Cost-Effectiveness Analysis of Telemedicine to Evaluate Diabetic Retinopathy in a Prison Population

Noriaki Aoki, MD[1,2]
Kim Dunn, MD[1,3]
Tsuguya Fukui, MD[4]
J. Robert Beck, MD[5]
William J. Schull, PhD[3]
Helen K. Li, MD[6]

OBJECTIVE — A cost-effectiveness analysis was conducted to investigate the clinical and economic impact of teleophthalmology in evaluating diabetic retinopathy in prison inmates with type 2 diabetes.

RESEARCH DESIGN AND METHODS — Based on a hypothetical teleophthalmology system to evaluate diabetic retinopathy patients with type 2 diabetes in a prison care setting, a Markov decision model was developed with probability and cost data derived primarily from published epidemiological and outcome studies. A 40-year-old African-American man with type 2 diabetes was used as a reference case subject. The number of quality-adjusted life-years (QALYs) gained was used as the clinical outcome, and the cost in U.S. dollars from the year 2003 was used as the economic outcome. Teleophthalmology and nonteleophthalmology strategies were compared using an expected QALYs calculation and two types of sensitivity analyses: probabilistic and traditional *n*-way sensitivity analyses.

RESULTS — The teleophthalmology strategy dominates in the cost-effectiveness analysis for the reference case subject: \$16,514/18.73 QALYs for teleophthalmology and \$17,590/18.58 QALYs for nonteleophthalmology. Ninety percent of the Monte Carlo simulations showed cost effectiveness (annual cost/QALYs ≤\$50,000) in the teleophthalmology strategy based on an assumed inmate population. Teleophthalmology is the better strategy if the number of diabetic inmates in the prison community is >500.

CONCLUSIONS — Our cost-effectiveness analysis demonstrates that teleophthalmology holds great promise to reduce the cost of inmate care and reduce blindness caused by diabetic retinopathy in type 2 diabetic patients.

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Local, state, and federal prison populations in the U.S. now exceed 2 million and are growing. The current cost for inmate medical care is estimated at over 5 billion dollars annually (1). A significant portion of prison health care delivery is dedicated to transportation and related security costs for sending inmates from remote prison locations to outside health care specialists. Because of this, telemedicine evaluation of diabetic retinopathy is seen by many as an ideal tool for health care delivery in a prison setting.

Adult-onset (type 2) diabetes is the seventh leading cause of death in the U.S. and a leading cause of blindness. The incidence of diabetes is increasing and may be even more acute in prison populations. Baillargeon et al. (2) studied 170,215 Texas Department of Criminal Justice inmates. They discovered that the three leading causes for higher rates of many diseases were low socioeconomic status, poor access to health care, and high-risk behavior (3). Diabetes was reported the 10th most prevalent disease, found in ~4,400 prison inmates (2.6% of total inmates).

Blindness from diabetic retinopathy has been shown to be preventable with timely treatment (4). Because the condition is often asymptomatic in its early phase, regular evaluation is critical to managing diabetic retinopathy. Cost-use studies have demonstrated an overall cost effectiveness of retinopathy detection for type 2 diabetic patients (5–8). A literature review did not reveal annual evaluation rates in the U.S. prison population, but annual evaluation rates for diabetic retinopathy range from 18 to 65% in the general population (8). Although telemedicine has been recognized as a tool in providing health care for prison inmates, the clinical effectiveness and economic value of telemedicine has not been clearly established. An ophthalmologist at the University of Texas Medical Branch at Galveston (UTMB) has designed a teleophthalmology system to evaluate diabetic retinopathy patients with type 2 diabetes in the Texas Department of Corrections regional medical facility. We evaluated the cost effectiveness of this hypothetical system to investigate its potential clinical and economic significance.

RESEARCH DESIGN AND METHODS

Perspective, target audience, and type of analysis

The use of telemedicine, or more specifically teleophthalmology, to reduce the frequency of late complications due to diabetes in a prison population is closely related to the allocation of budgetary re-

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From the [1]School of Health Information Sciences, University of Texas Health Science Center–Houston, Houston, Texas; the [2]Center for Health Service, Outcomes Research and Development–Japan (CHORD-J), Tokyo, Japan; the [3]The Schull Institute, Houston, Texas; the [4]Department of General Medicine and Clinical Epidemiology, Kyoto University Graduate School of Medicine, Kyoto, Japan; the [5]Department of Information Science and Technology, Fox Chase Cancer Center, Philadelphia, Pennsylvania; and the [6]Department of Ophthalmology and Visual Sciences, the University of Texas Medical Branch, Galveston, Texas.

Address correspondence and reprint requests to Noriaki Aoki, MD, PhD, MS, FJSIM Assistant Professor, School of Health Information Sciences, University of Texas, Health Science Center–Houston, 7000 Fannin, UCT-600, Houston, TX 77030. E-mail: noriaki.aoki@uth.tmc.edu.

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Abbreviations: ICER, incremental-effectiveness ratio; NNS, number needed to screen; QALY, quality-adjusted life-year; UTMB, University of Texas Medical Branch at Galveston.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

sources. Therefore, this analysis is targeted to policy makers including administrators of jails, state prisons, federal detention facilities, and physicians charged with inmate care. Major outcomes in this study are reported as quality-adjusted life-years (QALYs) gained and costs generated. We assessed the lifetime cost and QALYs gained based on a 3% annual discount rate as recommended by the Panel on Cost Effectiveness in Health and Medicine (9). We used a health care system perspective for this analysis and assumed all costs related to healthy inmates are "sunk" costs (expenses already incurred and therefore not recoverable regardless of future events).

Teleophthalmology program

The UTMB supports four regional medical facilities that provide primary health care to 125,000 inmates at prison units throughout East Texas. The Eastern Regional Medical Facility is located 120 miles north of Galveston. A strategy based on a hypothetical teleophthalmology system for evaluating diabetic retinopathy patients with type 2 diabetes in the Texas Department of Corrections Eastern Regional Medical Facility was used in this study.

In this strategy, diabetic patients at the regional prison medical facility would be consented and vision acuity evaluated using the Snellen chart and pinhole. Patients would then be consecutively imaged using a Topcon store-and-forward telemedicine system. Because undilated pupils progressively decrease in size when multiple images are taken, photographic quality is better with dilation. The system would be composed of a Topcon TRC-NW6S nonmydriatic retinal camera, JVC three-chip CCD color video camera, Windows 2000–based Intel Pentium III computer and monitor, and Topcon IMAGEnet 2000 Lite software. This system captures 45°, 24-bit color, 280 × 1,024 pixel images saved as uncompressed TIFF files. Ten 45° field undilated digital images would be taken per eye. The macular field would be taken as a stereo pair. The system was chosen because of its ergonomic design, on-screen alignment and focus guides, and mosaic software. The system also provides nine internal fixation points, enabling the operator to efficiently build an image showing a large area of the retina. The IMAGEnet mosaic tool allows automatic construction of a montage approximating a 75° field of view. The large field size lowers the possibility of missing diabetic retinal lesions located outside smaller photographic fields. Compared with small fields of view, large-field photography also permits distinguishing levels of retinopathy. A UTMB ophthalmologist would review and grade the montage images for diabetic retinopathy features.

Decision analysis model

A Markov model compared two strategies of evaluating diabetic retinopathy in prison inmates with type 2 diabetes: *1*) the teleophthalmology strategy and *2*) the nonteleophthalmology strategy. We classified diabetic retinopathy into five groups based on published cost-effectiveness analyses: (6,8) no retinopathy, nonproliferative retinopathy, proliferative retinopathy (levels greater than 53e), clinically significant macular edema, and legal blindness (defined as visual acuity of <20/100 in the better eye) (8).

Under the teleophthalmology strategy, screening and follow-up evaluations would be performed using teleophthalmology as described above. Patients would receive periodic telemedicine evaluation based on the severity of retinopathy. Patients would receive pan-retinal laser photocoagulation if proliferative retinopathy was detected or focal laser photocoagulation if clinically significant macular edema was detected.

Under the nonteleophthalmology strategy, screening and follow-up evaluation would be performed by eye care providers at the UTMB. Many patients would receive periodic evaluation, but others may not receive diagnostic and therapeutic effort until they experienced decreased vision from complications due to proliferative retinopathy or clinically significant macular edema. Clinical courses after detection of retinopathy would be similar to those in the teleophthalmology strategy except for the probability of disease progression. Age, disease-specific mortality, sex, and ethnicity-related mortality were considered in both strategies.

We selected a 40-year-old African-American man as a reference case subject based on a report by Baillargeon et al. (2). They reported that the largest segment of the diabetic population in the Texas prison system was 30- to 49-year-old African-American men, ~37% of all diabetes inmates. Further case-mix analyses were performed with a cohort of 10,000 diabetic inmates based on the age, sex, and ethnicity of the Texas prison system also described by Baillargeon et al. (2). The probability of being in a particular health state during each month in a Markov cycle (10,11) was iteratively calculated with computer simulation (DATA Professional; TreeAge Software, Williamstown, MA) until all patients in both cohorts progressed to death. Cumulative outcomes obtained for each cohort were measured as QALYs with the half-cycle correction (10).

Data sources and baseline probabilities

Probability data incorporated into the decision model are shown in Table 1. Data on the prevalence of each diabetic retinopathy type and the incidence of progression were derived from the large, long-term cohort studies (12–14).

Outcomes of pan-retinal laser photocoagulation and focal laser photocoagulation were derived from articles by Blankenship (14). The relative benefit of treatment versus no treatment was assumed to be permanent, based on two 15-year follow-up studies of patients treated with photocoagulation (15,16).

The annual mortality associated with each health state was calculated with disease-specific and age-specific mortality (17–19). Mortality rates were based on life tables published by the U.S. government. These mortality rates were modified to reflect the increased mortality rates observed in patients with diabetes in general (8) and further adjusted with retinopathy stages based on the observational study (17). The frequency of evaluation for each level of retinopathy was based on recommendations of the American Academy of Ophthalmology (20). In our analysis, we used: no retinopathy, 12 months; proliferative retinopathy, 3 months; proliferative after laser treatment, 3 months; and clinically significant macular edema, 3 months. For simplicity of analysis, we assumed nonproliferative retinopathy equaled 6 months.

Characteristics of retinopathy evaluation in the no teleophthalmology group (sensitivity and specificity) were obtained from published literature (21,22). Characteristics of retinopathy evaluation by digital photography were derived from two recently published articles (23,24).

Three important assumptions sub-

Table 1—*Probabilities* in the model*

Item	Baseline value	(Range) or [95% CI]	References
Natural course			
Prevalence			12
No retinopathy (NR)	0.741	[0.73–0.75]	
Nonproliferative retinopathy (NPDR)	0.254	[0.24–0.26]	
Proliferative retinopathy (PDR)	0.005	[0.0035–0.0072]	
Progression			12–14
NR to NPDR	0.065	[0.05–0.08]	
NPDR to PDR	0.116	[0.11–0.13]	
NPDR to clinical significant macular edema (CSME)	0.115	[0.07–0.17]	
PDR to legal blindness with photocoagulation	0.017	[0.01–0.04]	
CSME to legal blindness with photocoagulation	0.015	[0.00–0.05]	
PDR to legal blindness without photocoagulation	0.088	[0.01–0.30]	
CSME to legal blindness without photocoagulation	0.050	[0.02–0.11]	
Mortality multipliers			8, 17
NR	1.8	[1.60–2.00]	
NPDR	1.36	[1.24–1.48]	
PDR	1.76	[1.64–1.88]	
CSME	1.76	[1.64–1.88]	
Utility			
Legal blindness	0.71	[0.58–0.84]	30
Characteristics of screening test			
Nonteleophthalmology (face-to-face examination)			21, 22
NR called NPDR	0.05	[0.04–0.06]	
NR called PDR	0.003	[0.0002–0.012]	
NPDR called NR	0.22	[0.21–0.23]	
NPDR called PDR	0.02	[0.01–0.04]	
PDR called NR	0.02	[0.01–0.04]	
PDR called NPDR	0.03	[0.02–0.04]	
Sensitivity of CSME	0.82	[0.61–0.94]	
Specificity of CSME	0.79	[0.61–0.91]	
Teleophthalmology (digital image evaluation)			23, 24
NR called NPDR	0.04	[0.02–0.06]	
NPDR	0.10	[0.06–0.15]	
NPDR called PDR	0.004	[0.00–0.01]	
PDR called NPDR	0.19	[0.04–0.48]	
Sensitivity of CSME	0.88	[0.69–0.97]	
Specificity of CSME	0.94	[0.89–0.97]	
Assumptions			
Number of type 2 diabetic patients	750	(10–1000)	
Percent of examined patients with nonteleophthalmology	0.25	(0.0–1.0)	
Percent of examined patients with teleophthalmology	0.75	(0.0–1.0)	

*All probabilities represent annual transition probabilities in the Markov model.

jected to further sensitivity analyses were used in this study. *1*) The total number of diabetic patients in a targeted prison was assumed to be 750, calculated on the prevalence of diabetes and an average number of prison inmates. *2*) The proportion of examined patients without teleophthalmology was assumed to be 25% in the target population. *3*) The percent of patients examined using teleophthalmology was calculated to be 75% based on the assumption that the hypothetical system will improve the retinal examination rate. Transition probabilities were converted from rates with the DEALE (declining exponential approximation of life expectancy) method (25,26).

Utility measurement

Utility, the quantitative evaluation of patient-derived health states, refers to the desirability or preference that individuals or societies have for a given outcome (27,28). Patient preferences are the levels of satisfaction, distress, or desirability that people associate with a specific health outcome (29).

Quality weight assigned to legal blindness was obtained from a recent report by Brown et al. (30). They measured the utility of legal blindness from diabetic retinopathy patients with best-corrected visual acuity decreased to worse than 20/100 using the standard gamble method, which was subjected to sensitivity analyses across the full range (0.0–1.0) of sen-

Table 2—*Cost data in the mode*

Items	Baseline cost	Sensitivity analysis range	References
Teleophthalmology			
Initial cost	$70,200	[$56,160–$84,240]	*
Annual maintain cost	$83,930	[$67,144–$100,716]	*
Fundus photograph evaluation	$23.60	[$19–$28]	
Visual acuity evaluation	$8.80	[$7–$11]	
Transportation	$2	[$1–$2]	
Nonteleophthalmology (face-to-face examination)			
Examination cost	$54.60	[$44–$65]	
Transportation	$288	[$202–$374]	
Specific care			
Pan-retinal photocoagulation	$1,903	[$1,530–$2,276]	8
Focal photocoagulation	$1,653	[$1,329–$1,977]	8
Care for blind person			
(Age <65 years)	$14,420	[$11,593–$17,246]	31, 32
(Age ≥65 years)	$32	[$26–$38]	31, 32

*Data derived from actual cost.

sitivity analyses. The authors reported the utility of the blindness as 0.71 (95% CI 0.58–0.84).

Cost data

Cost data are shown in Table 2. Initial costs for teleophthalmology used for retinopathy evaluation include direct cost for devices, training, and overhead expenses. Annual costs for teleophthalmology include expenses for human resources, device maintenance, and overhead. Because there is no current Medicare code established for reviewing images taken for telemedicine purposes, we used $23.60 as the Medicare reimbursement to a hospital-based health system for fundus photograph interpretation. In addition, we used $8.80 for evaluating visual acuity, which is the Medicare reimbursement to a hospital-based health system for a level 1 evaluation. A transportation fee was considered because only one teleophthalmology system would be implemented within each prison community, and some inmates would need to be transferred to this teleophthalmology center from satellite prisons.

Costs for ophthalmologic care without teleophthalmology were based on current Medicare reimbursements to a hospital-based system for an ophthalmology visit with a dilated eye examination. The transportation fee from remote prisons to medical facilities includes the actual cost of transportation, a fee for guardians, and a one-night stay. The actual transportation charge from a remote site to UTMB was used. The cost for laser photocoagulations (pan-retinal and focal) was derived from the literature, as was the direct annual cost of care for legally blind patients (31,32).

Sensitivity analysis

Sensitivity analyses assess clinical uncertainty and homogeneity of results. We used two types of sensitivity analyses: traditional *n*-way analysis and probabilistic analysis.

Uncertainties among individual patients were evaluated using first-order Monte Carlo simulations. Ten thousand hypothetical patients in each strategy proceed through the decision model sequentially according to transition probabilities until death. Hence, we estimated the median and 95% CI of calculated QALYs for each strategy.

Second-order Monte Carlo simulation was used to assess the influence of clinical uncertainty in each variable and to apply case-mix in the decision analysis (33,34). Each variable was derived from its probability distribution, yielding a hypothetical distribution of QALYs. We incorporated actual population data including age, sex, and ethnicity distributions of diabetic inmates in Texas. The simulation was run 10,000 times, counting the number of times each strategy was preferable and calculating the differences in QALYs between the strategies. As described by Pasta et al. (35), the distribution of health care costs and prices tend to be skewed. We used a lognormal distribution for cost of blindness care. In contrast, the cost of photocoagulation and examination was assumed as normal distributions because the Medicare system provides reasonably standardized costs. Standard error was assumed to equal 10% of total costs according to their descriptions.

The influence of particular probabilities, utilities, and costs were assessed using traditional *n*-way sensitivity analyses. One-way sensitivity analyses were performed against all probability, utility, and cost values incorporated into this cost-effectiveness model. Further two-way sensitivity analyses were applied to evaluate clinically important combinations of factors.

RESULTS

Reference case analysis

Average baseline values were used to derive average QALYs for each strategy. Baseline analyses resulted in 18.73 average QALYs with the teleophthalmology strategy and 18.58 QALYs using the nonteleophthalmology strategy. Average cost in the baseline analysis showed $16,514 for teleophthalmology and $17,590 for nonteleophthalmology. The average cost effectiveness was $882 per QALY for the teleophthalmology and $947 for the nonteleophthalmology strategies. The teleophthalmology strategy dominates in the incremental cost-effectiveness analysis because it costs less and leads to a greater QALYs gain. In the teleophthalmology strategy, 12.4% of patients reached blindness versus 20.5% in the nonteleophthalmology strategy. The absolute risk reduction for blindness is 8.1%, and the number needed to screen (NNS) is 12.4, which means 12.4 prisoners need to be evaluated by teleophthalmology to prevent one case of blindness using reference data.

Case-mix analysis (probabilistic sensitivity analysis)

Monte Carlo simulation was used to analyze case-mix cost-effectiveness analysis based on the prevalence of diabetes adjusted by age, ethnicity, and sex in Texas prison systems based on the report by Baillargeon et al. (2).

First-order Monte Carlo simulation revealed the median QALYs to be 18.65

(95% CI 17.31–19.90) with teleophthalmology and 18.46 (17.05–19.74) with nonteleophthalmology. The simulated median cost per hypothetical patient was \$18,443 (\$6,615–\$41,457) for teleophthalmology and \$18,983 (\$8,084–\$46,461) for nonteleophthalmology.

Second-order Monte Carlo simulation simultaneously compared the two strategies among 10,000 hypothetical patients, suggesting a preferred strategy for each patient. The simulation selected a unique set of the probabilities listed in Tables 1 and 2 for each hypothetical patient based on the distribution for each variable.

Figure 1 reveals results of the Monte Carlo simulation. The graph shows only 1,000 of 10,000 simulated cases in each strategy. Figure 1*A* shows a distribution of the cost and QALYs for each simulated person. The figure indicates an individual with the teleophthalmology strategy tends to have higher QALYs and a lower cost compared with nonteleophthalmology.

Figure 1*B* shows simulated distributions of incremental cost and QALYs for 5,000 of the 10,000 hypothetical patients. Approximately 68% of the total cases are located in area 1 (the lower right quadrant, in which costs of teleophthalmology are lower and benefits are higher), in which the nonteleophthalmology strategy is dominated by the teleophthalmology strategy. Approximately 22.6% of total cases are located in area 2, indicating the nonteleophthalmology strategy is clinically effective but more costly, and its incremental cost-effectiveness ratio is <\$50,000. Therefore, the teleophthalmology strategy could provide cost-effective care for ~90% of diabetic inmates. The ellipse gives a 95% CI of the distribution of the incremental cost and QALYs.

Traditional *n*-way sensitivity analysis

Although probabilistic sensitivity analyses directly incorporates clinical uncertainty, consistent results were nevertheless obtained in this analysis. However, there remains a need to examine the validity of several critical assumptions that influence clinical decision making. Both one- and two-way sensitivity analyses were performed to evaluate these critical assumptions in the reference case. A one-way sensitivity analysis reveals that the incremental cost effectiveness of the teleoph-

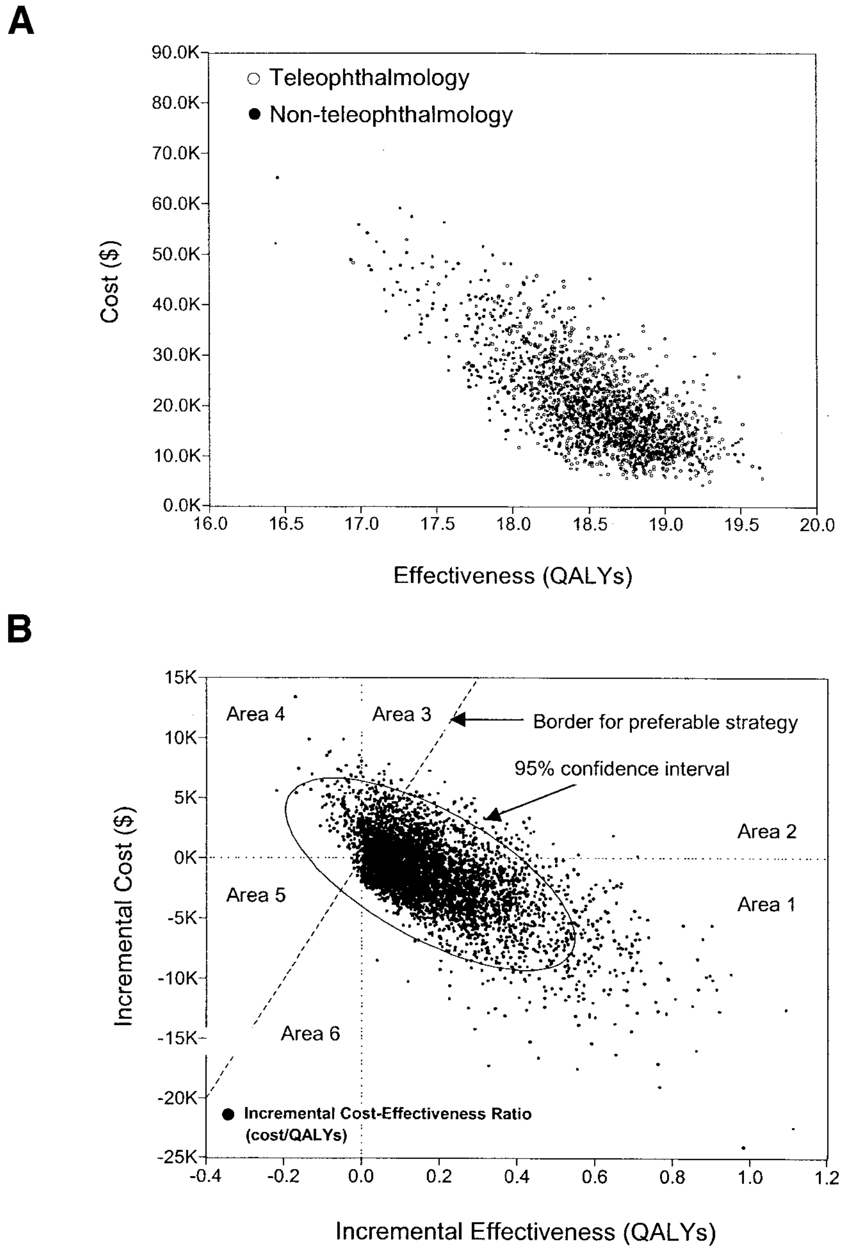

Figure 1—*Result of second-order Monte Carlo simulation analysis.* A: *Simulation of cost and QALYs for individuals. An individual with the teleophthalmology strategy tends to have higher QALYs and a lower cost compared with nonteleophthalmology.* ●, *simulated cost and QALYs for individual patients in the teleophthalmology strategy;* ○, *simulated cost and QALYs for individual patients using the nonteleophthalmology strategy.* B: *Simulation of the incremental cost-effectiveness ratio for individuals. Ninety percent of total cases are located in areas 1, 2, and 6, indicating that the nonteleophthalmology strategy is less effective than the teleophthalmology strategy in terms of clinical and economic impact.* ●, *simulated incremental-effectiveness ratio (ICER): cost/QALYs for individual patients in the teleophthalmology strategy compared with the nonteleophthalmology strategy. The ellipse indicates 95% CI of the simulated ICER. The clustering of circles in areas 1, 2, and 6 indicate that teleophthalmology strategy is preferred.* Area 1: *Nonteleophthalmology is dominated by the teleophthalmology strategy (teleophthalmology strategy is preferred).* Area 2: *Teleophthalmology strategy is more costly and effective, but its ICER is ≤\$50,000 (teleophthalmology strategy is preferred).* Area 3: *Teleophthalmology strategy is more costly and effectiveness, and its ICER is >\$50,000.* Area 4: *Teleophthalmology strategy is dominated by nonteleophthalmology.* Area 5: *The nonteleophthalmology strategy is more costly and effective, but its ICER is ≤\$50,000.* Area 6: *Nonteleophthalmology strategy is more costly and effective, but its ICER is >\$50,000 (teleophthalmology strategy is preferred).*

Table 3—*Sensitivity analysis for evaluation rates for teleophthalmology and nonteleophthalmology*

	Nonteleophthalmology		Evaluation ratio of teleophthalmology						
	Evaluation ratio	Baseline C/E	0%	20%	40%	60%	75%*	80%	100%
Cost	5%	$16,929	$12,823	$13,807	$14,791	$15,776	$16,514	$16,760	$17,744
QALYs		18.518	18.503	18.562	18.621	18.680	18.725	18.739	18.798
ICER			NE	Dominated	Dominated	Dominated	Dominated	Dominated	$2,905
Cost	25%*	$17,590	$12,823	$13,807	$14,791	$15,776	$16,514	$16,760	$17,744
QALYs		18.577	18.503	18.562	18.621	18.680	18.725	18.739	18.798
ICER			NE	NE	Dominated	Dominated	Dominated	Dominated	$694
Cost	45%	$18,252	$12,823	$13,807	$14,791	$15,776	$16,514	$16,760	$17,744
QALYs		18.636	18.503	18.562	18.621	18.680	18.725	18.739	18.798
ICER			NE	NE	NE	Dominated	Dominated	Dominated	Dominated
Cost	65%	$18,914	$12,823	$13,807	$14,791	$15,776	$16,514	$16,760	$17,744
QALYs		18.695	18.503	18.562	18.621	18.680	18.725	18.739	18.798
ICER			NE	NE	NE	NE	Dominated	Dominated	Dominated

NE indicates that teleophthalmology has a negative incremental effectiveness to nonteleophthalmology. Dominated denotes that nonteleophthalmology is dominated by teleophthalmology. *Baseline value in reference case. C/E, cost-effectiveness.

thalmology program is <$50,000/QALY if the number of diabetic patients is >151 and <$20,000/QALY if the number of patients is >260. Teleophthalmology was completely dominant if the number of diabetic patients is >500. A one-way sensitivity analysis for age demonstrated that the teleophthalmology strategy is preferred across all ages.

The importance of the proportion of screened patients with and without teleophthalmology was further studied using two-way sensitivity analysis. This approach evaluates both values simultaneously and shows the preferred strategy for combinations of transition probabilities within the expected clinical range (95% CI). The relationship between evaluation adherence and cost effectiveness in both teleophthalmology and nontelemedicine strategy is shown in Table 3. The NNS is ~62 if the evaluation adherence in teleophthalmology is 10% superior to that in nonteleophthalmology. For example, an NNS decrease to 31 if the difference in the evaluation rate is 20% (e.g., 50% in teleophthalmology and 30% in nonteleophthalmology).

CONCLUSIONS — This cost-effectiveness analysis was designed to evaluate the expected benefits of a hypothetical teleophthalmology program for prison inmates. Our results using Monte Carlo simulation showed the teleophthalmology strategy ordinarily generated higher QALYs and lower cost compared with the nonteleophthalmology strategy. It also successfully simulated homogeneity among individuals in terms of cost saving and QALYs gained, favoring the teleophthalmology strategy. In addition, follow-up *n*-way sensitivity analyses showed that three critical factors influenced the choice of strategies: the number of diabetic patients in the target prison and percent of screened patients with and without teleophthalmology. These factors might be used to determine whether a teleophthalmology program provides benefits in a particular setting.

We successfully quantified clinical effectiveness in terms of morbidity and mortality; however, telemedicine itself may not directly alter quantitative clinical outcomes such as mortality and morbidity, because it is not a direct therapeutic or diagnostic instrument. However, telemedicine is a useful tool for improving communication, accessibility, and management. This suggests telemedicine could have an indirect influence on qualitative clinical outcome, such as quality of care improvement and patient satisfaction. Any telemedicine program evaluation that includes a cost-effectiveness analysis should be tempered by a review of qualitative factors that may impact the usefulness of the program.

There are several limitations inherent in our study. First, not all data we required were available in the published literature, especially for the detailed profile of diabetic inmates. Although minorities tend to have higher reported rates of retinopathy, such data are not included because we could not identify well-stratified reports for sex, ethnicity, and age. Second, due to rapid progress in the field of medical information technology, new information may be now available (36). Continuous updates based on new information could be important because this is a prospective analysis. Third, our results can be exactly applicable only for the described telemedicine project in Texas. The concept model of this analysis, however, can be used to evaluate similar programs in other geographic areas.

Last but not least, the cost-effectiveness analysis for prison inmates stimulated interesting discussions relative to the appropriate perspective for the analysis. The societal perspective could not be used because the annual cost for prison inmates is >$50,000. This cost is higher than many acceptable forms of medical interventions. For instance, the annual societal cost for individuals with blindness is calculated as $14,420 in this analysis, which is much less than the cost for healthy prisoners paid by the government. This could lead to the theoretical absurdity that blindness in the prison population, if accompanied by parole, would be cost saving! To avoid this absurdity, we assumed that all costs related to healthy inmates are sunk costs and we used the Medicare cost for blindness as the price to care for blind prisoners.

In conclusion, our cost-effectiveness analysis demonstrates teleophthalmology holds great promise in reducing the cost of care and the occurrence of retinopathy followed by blindness in type 2 diabetes patients. Monte Carlo simulation affords a means to evaluate uncertainties and provides a measure of the program's success.

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References

1. Robertson JM: The disease profile of Texas prison inmates. *Ann Epidemiol* 10:71–73, 2000
2. Baillargeon J, Black SA, Pulvino J, Dunn K: The disease profile of Texas prison inmates. *Ann Epidemiol* 10:74–80, 2000
3. Anno B: Health behavior in prisons and correctional facilities. In *Handbook of Health Behavioral Research*. Gochmann DS, Ed. New York, Plenum Publishing, 1997
4. *Diabetes in America*. Bethesda, MD, National Institute of Health, National Institute of Diabetes and Digestive and Kidney Disease, 1995
5. Lambert M: Cost-effectiveness of detecting and treating diabetic retinopathy. *Ann Intern Med* 125:939, 1996
6. Javitt JC, Aiello LP: Cost-effectiveness of detecting and treating diabetic retinopathy. *Ann Intern Med* 124:164–169, 1996
7. Fendrick AM, Javitt JC, Chiang YP: Cost-effectiveness of the screening and treatment of diabetic retinopathy: what are the costs of underutilization? *Int J Technol Assess Health Care* 8:694–707, 1992
8. Vijan S, Hofer TP, Hayward RA: Cost-utility analysis of screening intervals for diabetic retinopathy in patients with type 2 diabetes mellitus. *JAMA* 283:889–896, 2000
9. *Cost-Effectiveness in Health and Medicine*. Gold MR, Siegel JE, Russel LB, Weinstein MC, Eds. New York, Oxford University Press, 1996
10. Sonnenberg FA, Beck JR: Markov models in medical decision making: a practical guide. *Med Decis Making* 13:322–338, 1993
11. Petitti DB: Meta-analysis, decision analysis, and cost-effectiveness analysis. New York, Oxford University Press, 2000
12. Younis N, Broadbent DM, Vora JP, Harding SP: Incidence of sight-threatening retinopathy in patients with type 2 diabetes in the Liverpool Diabetic Eye Study: a cohort study. *Lancet* 361:195–200, 2003
13. Moss SE, Klein R, Klein BE: The 14-year incidence of visual loss in a diabetic population. *Ophthalmology* 105:998–1003, 1998
14 Blankenship GW: Fifteen-year argon laser and xenon photocoagulation results of Bascom Palmer Eye Institute's patients participating in the diabetic retinopathy study. *Ophthalmology* 98:125–128, 1991
15. Ferris FL: How effective are treatments for diabetic retinopathy? *JAMA* 269:1290–1291, 1993
16. Vander JF, Duker JS, Benson WE, Brown GC, McNamara JA, Rosenstein RB: Long-term stability and visual outcome after favorable initial response of proliferative diabetic retinopathy to panretinal photocoagulation. *Ophthalmology* 98:1575–1579, 1991
17. Klein R, Moss SE, Klein BE, DeMets DL: Relation of ocular and systemic factors to survival in diabetes. *Arch Intern Med* 149: 266–272, 1989
18. Davis MD, Hiller R, Magli YL, Podgor MJ, Ederer F, Harris WA, Long JW, Haug GA: Prognosis for life in patients with diabetes: relation to severity of retinopathy. *Trans Am Ophthalmol Soc* 77:144–170, 1979
19. Knatterud GL: Mortality experience in the diabetic retinopathy study. *Isr J Med Sci* 19:424–428, 1983
20. American Academy of Ophthalmology Quality of Care Committee: *Preferred Practice Pattern: Diabetic Retinopathy*. San Fransisco, CA, American Academy of Ophthalmology, 1993
21. Klein R, Klein BE, Neider MW, Hubbard LD, Meuer SM, Brothers RJ: Diabetic retinopathy as detected using ophthalmoscopy, a nonmydriatic camera and a standard fundus camera. *Ophthalmology* 92:485–491, 1985
22. Moss SE, Klein R, Kessler SD, Richie KA: Comparison between ophthalmoscopy and fundus photography in determining severity of diabetic retinopathy. *Ophthalmology* 92:62–67, 1985
23. Fransen SR, Leonard-Martin TC, Feuer WJ, Hildebrand PL: Clinical evaluation of patients with diabetic retinopathy: accuracy of the Inoveon diabetic retinopathy-3DT system. *Ophthalmology* 109:595–601, 2002
24. Lin DY, Blumenkranz MS, Brothers RJ, Grosvenor DM: The sensitivity and specificity of single-field nonmydriatic monochromatic digital fundus photography with remote image interpretation for diabetic retinopathy screening: a comparison with ophthalmoscopy and standardized mydriatic color photography. *Am J Ophthalmol* 134:204–213, 2002
25. Beck JR, Kassirer JP, Pauker SG: A convenient approximation of life expectancy (the "DEALE"). I. Validation of the method. *Am J Med* 73:883–888, 1982
26. Beck JR, Pauker SG, Gottlieb JE, Klein K, Kassirer JP: A convenient approximation of life expectancy (the "DEALE"). II. Use in medical decision-making. *Am J Med* 73: 889–897, 1982
27. Torrance GW: Utility approach to measuring health-related quality of life. *J Chronic Dis* 40:593–603, 1987
28. Torrance GW, Feeny D: Utilities and quality-adjusted life years. *Int J Technol Assess Health Care* 5:559–575, 1989
29. Froberg DG, Kane RL: Methodology for measuring health-state preferences. I. Measurement strategies. *J Clin Epidemiol* 42:345–354, 1989
30. Brown MM, Brown GC, Sharma S, Shah G: Utility values and diabetic retinopathy. *Am J Ophthalmol* 128:324–330, 1999
31. Javitt JC, Aiello LP, Chiang Y, Ferris FL 3rd, Canner JK, Greenfield S: Preventive eye care in people with diabetes is cost-saving to the federal government: implications for health-care reform. *Diabetes Care* 17:909–917, 1994
32. Chiang YP, Bassi LJ, Javitt JC: Federal budgetary costs of blindness. *Milbank Q* 70:319–340, 1992
33. Doubilet P, Begg CB, Weinstein MC, Braun P, McNeil BJ: Probabilistic sensitivity analysis using Monte Carlo simulation: a practical approach. *Med Decis Making* 5:157–177, 1985
34. Pass TM, Goldstein LP: A computerized aid for medical cost-effectiveness analysis (Abstract). *Med Decis Making* 1:465, 1981
35. Pasta DJ, Taylor JL, Henning JM: Probabilistic sensitivity analysis incorporating the bootstrap: an example comparing treatments for the eradication of *Helicobacter pylori*. *Med Decis Making* 19:353–363, 1999
36. Aoki N, Beck JR, Kitahara T, Ohbu S, Soma K, Ohwada T, Cone RW, Fukui T: Reanalysis of unruptured intracranial aneurysm management: effect of a new international study on the threshold probabilities. *Med Decis Making* 21:87–96, 2001