procedures that are used to prevent, diagnose, or treat diseases, disorders, and other health conditions" [2].

Cataract is the leading cause of blindness in the world [3], and cataract surgery is the most frequent surgical procedure in people aged 65 years or older in the Western world, as well as in Japan [4, 5]. The value of cataract surgery is firmly established, and as a result, cataracts account for approximately one-third of medical spending on eye care [6]. As the Japanese population ages, the prevalence of visual impairment is projected to increase from 1.35% of the population in 2007 to 2.0% by 2050 [7]; hence, visual impairment resulting from cataracts is on the rise. Therefore, an important challenge is to assess the cost-effectiveness of cataract surgery.

A cost-effectiveness study that uses the concepts of utility and quality-adjusted life-years (QALYs), in which the quantity of life is combined with the quality of life (QOL), is termed a cost-utility analysis. Several previous studies have assessed the cost-utility of cataract surgery [8–13]. In the US, Busbee et al. [8] reported that the cost-utility of first eye cataract surgery was $2,020/QALY and concluded that initial cataract surgery was highly cost-effective when compared with procedures across multiple medical specialties. In Sweden, Kobelt et al. [9] estimated the cost-utility of cataract surgery in one eye as US $4,500/QALY, and a recent systematic review to determine the cost-effectiveness of cataract surgery concluded that it is a cost-effective procedure by any measure in the Western world [11]. To confirm the generalizability of the cost-utility of cataract surgery in the real-world setting in Japan, we conducted a multicenter study based on data from 12 clinical sites in Japan.

Participants and methods

This study was a prospective multicenter observational study conducted by the Eye Care Comparative Effectiveness Research Team (ECCERT) at 12 clinical sites in Japan (see Appendix). A prospective observational protocol was developed by ECCERT to evaluate visual and patient-reported outcomes before and after routine cataract surgery. Seven ophthalmologic departments in university hospitals, three ophthalmologic departments in public hospitals, and two private surgical clinics were recruited; all agreed to participate in the study. The study protocol was approved by the institutional review board of each facility, and the conduct of the study followed the tenets of the Declaration of Helsinki.

Study population

Patients were eligible for inclusion in the study if they were scheduled for first eye, second eye, or bilateral cataract surgery, and were aged 50 years or older. Patients were excluded if the planned cataract surgery was a combined procedure involving glaucoma, corneal, or vitreoretinal surgery. Further exclusions were made if patients had any visually significant coexisting ocular pathology, such as macular diseases, glaucoma, optic atrophy, amblyopia, and proliferative diabetic retinopathy with dementia, or were unwilling or unable to respond to the complex questions. Each participant gave written informed consent to participate in this study. Patients were recruited from 1 November 2008 through 28 February 2010. A total of 549 patients were initially registered.

A full preoperative medical history and an ophthalmic examination for each patient were obtained. The ophthalmic examination included visual acuity, types of cataract (nuclear, cortical, or posterior subcapsular cataract), and presence of any other ocular disease. The visual acuity was reported as a corrected decimal acuity obtained according to the usual routine of each clinic. The ophthalmologist who performed the examination reported the results using a structured data sheet. Intraoperative techniques, complications, and 3-month clinical outcomes were also reported by the treating ophthalmologist. All patients were asked whether they had a history of systemic comorbidities, including cardiovascular diseases (hypertension, angina, heart failure, myocardial infarction, use of a pacemaker), cancer, diabetes, renal and hepatic diseases, gastrointestinal diseases (gastric ulcer, enteritis, colitis), respiratory diseases, musculoskeletal diseases (rheumatoid arthritis, spinal disorder), neurological diseases (paralysis such as stroke, need for ambulatory assistance), and deafness or hearing impairment.

Utilities assessment

Prospective assessment of patient preference-based QOL (utility) was performed before and after the surgery. In health economic analysis, utility is defined on a continuous scale from 0 to 1, where 0 corresponds to the worst possible QOL weight (equal to death) and 1 corresponds to the best possible QOL weight (equal to perfect health). The patient preference-based time tradeoff (TTO) method was used in this study [14]. Each patient was interviewed preoperatively by trained interviewers, not by the attending ophthalmologists. All the interviewers in the participating clinics had completed the training workshop, and utility values were obtained by them in an agreed-upon fashion using the same questionnaire and the standard technique of each facility. The patient was asked if he/she would be willing to trade a certain portion of his/her remaining life, from a life expectancy of 20 years, in return for being rid of visual impairment and all its associated effects under these hypothetical conditions. Time tradeoff utility was calculated according to the following equation: utility = $1 - x/20$ (x = years of life he/she would be willing to give up). Out of the 12 clinical sites, 1 site could not conduct the TTO interview; therefore, results from questionnaires completed by 440 patients from 11 clinical sites were included in the TTO analysis at baseline.

Information for other utility assessments was collected from the patients by means of survey questionnaires. The questionnaires consisted of the Japanese versions of the EuroQol (EQ5D) [15, 16] and the Health Utility Index Mark 3 (HUI3) [17, 18]. The EQ5D comprises 5 questions that measure 5 health concepts (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression), with 3 levels of answers leading to 243 possible combinations of answers describing a different health status between 1 (= perfect health) and −0.063 (a health status that can be considered worse than death). The HUI3 comprises 15 questions addressing 8 health attributes (vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain) and 1 question that measures overall self-assessed health status. A weighted-scoring algorithm is applied to combine the scores of each attribute to derive a value between 0 and 1 to represent utility of the overall health state (perfect health = 1, deceased = 0). These questionnaires were collected from the 12 clinical sites; however, because of inability to collect survey forms and no method to account for the missing values, we were able to obtain answers from only 541 patients for the EQ5D and 496 patients for the HUI3 at baseline. The patients were encouraged to complete the follow-up questionnaires, which included the TTO, EQ5D, and HUI3 questionnaires, mailed to their homes 3 months after the surgery, and to return them by post. Later, however, for reasons including withdrawal of consent, insufficient information on clinical findings from the responsible physicians, and inability to collect survey forms from patients, we were able to obtain complete information on only 381 patients for the TTO method, 482 patients for the EQ5D, and 434 patients for the HUI3.

Cost-utility analysis

The cost estimates for this study included only direct costs. All medical costs are uniformly standardized by the social medical insurance system in Japan The medical costs associated with cataract surgery were calculated based on the Japanese social insurance medical fee payment The unilateral cataract and bilateral cataract surgery fees were ¥121,000 and ¥242,000, respectively. We assumed that the cost of treating posterior capsule opacification (PCO) by neodymium yttrium–aluminium-garnet (Nd·YAG) capsulotomy needed to be taken into account postoperatively for 11.4% of the patients according to the results of a meta-analysis of 6 prospective studies performed in Japan [19–24] The other medical costs included the initial consultation, preoperative visit, cost of hospital treatment (postoperative medications, anesthesia fees, inpatient facility fee, eye examinations), and postoperative management (3 postoperative visits) associated with cataract surgery. The costs of complications other than PCO were not encompassed by the medical costs

Cost-utility analysis was performed on the basis of the cost model and measured utility data. The utility gain was assumed to last until the end of the remaining statistical life expectancy of each patient as determined on the basis of the abridged life tables for 2008 in Japan [25] The number of QALYs gained was calculated by multiplying the measured utility gain (difference in utility before and after surgery) and the patient's mean life expectancy, together with an assumed annual discount rate of 3% The cost of cataract surgery was divided by the number of QALYs gained, which was estimated as Japanese yen/QALY (¥/QALY) The costs were converted into US dollars at a 2009 exchange rate of 93.68 Japanese yen to 1 US dollar (Federal Reserve, https://www.federalreserve.gov/releases/g5a/current/)

Statistical methods

Data were analyzed using Stata 10 software (StataCorp, College Station, TX). The results are given as the mean and standard deviation (SD), as the mean and 95% confidence interval (CI), or as the median The significance of the difference in utility before and after cataract surgery was analyzed with a paired t test for dependent samples. An independent samples t test was used to compare the utility gain in unilateral surgery with that in bilateral surgery. Multiple linear regression models were used to assess the associated factors affecting utility at baseline for all patients The regression model with robust standard errors (Eicker-Huber-White) was adjusted for age, sex, corrected distance visual acuity in the better-seeing eye (better VA), corrected distance visual acuity in the worse-seeing eye (worse VA), types of cataract, ocular past history, other ocular diseases, and the number of systemic comorbidities First, each variable was analyzed in a univariate model Then, all variables with a significance level (P) of less than 0 25 were included in a multivariate model Because each of the clinical sites was an independent unit with its own examiners, infrastructure, and administrative structure for eye care, the assignment of patients was conducted separately and independently, and the cataract surgery procedures varied according to the clinical site. For analysis of the data pooled from the multiple centers, we also performed a meta-analysis to assess the utility gain after unilateral cataract surgery and bilateral cataract surgery The random effect model was used to evaluate the pooled effect of the utility gain. Visual acuity data obtained by the decimal unit (counting fingers was categorized as an acuity of 0 004, hand motions as 0.002, and light perception as 0 001) were converted to logarithm of the minimal angle of resolution (LogMAR) units for statistical analysis. A P value of less than 0.05 was considered statistically significant.

Sensitivity analysis

One-way sensitivity analyses were performed by varying the discount rate of 0 and 5%, the cost by 25%, the cost excluding the PCO treatment cost, the treatment effectiveness using the results from the meta-analysis and within the 95% CI observed in the study, and survival in the short term (5 and 10 years).

Results

The age of the patients ($n = 549$) enrolled in the study ranged from 50 to 89 years (average, 71.0 ± 7.9 years, 214 men and 335 women). These 549 patients with complete data on visual acuity before surgery were available for inclusion in the study, and the utility from the TTO method ($n = 440$), EQ5D ($n = 541$) and HUI3 ($n = 496$) could be used in the analysis at baseline. Table 1 summarizes the characteristics of the samples at baseline. The baseline mean utility (TTO) (0.60) was lower than the utility of the EQ5D (0.84) and HUI3 (0.65).

The preoperative utilities (TTO) obtained from 440 patients at baseline were stratified according to the corrected distance visual acuity in the better VA (decimal) (Table 2). The utilities were correlated with 6 different visual stratifications. As the visual acuity in the better VA decreased, the corresponding utilities (TTO) decreased at every visual stratification level (Table 2).

Factors associated with preoperative utilities (TTO) are given in Table 3. In a multiple linear regression model adjusting for age, sex, visual acuity in the worse VA (logMAR), types of cataract, ocular history, ocular comorbidities, and the history of systemic comorbidities, the better VA (logMAR) showed a significant correlation with utilities (TTO). Utility changed by 0.21 for each change in visual acuity of one (logMAR) ($P < 0.001$, Table 3). Although age also had a significant effect, the regression coefficient was very small (−0.01), and the overall model was significant ($n = 429$, $F < 0.0001$, $R^2 = 0.10$).

Before the surgery, 15 patients cancelled undergoing cataract surgery, and by 3 months, 5 more patients had also withdrawn. Thus, complete data on visual acuity were obtained for 529 interventions. Although completed follow-up questionnaires were received from 490 patients, no method was provided to account for the missing values, and therefore, incomplete questionnaires were excluded. Finally, the utilities using the TTO method ($n = 381$), EQ5D ($n = 482$), and HUI3 ($n = 434$) could be used in the analysis of the final outcome.

Intraoperative techniques were phacoemulsification and aspiration with intraocular lens implantation in all cases. Out of 529 surgeries, 18 had the complication of posterior capsule rupture (3.4%). The mean better VA (logMAR) and worse VA (logMAR) improved to −0.05 ± 0.10 and 0.03 ± 0.25, respectively.

The study population consisted of 3 subgroups: group 1, in which both eyes were operated on ($n = 312$); group 2, in which only the first eye was operated on ($n = 157$), and group 3, in which the second eye was operated on (the first eye had been operated on previously) ($n = 60$). In the entire group of 381 participants, the overall utility (TTO) showed a statistically significant improvement from 0.60 at baseline to 0.85 3 months after cataract surgery. In the subgroup analysis, all groups showed a statistically significant improvement of utility in the TTO, EQ5D, and HUI3 (Table 4). The utility gain from the bilateral cataract operations was significantly higher than that from the unilateral cataract operations (combined first eye and second eye operations) in the TTO method ($P = 0.01$) and HUI3 ($P = 0.02$), but not in the EQ5D ($P = 0.88$). Tables 5 and 6 illustrate the combined effect of the pooled

Table 1 Patients' characteristics before surgery

Characteristic	n	Mean ± SD	Median
Age (years)	549	71.0 ± 7.9	71
Women	335	71.7 ± 7.5	72
Men	214	69.7 ± 8.4	70
VA (logMAR)	549		
Better eye		0.16 ± 0.28	0.1
Worse eye		0.51 ± 0.52	0.4
Utility			
TTO	440	0.60 ± 0.28	0.65
EQ5D	541	0.84 ± 0.15	0.79
HUI3	496	0.65 ± 0.24	0.69

VA visual acuity, *logMar* logarithm of minimal angle of resolution, *TTO* time tradeoff, *HUI3* Health Utility Index Mark 3

Table 2 Utility values associated with visual acuity in the better-seeing eye

Visual acuity (decimal)	Utility (TTO)	SD	n
<0.1	0.350	0.399	6
<0.2	0.419	0.289	8
<0.4	0.553	0.293	29
<0.8	0.558	0.293	167
<1.0	0.613	0.256	89
≥1.0	0.685	0.250	141
Overall	0.604	0.281	440

Table 3 Factors associated with preoperative utility

Variable	Univariate analysis			Multivariate analysis*		
	Coefficient	(95% CI)	*P* value	Coefficient	(95% CI)	*P* value
Age (per +1 year old)	−0.01	(−0.01 to −0.00)	<0.001	−0.01	(−0.01 to −0.00)	<0.01
Female (vs. male)	−0.06	(−0.12 to −0.01)	0.02	−0.05	(−0.10 to 0.01)	0.10
VA better (per +1 logMAR VA)	−0.25	(−0.34 to −0.15)	<0.001	−0.21	(−0.32 to −0.09)	<0.001
VA worse (per +1 logMAR VA)	−0.06	(−0.11 to −0.01)	0.02	0.00	(−0.05 to 0.06)	0.91
Nuclear cataract (present vs. absent)	0.00	(−0.07 to 0.06)	0.94			
Cortical cataract (present vs absent)	−0.04	(−0.09 to 0.02)	0.20	−0.03	(−0.09 to 0.03)	0.32
PSC cataract (present vs absent)	−0.04	(−0.10 to 0.01)	0.11	−0.05	(−0.11 to 0.01)	0.09
Ocular past history (present vs. absent)	0.01	(−0.07 to 0.09)	0.78			
Other ocular diseases (present vs absent)	−0.05	(−0.13 to 0.03)	0.23	−0.03	(−0.11 to 0.05)	0.51
Systemic comorbidity[a]	−0.02	(−0.09 to 0.04)	0.48	0.00	(−0.06 to 0.06)	0.99
Systemic comorbidities[b]	−0.08	(−0.14 to −0.01)	0.03	−0.04	(−0.11 to 0.03)	0.25

VA better logMAR visual acuity in better-seeing eye, *VA worse* logMAR visual acuity in worse-seeing eye, *PSC* posterior subcapsular

*Only variables with a *P* value of less than 0.25 in the univariate analysis were included in the multivariate model

[a] One systemic comorbidity versus no systemic comorbidity

[b] More than 2 systemic comorbidities versus no systemic comorbidity

Table 4 Utility gain (before-and-after utility change by cataract surgery)

Characteristic	1st eye surgery	2nd eye surgery	Bilateral surgery
Age (mean ± SD)	69.0 ± 8.2	69.9 ± 7.9	72.2 ± 7.7
n	157	60	312
Utility (mean ± SD)			
TTO Utility (*n*)	109	38	234
Utility (before surgery)	0.66 ± 0.25	0.64 ± 0.29	0.58 ± 0.29
Utility (after surgery)	0.84 ± 0.28	0.88 ± 0.23	0.85 ± 0.25
Utility gain	0.18 ± 0.27	0.24 ± 0.30	0.27 ± 0.33
P value*	*P* < 0.001	*P* < 0.001	*P* < 0.001
EQ5D Utility (*n*)	138	52	292
Utility (before surgery)	0.85 ± 0.16	0.83 ± 0.16	0.84 ± 0.15
Utility (after surgery)	0.89 ± 0.15	0.92 ± 0.13	0.90 ± 0.15
Utility gain	0.05 ± 0.15	0.09 ± 0.17	0.06 ± 0.16
P value*	*P* < 0.001	*P* < 0.001	*P* < 0.001
HUI3 utility (*n*)	131	47	256
Utility (before surgery)	0.71 ± 0.25	0.70 ± 0.20	0.62 ± 0.24
Utility (after surgery)	0.79 ± 0.18	0.79 ± 0.22	0.76 ± 0.25
Utility gain	0.08 ± 0.21	0.08 ± 0.25	0.14 ± 0.25
P value*	*P* < 0.001	*P* < 0.05	*P* < 0.001

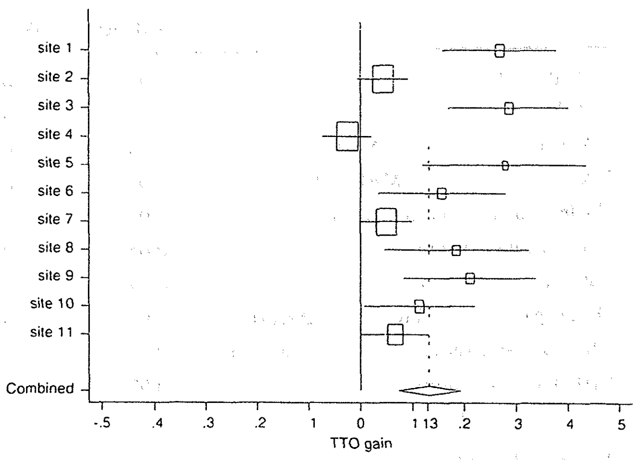
* The significance of the differences in utility before and after cataract surgery was analyzed with a paired *t* test

data of utility gain (TTO) obtained from the multiple centers. The utility gain (TTO) was 0.13 for unilateral surgery and 0.26 for bilateral surgery when all clinical sites were combined in a meta-analysis using the random effect model.

Mean QALYs gained by cataract surgery, which were calculated by multiplying the utility gain [difference in utility (TTO) before and after surgery] and the life expectancy of each patient, together with an assumed annual discount rate of 3%, was 2.40 (95% CI 1.61–3.20) for unilateral operations (the first operation) and 3.40 (95% CI 2.86–3.95) for bilateral operations. The medical costs associated with unilateral cataract surgery and bilateral cataract surgery were estimated at ¥294,055 and ¥495,225, respectively (Table 7). This encompassed the hypothetical cost of YAG for 11.4% of the patients in the study. Given

Table 5 Meta-analysis utility gain (TTO) of unilateral surgery

Clinical sites	Weights	Utility gain	95% CI
Site 1	90.0	0.27	(0.16 to 0.38)
Site 2	116.8	0.04	(-0.01 to 0.09)
Site 3	86.9	0.29	(0.17 to 0.40)
Site 4	117.4	-0.03	(-0.07 to 0.02)
Site 5	68.5	0.28	(0.12 to 0.44)
Site 6	83.6	0.16	(0.03 to 0.28)
Site 7	116.2	0.05	(-0.00 to 0.10)
Site 8	76.6	0.19	(0.04 to 0.33)
Site 9	81.8	0.21	(0.08 to 0.34)
Site 10	91.8	0.11	(0.01 to 0.22)
Site 11	111.0	0.07	(0.00 to 0.13)
Combined		0.13	(0.07 to 0.19)



the cost of cataract surgery, the resultant cost-effectivenesses (¥/QALY) gained from unilateral cataract surgery and bilateral cataract surgery were found to be ¥122,472/QALY and ¥145,526/QALY, respectively. Based on the 2009 yen-US dollar exchange rate, $/QALYs gained from unilateral cataract surgery and bilateral cataract surgery were calculated to be $1,307/QALY and $1,553/QALY, respectively. The results from the utility gains in the EQ5D and HUI3 are also given in Table 8.

Sensitivity analysis

In one-way sensitivity analysis, the cost per QALY was relatively robust against discounting or varying the cost (Table 9). Our results did not vary significantly when varying the treatment effectiveness according to the results of the meta-analysis and were within the range of 95% CI observed in the study. However, varying the life expectancy resulted in a substantially increased cost per QALY.

Discussion

Cost-utility analysis is a type of economic evaluation that quantifies the cost-effectiveness of a process, such as a treatment, a screening, or a diagnostic examination, through the measurement of QALYs in which years of life are adjusted using utility as qualitative weighted factors. Cost-utility analysis is increasingly advocated as a method for assessing the value for money of different health-care interventions since it allows for a comparison of health-care interventions across all medical specialties. Previous studies have demonstrated that cataract surgery is a very cost-effective procedure in medicine [8, 11, 26, 27], and the results of our analysis provide support that this is also the case in Japan. The data presented herein show that cataract surgery yields a ¥/QALY gain of ¥122,472 ($1,307) for unilateral surgery and ¥145,526 ($1,553) for bilateral surgery using TTO utility, a 3% discount rate, and nominal 2009 US dollar-yen exchange rate. The results of our study were roughly comparable to those reported by Busbee ($2,020, first eye, $2,727, second eye) [8, 27]. While there is no explicit threshold for the incremental cost per QALY, there is some consensus on the rule of thumb that costs are economically attractive below $20,000 per QALY, are acceptable up to $50,000 per QALY, and are possibly acceptable up to $100,000 per QALY [28, 29]. Therefore, considering cost, our study has demonstrated that cataract surgery is extremely cost-effective not only for one eye, but also for both eyes. Most previous studies demonstrated the cost-utility of cataract surgery only for one eye. However, because approximately 60% of the patients in our study had cataract surgery in both eyes, our result indicates that the cost-utility of bilateral cataract surgery is virtually identical to that of "incremental" cataract surgery in the actual situation in Japan.

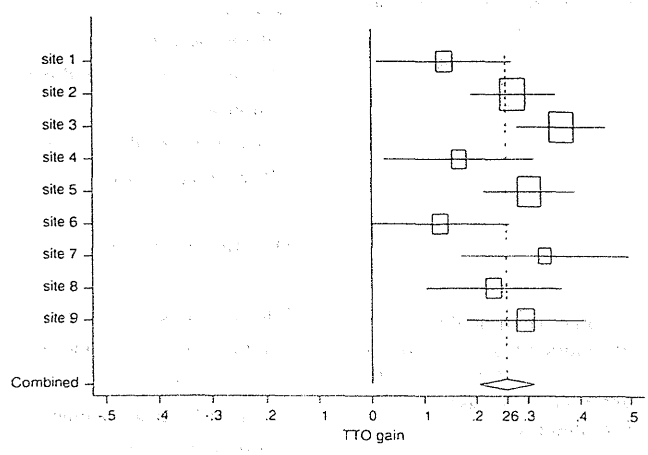
Many of the previous reports were based on models or registry data rather than on a real-world setting [8, 9], indicating that previous estimates were based on observed visual acuity data translated into utility, not on actual measurement of utility obtained from individual patients, as in our study. We measured each patient's utility before and after surgery at 3 months, thus, the change in the utility can reflect the direct effect of utility gained by the cataract surgery without the involvement of other comorbidities.

Although several methods are available to measure utility, the TTO method requires patients to decide which health state they prefer—their present health state or a normal health state in return for which they give up time of life—and thus, it can directly measure the preference-based QOL of patients. Time tradeoff utility is reproducible and reliable on a test-retest basis over a prolonged period of

Table 6 Meta-analysis utility gain (TTO) of bilateral surgery

Clinical sites*	Weights	Utility gain	95%CI
Site 1	130.3	0.14	(0.01 to 0.27)
Site 2	196.8	0.27	(0.19 to 0.36)
Site 3	188.7	0.37	(0.28 to 0.45)
Site 4	114.2	0.17	(0.02 to 0.31)
Site 5	187.2	0.30	(0.21 to 0.39)
Site 6	125.6	0.13	(-0.00 to 0.26)
Site 7	97.2	0.33	(0.17 to 0.50)
Site 8	127.7	0.23	(0.10 to 0.37)
Site 9	149.0	0.30	(0.18 to 0.41)
Combined		0.26	(0.20 to 0.31)

* Owing to the small sample size, 2 sites were excluded from the analysis



time and has excellent intraobserver and interobserver reliability [14, 30]. At the same time, it is applicable to all health states and readily understood by patients, and thus regarded as the most suitable instrument for use in cost-utility analysis [14]. Therefore, the TTO method is accepted as a formal method for quantifying the relative impact of a given health state or disease on patient lives [8, 14, 26, 31, 32]. To measure the utility gain from ophthalmic treatment, the TTO method is more sensitive to small changes in utility than are generic survey questionnaires, such as the EQ5D and HUI3. The EQ5D does not address visual impairment, and the HUI3 has only 2 questions about sight out of 16 questions. Predictably, the utility measured by the TTO method showed higher improvement than did those of the EQ5D and HUI3 in our study. While using generic measures should theoretically allow us to compare results for a variety of different health states, as revealed by previous studies [33–37], our study has shown that disparities exist in the utilities derived from the EQ5D and HUI3.

Utility associated with ophthalmic disease has been most highly correlated with better VA [38]. Data from the analysis presented here also indicate the same relation between visual acuity and utility. Vision is only one of the many factors affecting utility, thus, the vision improvement resulting from cataract surgery seemed to account for a small part of the change in utility. However, the effect of cataract surgery on utility (TTO) was highly significant. Moreover, our findings indicated that even in the utility gain demonstrated by the EQ5D and HUI3, the change in utility was significant. In our study, 144 of 440 patients had better VA of >1.0 (decimal), and the corresponding utilities (TTO) were fairly low (0.685). However, even in the patients with better VA of >1.0 (decimal) a mean utility gain of 0.18 was obtained by cataract surgery. This means that while for clinicians visual acuity is the precise and most important standard to measure the effectiveness of the surgery, it is not so for patients. Although visual acuity is the most important predictive factor of utility, patients place emphasis on their daily life activities and overall subjective quality of life.

One of the most outstanding features of cataract surgery is its ease of maintenance of the visual outcome. After a few months for recovery from the surgery, patients usually do not need any medication or additional treatment for the rest of their lives, and therefore, the additional medical costs are very low. Another feature is the long duration of the benefit of visual outcome. Posterior capsule opacification is the most common long-term complication after cataract surgery, with an estimated incidence of almost 11.4% [19–24], but usually visual losses due to PCO are not very severe. Even for cases of PCO, a one-time YAG capsulotomy can provide lifelong recovery of good vision. Lundstrom and Wendel's long-term study showed that 80% of the patients who had cataract surgery still had improved visual function 7 years after surgery [39]; therefore, the cost-utility of cataract surgery is valid for the life span of the patient.

Some limitations in this study must be considered. Although the common inclusion and exclusion criteria for selection of the patients were established, the study population was not randomly selected at each clinical site. In addition, owing to incomplete questionnaires and withdrawal of patients from the study, complete data for utility (TTO, EQ5D, and HUI3) were obtained from 381, 482, and 434 patients, respectively. Despite this potential source of error in the outcome measures, our samples were not random but representative of the current situation of cataract surgery in Japan since they were large samples obtained

Table 7 Medical costs (2009 nominal Japanese yen-US dollar exchange rate)

Services	Costs (yen)	(US $)[b]
Cataract surgery (1 eye)		
Initial consultation and preoperative visit	¥27,070	US$289
Surgical fee	¥121,000	US$1,292
Cost of hospital treatment	¥127,680	US$1,363
Postoperative visit	¥15,250	US$163
	Subtotal ¥291,000	US$3,106
PCO treatment (1 eye)	¥26,800	US$286
	Total ¥294,055[a]	US$3,139
Cataract surgery (both eyes)		
Initial consultation and preoperative visit	¥27,070	US$289
Surgical fee	¥242,000	US$2,583
Cost of hospital treatment	¥201,260	US$2,148
Postoperative visit	¥19,980	US$213
	Subtotal ¥490,310	US$5,234
PCO treatment (both eyes)	¥43,120	US$460
	Total ¥ 495,225[a]	US$5,286

[a] Value based on the assumption that 11.4% of the patients would develop PCO and need YAG laser capsulotomy

[b] Costs were converted into US dollars using the 2009 foreign exchange rate of 1 US $ = 93.68 Japanese yen (Federal Reserve)

Table 8 Cost-utility of cataract surgery

Group	QALYs gain	Cost	Cost/QALY (yen)	(US dollars)
One eye[a]				
TTO	2.40	¥294,055	¥122,472	US$1,307
EQ5D	0.81		¥364,380	US$3,890
HUI3	1.36		¥216,058	US$2,306
Both eyes				
TTO	3.40	¥495,225	¥145,526	US$1,553
EQ5D	0.75		¥659,421	US$7,039
HUI3	1.85		¥267,834	US$2,859

[a] The utility gain in 1 eye used here is the utility gain for the first eye operation

Table 9 Cost-utility sensitivity analysis

	One eye			Both eyes		
	TTO	EQ5D	HUI3	TTO	EQ5D	HUI3
Base case	¥122,472	¥364,380	¥216,058	¥145,526	¥659,421	¥267,834
Varying the discount rate (%)						
0	¥94,582	¥267,080	¥159,639	¥115,115	¥527,396	¥208,780
5	¥142,193	¥436,283	¥257,266	¥166,742	¥751,480	¥309,322
Varying treatment effectiveness						
Meta-analysis utility[a]	¥168,590	¥487,446	¥287,468	¥146,365	¥629,371	¥246,812
QALYs (upper 95% CI)	¥92,036	¥245,046	¥154,198	¥74,539	¥297,025	¥130,286
QALYs (lower 95% CI)	¥182,984	¥701,802	¥360,362	¥102,780	¥573,207	¥204,063
Varying life expectancy (years)						
5	¥354,710	¥1,284,083	¥738,832	¥387,197	¥1,725,523	¥745,821
10	¥190,450	¥688,653	¥396,835	¥207,903	¥925,654	¥400,020
Varying costs						
Increased by 25%	¥153,090	¥455,476	¥270,073	¥181,908	¥824,276	¥334,792
Decreased by 25%	¥91,854	¥273,285	¥162,044	¥109,145	¥494,566	¥200,875
Without PCO treatment	¥121,200	¥360,595	¥213,813	¥144,082	¥652,876	¥265,176

[a] The utility gain from the results of the meta-analysis and the mean life expectancy of the whole sample (16.3 years) were used

from 12 different clinical sites that included university hospitals, general hospitals, and private practices The mean age and postoperative better VA of the missing samples did not significantly differ from the values of the entire sample, indicating that there was no difference between patients who answered all the questions on the follow-up questionnaire and those who did not. Another limitation of this study was the incomplete analysis of all the incremental costs of cataract surgery or of those induced by performing surgery versus no surgery In this study, only the direct cost (including PCO treatment for 11.4% of the patients) without any complications was assessed An in-depth cost analysis, the influence of complications, and a risk analysis may provide further understanding of the cost-effectiveness of cataract surgery

In summary, routine cataract surgery in Japan is highly cost-effective, not just for unilateral surgery, but also for bilateral surgery Contributing factors are the high clinical effectiveness of the surgery, the substantial improvement in patient-perceived quality of life, and the reasonable cost of the surgery These results were strongly supported by the results derived from the generic outcome measures, such as the EQ5D and HUI3, and this consistency supports the validity and generalizability of our findings Given the limited resources for health care, cataract surgery is one of the most powerful health-care interventions to produce great health gains for a great number of people at low cost This information, taking into account the clinical effectiveness that incorporates patient preferences and cost, will play an increasingly crucial role in the evaluation of health care in the future.

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Appendix

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CLINICAL INVESTIGATION

Quality of life and cost-utility assessment after strabismus surgery in adults

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Abstract
Purpose To understand the functional and psychosocial aspects of strabismus surgery, an evaluation based on the patient's perspective is essential. In this study, we assessed quality of life and utility in adult patients who had undergone strabismus surgery, and we modeled the cost of providing this intervention in order to calculate the cost-utility of strabismus surgery in adults.
Methods The study population comprised 226 patients with strabismus aged 18 years or older who were scheduled for ocular alignment surgery at 12 facilities of the Strabismus Surgery Study Group in Japan. Survey questionnaires consisting of the Japanese versions of the Visual Function Questionnaire-25 (VFQ-25) and 8-Item Short-Form Health Survey (SF-8) and utility assessment by a time trade-off method were administrated preoperatively and 3 months postoperatively. On the basis of the cost model and measured utility data, the gains in quality-adjusted life years (QALYs) and $/QALY were estimated.
Results Postoperatively, the subscale scores of the VFQ-25 and the physical and mental component summary scores of the SF-8 showed a statistically significant improvement. A significant improvement of utility was also noted. 0.82 ± 0.28 postoperatively versus 0.76 ± 0.31 preoperatively. On the basis of the life expectancy of these patients and the cost model, the surgery resulted in a mean value gain of 0.99 QALYs and a cost-utility for strabismus surgery of 1,303 $/QALY.
Conclusions By using standard tools to assess vision-associated and general health status, we confirmed the psychosocial benefits of corrective surgery for adults with strabismus. Our study concurrently demonstrated that strabismus surgery in adults is very cost-effective.

Keywords Burden of disease · Quality of life · Strabismus · Utility · VFQ-25

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Introduction

Several studies have demonstrated favorable clinical and functional outcomes of strabismus surgery in adults [1–6]. Elimination of diplopia, sensory fusion, restoration of binocularity, and expansion of the binocular visual fields are recognized as functional outcomes of adult strabismus surgery. An additional aspect of adult strabismus is psychosocial functioning [1, 7–9]. Olitsky and associates [8] reported that strabismic participants were more likely to be perceived as being less intelligent and less competent and as having poorer communication skills than orthotropic participants. Coats and associates [9] reported potential adverse vocational implications of strabismus. These negative social impacts associated with noticeable strabismus are likely to cause patients to develop psychological difficulties. Menon and associates [10] reported that 80% of patients with strabismus felt that they had problems in their social lives and that a positive change in self-esteem and self-confidence was noticed by 95% of the patients after surgery. Satterfield and associates [11] reported that correction of strabismus in adults might offer improvement in psychosocial functioning. From these observations, a recent report of the

American Academy of Ophthalmology concluded that surgical treatment of strabismus in adults is generally safe and effective in improving ocular alignment [12]

Despite these favorable outcomes, the value of adult strabismus surgery appears to be underestimated and is sometimes regarded as only a cosmetic treatment, even by ophthalmologists [13] Unlike other eye surgeries, such as cataract surgery and retinal detachment surgery, adult strabismus surgery does not usually improve the visual acuity nor save the eyes from permanent visual loss To capture the multidimensional outcomes of strabismus surgery including the functional and psychosocial aspects, evaluation based on the patient's perspective is important For patient-based outcomes, quality of life (QOL) assessment and utility analysis are generally used In the field of ophthalmology, assessment of the impact of eye disease on the daily lives of patients and on social economics has been actively performed in the United States and European countries [14–17] Regarding strabismus surgeries, however, there are as yet few reports that use quantitative measurement to evaluate the functional and psychosocial benefits and also assess the cost-utility of strabismus surgery [18, 19]

For quantitative evaluation of QOL, it is essential to apply measurement tools with verified reliability and validity Hence, the Japanese versions of the Visual Function Questionnaire-25 (VFQ-25) and 8-Item Short-Form Health Survey (SF-8) were selected for this study [20, 21] The VFQ-25, originally developed by Mangione and associates [22], has become the standard tool to assess vision-related QOL. The SF-8 is a shortened form of the standard tool for generic QOL, the 36-Item Short-Form Health Survey (SF-36) [23]

Another method adopted in the present study was utility assessment, which summarizes QOL status as a single number [24] Utility assessment is a formal method for quantifying the relative impact of a given health state or disease on a patient's life Although several methods have been developed to assess utility, the time trade-off method is the most standard and widely used [24, 25]; hence, it was used in this study Utilities could be used to compare patients' preferences for strabismus outcomes with those for different symptomatic medical conditions, such as angina, asthma, and visual impairment [26–28] They could also be used as weights in the calculation of quality-adjusted life years (QALYs), which are used as denominators in cost-utility analyses [26–28] The outcome of an intervention is thus evaluated by offsetting the cost of the intervention with QALYs gained from the intervention In this study, we assessed the utilities in adult patients who underwent strabismus surgery and modeled the cost to provide this intervention in order to calculate the cost-utility of strabismus surgery in adults.

Participants and methods

This multicenter study was conducted at 12 facilities of the Strabismus Surgery Study Group in Japan (see Appendix) The inclusion criteria were that the patients had to be aged 18 years or older and scheduled for strabismus surgery at any of these facilities Patients who were unable to answer the survey questionnaire or who planned to undergo surgery or laser treatment for an ocular comorbidity were excluded. The principles of the World Medical Association Declaration of Helsinki were followed Each patient received a thorough explanation of the purpose of the study and of all the procedures involved in the study and had the opportunity to examine the informed consent form prior to enrollment The protocol was approved by the institutional review board of each facility, and all patients provided written informed consent.

Registration of the patients was carried out between March 2007 and November 2008 with 273 patients being initially registered Later, however, owing to reasons including withdrawal of consent, insufficient information on clinical findings from the responsible physicians, and inability to collect survey forms from patients, we were unable to obtain complete information on 47 patients. Therefore, the final number of participants was 226 after exclusions

For the 226 registered patients, information on ophthalmological findings was collected from the responsible physicians, and information on QOL and utility assessment collected from the patients by means of survey questionnaires The questionnaires consisted of the Japanese versions of the VFQ-25 and SF-8 and of a questionnaire for the time trade-off measurements The reliability and validity of the Japanese versions of the VFQ-25 and SF-8 are considered comparable to the English versions [20, 21]

Utility is defined on a continuous scale from 0 to 1, where 0 corresponds to the worst possible QOL weight (equal to death) and 1 to the best possible QOL weight (equal to perfect health) The time trade-off method used in the study consisted of 2 questions [19, 24] In the first question, the patient was asked to estimate his/her own life expectancy The patient was then asked if he/she would be willing to trade a certain portion of the remaining life from the estimated life expectancy (off the end of his/her life) in return for being free from strabismus and all its associated effects under these hypothetical conditions Time trade-off utility was calculated according to the following equation Utility $= 1 - x/t$ (where x = years of life he/she would be willing to give up and t = his/her own life expectancy) After having had the questionnaires explained to them, the patients were asked to fill them out at home and to return them by post. The surveys were distributed preoperatively, either at the initial consultation or at the preoperative visit, and 3 months postoperatively.

All medical costs in Japan are uniformly standardized by a social medical insurance system. Medical costs associated with strabismus surgery were calculated on the basis of the Japanese Social Insurance Medical Fee Payment for fiscal year 2008 (Table 1). The surgical fee was calculated from the information regarding the number and type of surgery performed for each case. Other medical costs included the initial consultation, preoperative visit, anesthesia fees, postoperative medication, and 3 postoperative visits (the next day, 1 week, and 1 month after surgery) For cases in which a second operation was performed because the first operation was not adequate, an additional surgical fee, postoperative drug costs, and costs for 3 postoperative visits were added The costs of complications were not included in the medical cost model

Cost-utility analysis was performed on the basis of the cost model and measured utility data. The utility gain was assumed to last until the end of the remaining life expectancy of each patient as estimated using the abridged life tables for 2008 in Japan. The number of QALYs gained was calculated by multiplying the measured utility gain (difference in utility before and after surgery) and the patient's life expectancy, together with an assumed annual discount rate of 3%. The cost for strabismus surgery was divided by the number of QALYs gained, which resulted in an estimate of Japanese yen/QALY The $/QALY was calculated on the basis of the yen–US dollar exchange rate in November 2008 (1 US dollar = 96.4 Japanese yen) One-way sensitivity analyses were performed by varying the discount rate of 0 and 5%, medical cost of 25%, utility gain within the 95% confidence interval (CI) observed in the study, and duration of alignment in the shorter term (5, 10, and 20 years).

For statistical analyses, IBM SPSS Statistics software (IBM SPSS Japan, Tokyo, Japan) was used The results were given as the mean and standard deviation (SD) or as the mean and 95% CI. The significance of the differences was analyzed with the Wilcoxon signed rank test or the chi-squared test. A probability value <0.05 was considered statistically significant. Multiple linear regression models were used to assess the associated factors affecting postoperative utility value. The regression model was adjusted for age, sex, type of strabismus, cure grades based on the Japanese criteria, postoperative composite VFQ-25 score, and summary SF-8 scores. Each variable was first analyzed in a univariate model and then all variables were included in a multivariate model

Table 1 Medical costs associated with extraocular muscle surgery for strabismus in Japan

Service	Cost (yen)
Initial consultation and preoperative visit	21,000
Surgical fee	
Recession	42,800
Resection	42,000
Recession and resection	84,400
Oblique muscle surgery	66,100
Horizontal and oblique muscle surgery	94,300
Muscle transposition	124,000
Anesthesia fee and postoperative drug costs	6,000
Three postoperative visits	10,000

Results

The 226 patients (106 men and 120 women) enrolled in the study ranged in age from 18 to 87 years (average 45.7 ± 18.5 years) (Table 2) Of these, 168 patients were diagnosed as having concomitant strabismus (CS group; 136 patients with exotropia and 32 with esotropia) and 58 patients with noncomitant strabismus (NCS group; 38 patients with paralytic strabismus, 17 with restrictive strabismus, and 3 with strabismus of unknown etiology) When the patients were divided into the CS group or NCS group, there were no statistical differences in age and sex between the 2 groups Approximately one half of the patients in the CS group had congenital or childhood-onset strabismus ($P < 0.001$, chi-squared test), and 32 cases (19 5%) had a history of previous strabismus surgery ($P < 0.01$, chi-squared test) In contrast, 70 7% of patients in the NCS group were adulthood-onset patients and likely to suffer from diplopia ($P < 0.001$, chi-squared test)

There were no major surgical complications such as postoperative infections, lost muscles, and refractory diplopia (Table 3); however, 16 patients (8 in the CS group and 8 in the NCS group) required additional surgery because of inadequate alignment. When postoperative conditions were classified according to the Japanese criteria of strabismus cure [29], 38 patients (16.8%) were classified as excellent, 41 (18.1%) as good, 5 (2 2%) as fair, 100 (44.2%) as cosmetically satisfactory, and 42 patients (18 6%) as not improved. Difference in the grades of cure status between the CS and NCS groups was not statistically significant (Pearson's chi-squared test)

The VFQ-25 scores of the participants are shown in Table 4. The VFQ-25 scores are expressed from 0 to 100 by each subscale with 0 representing the worst and 100 the best. One hundred and fifty participants (68.1%) answered the driving subscale of the questionnaire, the remaining participants who did not drive completed the rest of the questionnaire. When the postoperative subscale scores of the VFQ-25 were compared with those obtained

Table 2 Demographic features of study participants preoperatively

	Strabismus patients enrolled in the study		
	CS (n = 168) (%)	NCS (n = 58) (%)	Total (n = 226) (%)
Age (mean ± SD, years)	45.1 ± 18.4	47.6 ± 18.7	45.7 ± 18.5
Sex			
Male	82 (48.8)	24 (41.4)	106 (46.9)
Female	86 (51.2)	34 (58.6)	120 (53.1)
Onset of strabismus			
From birth/childhood	88 (52.4)	17 (29.3)	105 (46.4)
Adulthood	69 (41.1)	41 (70.7)	110 (48.7)
Unknown	11 (6.5)	0	11 (4.9)
Direction of strabismus			
Esotropic	32 (19.0)	13 (22.4)	45 (19.9)
Exotropic	136 (81.0)	1 (1.7)	137 (60.6)
Vertical	0	28 (48.3)	28 (12.4)
Others	0	16 (27.6)	16 (7.1)
Previous strabismus surgery	32 (19.5)	2 (3.4)	34 (15.0)
Presence of diplopia	35 (20.8)	41 (70.7)	76 (9.5)

CS concomitant strabismus, *NCS* noncomitant strabismus

Table 3 Surgical results of study participants

	Strabismus patients enrolled in the study		
	CS (n = 168) (%)	NCS (n = 58) (%)	Total (n = 226) (%)
Major complications	0 (0.0)	0 (0.0)	0 (0.0)
Additional surgery	8 (4.8)	8 (13.8)	16 (7.1)
Cure status			
Grade 4: excellent	26 (15.5)	12 (20.7)	38 (16.8)
Grade 3: good	28 (16.7)	13 (22.4)	41 (18.1)
Grade 2: fair	5 (3.0)	0 (0.0)	5 (2.2)
Grade 1: cosmetically satisfactory	76 (45.2)	24 (41.3)	100 (44.2)
Grade 0: not improved	33 (19.6)	9 (15.5)	42 (18.6)

CS concomitant strabismus, *NCS* noncomitant strabismus

preoperatively, all VFQ-25 subscales except for the general health subscale in the NCS group showed a statistically significant improvement ($P < .05$, Wilcoxon signed rank test).

The SF-8 scores of the participants are shown in Table 5. The SF-8 scores including the physical and mental component summary scores were all between 45 and 50. When the preoperative and postoperative subscale SF-8 scores of all participants were compared, 6 out of 8 subscales (not the bodily pain and vitality subscales) showed statistically significant differences ($P < 0.05$, Wilcoxon signed rank test). The differences between the summary scores for the physical and mental component scores were statistically significant ($P < 0.05$, Wilcoxon signed rank test).

The distribution of utility is shown in Fig. 1. Thirty-three patients were excluded because they did not answer the questions that determine utility values. The profile of these 33 patients did not significantly differ in age, sex, and types of strabismus from those of the remaining 193 patients. Of the 193 patients who completed the time trade-off questionnaire, 39 indicated the same utility before and after surgery, 4 reported a loss in utility, and the remaining 150 patients reported a gain in utility. Overall, the mean utility value in the preoperative period was 0.76 ± 0.31 (Table 6). Postoperatively, the mean utility value was 0.82 ± 0.28, resulting in a 0.05 ± 0.15 gain in utility. Statistical differences in preoperative utility, postoperative utility, and gain in utility were not observed between the CS and NCS groups (Wilcoxon signed rank test).

Factors associated with postoperative utility are shown in Table 7. When each variable was analyzed in a univariate model, postoperative utility had a significant, but weak correlation with age, VFQ-25 composite score, and SF-8 physical component summary score ($r = -0.303$, $r = 0.187$, and $r = 0.252$, respectively, Pearson's product-

Table 4 Preoperative and postoperative VFQ-25 subscale scores of the participants

Subscales	CS ($n = 168$)		NCS ($n = 58$)		Total ($n = 226$)	
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
General health	60.8 ± 18.1	65 1 ± 18.5*	55.9 ± 18 7	59.2 ± 17.5	59 5 ± 18.3	63.3 ± 18.8*
General vision	58.8 ± 19 1	73.2 ± 15.9*	50.8 ± 19.3	69.8 ± 16.6*	56.7 ± 19.4	72.4 ± 16.0*
Ocular pain	76.0 ± 20.4	82.3 ± 15.6*	69.0 ± 24.8	79.5 ± 19 1*	74.2 ± 21.8	81.5 ± 16.5*
Near vision	75.0 ± 18.0	83.8 ± 14.7*	68.2 ± 19.1	77.6 ± 17 1*	73.2 ± 18.5	82.3 ± 15.3*
Distance vision	72.3 ± 18.9	82.7 ± 14.8*	65.5 ± 21.1	76.9 ± 16 1*	70.5 ± 19 7	81.3 ± 15 1*
Vision-specific						
Social functioning	82.0 ± 16.3	89.8 ± 13.0*	75 8 ± 21.1	85.6 ± 12.6*	80.4 ± 17.9	88.9 ± 12.8*
Mental health	65.2 ± 23.7	79.9 ± 18.3*	52.1 ± 25.8	72.3 ± 24.2*	61 8 ± 24 9	78 1 ± 20.2*
Role difficulties	81.2 ± 18.5	88.4 ± 15.4*	69.2 ± 21.8	80.0 ± 19 2*	78 1 ± 20.0	86.3 ± 16.8*
Dependency	85.4 ± 19.3	91.6 ± 14.5*	79.7 ± 23.7	87.0 ± 19.3*	83 9 ± 20.6	90.4 ± 15.9*
Driving	71.6 ± 26.4	77.5 ± 22.3*	58.1 ± 31.7	72.4 ± 26.8*	68.1 ± 28.4	75 9 ± 23.9*
Color vision	91.0 ± 13.8	93.3 ± 12.1*	86.2 ± 15.8	91.7 ± 11.9*	89.8 ± 14.5	93.0 ± 12.0*
Peripheral vision	64.8 ± 23 2	75.2 ± 21.4*	57.6 ± 29.7	68.0 ± 24.4*	63.0 ± 25.2	73 6 ± 22.2*
Composite score	73.5 ± 15.2	81.9 ± 12.0*	65.9 ± 18.3	76.7 ± 13.8*	71 6 ± 16.3	80.6 ± 12.6*

Results are expressed as mean ± SD

CS concomitant strabismus, *NCS* noncomitant strabismus

* Statistically significant difference ($P < 0.05$, Wilcoxon signed rank test)

Table 5 Preoperative and postoperative SF-8 subscale scores of the participants

Subscales	CS ($n = 168$)		NCS ($n = 58$)		Total ($n = 226$)	
	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
General health	49 9 ± 6.8	51.8 ± 6.3*	49 1 ± 7 1	50.3 ± 7 1	49 7 ± 6.9	51.4 ± 6.6*
Physical functioning	47 9 ± 6.0	49.6 ± 6.7	47 4 ± 6.4	48.9 ± 5.9*	48.6 ± 6.2	49.4 ± 6.5*
Role physical	47.5 ± 7 6	49 9 ± 6.0	44.8 ± 11 3	48.5 ± 6.9*	47 7 ± 8.8	49.5 ± 6.3*
Bodily pain	52.0 ± 8.5	52.5 ± 8.8	51 3 ± 9 2	53.6 ± 8.8*	52.2 ± 8.7	52.8 ± 8.8
Vitality	50.6 ± 6.2	51.3 ± 6.6	49 9 ± 7 3	51.1 ± 6.4	50.6 ± 6.5	51.3 ± 6.5
Social functioning	46 7 ± 8.5	49 3 ± 7 8*	46.5 ± 9.6	47.4 ± 8.4	47 2 ± 8.8	48.8 ± 8.0*
Mental health	49.1 ± 7 1	50.3 ± 7.3*	46.0 ± 6.9	48.9 ± 7.4*	48.2 ± 7 1	49 9 ± 7 3*
Role emotional	47.7 ± 7.0	49.9 ± 6.4*	45 6 ± 10.4	48.7 ± 5.8*	47 7 ± 8.0	49.6 ± 6.3*
Physical component summary	48.6 ± 7.0	50.0 ± 6 6	47 7 ± 7 8	49.5 ± 7.4*	49.1 ± 7.3	49.8 ± 6.8*
Mental component summary	47 7 ± 7 2	49 2 ± 7 0*	45 3 ± 7 9	47.3 ± 8.0	47.0 ± 7.4	48.7 ± 7 3*

Results are expressed as mean ± SD

CS concomitant strabismus, *NCS* noncomitant strabismus

* Statistically significant difference ($P < 0.05$, Wilcoxon signed rank test)

moment correlation). In a multiple linear regression model adjusting for age, sex, type of strabismus, postoperative cure grade, VFQ-25 composite score, and SF-8 physical and mental component summary scores, only age had a significant effect, although the standardized β coefficient was small (−0.004).

The QALYs gained by the surgery, which were calculated by multiplying the utility gain (difference in utility before and after surgery) and the patient's life expectancy, together with an assumed annual discount rate of 3%, was 0.99 ± 2 89 The average medical cost associated with extraocular muscle surgery for strabismus was 124,926 ± 32,395 yen Given the cost of strabismus surgery, this resulted in a cost-utility of 125,630 ± 41,728 yen/QALY. The $/QALY, calculated based on the yen–US dollar exchange rate in November 2008, was 1,303 ± 434 $/QALY Differences in QALYs gained by surgery, medical costs, and yen/QALY ($/QALY) between the CS and NCS groups were not statistically significant (Wilcoxon signed rank test)