Cost-Effectiveness of Alternative Methods for Diabetic Retinopathy Screening

DAVID R. LAIRSON, PHD
JACQUELINE A. PUGH, MD
ASHA S. KAPADIA, PHD
RONALD J. LORIMOR, PHD
JAMES JACOBSON, MD
RAMON VELEZ, MD

OBJECTIVE — To assess from the perspectives of a government delivery system and patients, the cost-effectiveness of the 45-degree retinal camera compared to the standard ophthalmologist's exam and an ophthalmic exam by a physician's assistant or nurse practitioner technician, for detecting nonproliferative and proliferative diabetic retinopathy.

RESEARCH DESIGN AND METHODS — Comparison of 45-degree fundus photographs with and without pharmacological pupil dilation taken by technicians and interpreted by experts, direct and indirect ophthalmoscopy by ophthalmologists, and direct ophthalmoscopy by technicians with seven-field stereoscopic fundus photography (reference standard). Costs were estimated from market prices and actual resource use. The study included 352 patients attending outpatient diabetes and general-medicine clinics at VA and DOD facilities.

RESULTS — Medical system costs per true positive were: 45-degree photos with dilation, $295; 45-degree photos without dilation, $378; ophthalmologist, $390; and technician, $794. Patient costs per true positive were: 45-degree photos with dilation, $139; 45-degree photos without dilation, $171; ophthalmologist, $306; and technician, $1009. Cost-effectiveness is sensitive to program size due to high fixed cost of the camera methods but not to prevalence. Cost-effectiveness of the technician exam is strongly affected by its sensitivity.

CONCLUSIONS — Primary-care screening with retinal photographs through pharmacologically dilated pupils for diabetic retinopathy is an appropriate and cost-effective alternative to screening by an ophthalmologist in this setting. Ophthalmologists are scarce, primary-care physicians are extremely busy, and large clinics allow fixed equipment costs to be spread across many patients.

FROM THE UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER AT HOUSTON, SCHOOL OF PUBLIC HEALTH, HOUSTON; THE AUDIE L. MURPHY VA HOSPITAL, SAN ANTONIO; AND THE WILFORD HALL USAF MEDICAL CENTER, SAN ANTONIO, TEXAS.

ADDRESS CORRESPONDENCE AND REPRINT REQUESTS TO DAVID R. LAIRSON, PHD, SCHOOL OF PUBLIC HEALTH, PO BOX 20186, UNIVERSITY OF TEXAS HEALTH SCIENCE CENTER, HOUSTON, TX 77225.

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Epidemiological and health-services research has established diabetic retinopathy as a candidate for secondary prevention through retinal screening. Using either excavated or computer-simulated cost estimates derived usually from a funding agency perspective, studies have provided economic justification for ophthalmoscopy screening by an ophthalmologist (1,2) and, under certain cohort conditions, fundus photography through pharmacologically dilated pupils as a more cost-effective mode of screening for proliferative diabetic retinopathy (3).

Unfortunately, half of the high-risk diabetic population may be unaware of diabetic retinopathy (4), which is the leading cause of new cases of blindness in people 20–74 yr of age (5). Afflicting 5% of the U.S. population (5), diabetes is estimated to have a total economic impact of at least $14 billion annually (6), with diabetic blindness accounting for $75 million annually in lost income and public-welfare expense (7). Furthermore, a large percentage of people with diabetes do not obtain screening exams (8–10).

Cost-effective alternatives to ophthalmologist screening that use less-expensive manpower substitutes can ease the adoption of routine screening by the VA and other public health-care organizations. Ophthalmoscopic examination by an ophthalmologist and stereoscopic fundus photography have been demonstrated as methods of detection and severity assessment (11); however, the development of a wide-angle 45-degree camera that can be used without pharmacological dilation has made primary-care and large-scale screening programs appear more feasible. Because 8–15% of all lesions and 27% of proliferative retinopathy cases have been observed outside a single 45-degree field and because of a decreased ability to detect macula edema without stereoscopic photographs, the application of nonstereoscopic photography confronts an important restriction (11). However, research by Klein et al. (12) suggests that it may be an effective alternative in routine screening, especially where the availability of ophthalmologists and physicians is limited.

Investigations have only recently extended beyond issues of test accuracy and the cost-effectiveness of a single technology to address manpower substitutability and the comparative cost-effectiveness of screening alternatives under normal primary-care practice conditions. Evidence from Foulds et al. (1) implied that an ophthalmoscopy screening by either an ophthalmologist or a diabetologist is cost-effective. Using annual incidence figures derived from the study's screen of all patients attending a diabetic outpatient clinic, we developed staff and workload projections to estimate the annual cost of undertaking a screening program for 25,000 patients with serious retinopathy. In U.S. dollars, the total annual cost projection for detection and treatment was $757/person compared with an average annual saving in social benefits of $6994/person (4). However, resource constraints prohibited the use of the stereoscopic photo reference standard. More recently, Nathan et al. (13) determined that an ophthalmoscopic examination by a diabetologist was a competitive substitute for ophthalmologist screening in terms of accuracy in classifying disease severity, promising savings of 10% by avoiding unnecessary ophthalmologist exams. However, only two diabetologists participated in the study, making the results less generalizable.

Assessed from the perspective of the delivery system and participating patients, this paper examines the cost-effectiveness of the 45-degree retinal camera as an alternative screening method for nonproliferative and proliferative diabetic retinopathy. The standard ophthalmologist's exam and an ophthalmic exam by a technician (PA or nurse practitioner) are compared with the camera's performance with and without pharmacological dilation of the pupils and with photos interpreted by expert readers in a centralized reading center. Effectiveness was defined as the number of true-positive cases, and the accuracy of each method was determined by comparing the methods with the reference standard of stereoscopic photos, also scored by the reading center. This paper focuses on the economic methods and analysis.

RESEARCH DESIGN AND METHODS

The study determined the effectiveness by comparing performance of the four methods in identifying true-positive cases of diabetic retinopathy among 352 individuals. About 50% were veterans receiving care at the Audie L. Murphy Memorial VA Hospital and 50% were USAF personnel, dependents, or retirees receiving care at the Wilford Hall USAF Medical Center, both located in San Antonio, Texas. Details of recruitment are included in a companion paper that has been submitted for publication (J.A.P., J.J., W.A.J. Van Heuver, J.A. Walters, M. Tuley, D.R.L., R.J.L., A.S.K., R.V., "Screening for Diabetic Retinopathy: The Wide Angle Retinal Camera").

Description of screening exam and interpretation

For the cost-effectiveness analysis, we assumed that each person screened responds to an intake questionnaire and complies with a routine preliminary exam consisting of intraocular pressure; visual acuity; and height, weight, and blood pressure measurements. Patients are screened by one of four methods. The 45-degree photographic method without pharmacological dilation includes one photograph of each eye encompassing a field centered horizontally between the optic disc and the macula taken by a PA or nurse practitioner with a 45-degree camera. The photos are read by an internist at the clinic and by trained readers at the University of Wisconsin Fundus Photograph Reading Center. For the second 45-degree photographic method, the pupils first are dilated, and three photographs are taken of each eye encompassing the same field as above but in stereo (achieved by moving the camera slightly lateral for the 2nd photo) and a third photo temporal to the macula with the optic disc at the far nasal edge of the photo. Again, the 45-degree camera is operated by a PA or nurse practitioner. All positive findings are verified by photographs through dilated eyes with seven-field stereoscopic 30-degree photographs of each eye taken by a certified retinal photographer and read by trained readers at the Reading Center. The ophthalmologist conducts both direct and indirect funduscopic exams through dilated pupils, and the technician (PA or nurse practitioner) examines dilated eyes with direct ophthalmoscopy. Positive findings also are verified by the same method described for the photographic screening modalities. The technicians have minimal advanced ophthalmological training, having only completed the self-taught module of the Pennsylvania Diabetes Academy on recognizing diabetic retinopathy (16).

Analysis is conducted from the perspectives of the public provider of health-care services (VA and DOD) and the patient.

Accuracy of the screening methods was determined by having subjects sequentially screened by the four methods, testing results against the reference standard of seven-field stereoscopic fundus photographs of each eye. Procedures were adapted from the Early Treatment of Diabetic Retinopathy Study. Slides were mailed to the Reading Center and graded for lesions of diabetic retinopathy with a modification of the Airlie House Classification (17–19). Details of description of the effectiveness analysis are included in a companion paper that has been submitted for publication (J.A.P., J.J., W.A.J. Van Heuven, J.A. Walters, M. Tuley, D.R.L., R.J.L., A.S.K., R.V., "Screening for Diabetic Retinopathy: The Wide Angle Retinal Camera").

Assessment measures

Effectiveness. The number of true-positive tests was the chosen indicator of effectiveness for the alternative screening methods. The focus is on the intermediate outcome of test accuracy, because decision makers have decided to recommend an annual screen based on previous research on the final outcome of sight-years saved and cost savings. The issue is whether the camera methods are a more efficient means of achieving the screening goal. A true positive was defined as any retinopathy beyond mild nonproliferative or, more specifically, a modified Airlie House classification level ≥40 on the reference standard. This cut off was chosen because this is the level at which it is recommended that an ophthalmologist should follow the retinopathy. Up to this level, screening could take place in a primary-care setting on an annual basis if the screening method had a similar level of accuracy as an ophthalmologist's exam. The Early Treatment of Diabetic Retinopathy Study suggests that ~12% of those with a modified Airlie House classification of 40 will progress to proliferative disease in 1 yr and 3.6% to high-risk proliferative disease. Although this may be a worst-case scenario (because high-risk individuals might be enrolled in treatment trials), this rate of progression would warrant referral to an ophthalmologist if any level higher than mild nonproliferative is found. Ungradable photos were counted as positive because they would require referral for further evaluation.

Cost assessments. Actual resources required to provide screening by the alternative methods were identified, enumerated, and valued with market prices paid by the system and proxy measures of patient-time value. Medical system costs consisted of personnel, equipment and supplies, participants' time, space, overhead, and Reading Center fees. Personnel costs were comprised of salaries and fringe benefits of ophthalmologists, primary-care physicians, nurse practitioners, PAs, and intake clerks. Time was recorded prospectively with a stop watch at each station as the patient progressed through the screening process. Prices, wages, cost of capital items, space, and overhead were obtained from VA records. Equipment included a Canon CR 2-45NM camera, pneumatic chairs, Visulite base and viewer, and other associated small equipment items for viewing slides and taking photographs. Equipment costs were amortized over their expected life (Appendix 1). Values for computing amortization of equipment and facilities were obtained from medical system records and equipment manufacturers. The rate on long-term U.S. government bonds in 1989, 8.24%, was selected for the interest rate to estimate the government's cost of funds. It was assumed that the camera and associated equipment would be used only for the screening. Overhead costs are estimated at 29.7% of ambulatory care health-system costs. This rate was determined by the local VA hospital administration and includes administration, data processing, engineering, housekeeping, and utilities.

Patient costs included the costs of transportation and opportunity costs (the value of time spent traveling, waiting, and being screened) and were calculated on the basis of information recorded at the clinic and provided by the patient. Patient waiting and screening time was measured prospectively with a stopwatch, whereas travel time and cost were self-reported. When employed, patients' time was valued by their reported wage rate. For those not employed, the minimum wage ($3.35/h) was used as a proxy for patient-time value.

We assumed that every positive test would be referred for a stereoscopic photo exam for verification. The cost of that exam, calculated from the perspective of the medical system and the patient, is therefore the estimated cost of a false-positive test. The cost of false negatives, in terms of sight-years lost or other consequences, was beyond the scope of our data. However, the false negatives are determined for each method, and the implications for relative cost-effectiveness are described.

Cost-effectiveness analysis

The cost-effectiveness measure was the ratio of the total cost of each screening method to the number of true-positive tests achieved by that method or the cost per true-positive test. The ratio may obscure whether the result is attributable to relatively low cost or high effectiveness, and therefore the results are presented in graphical form with the cost of screening on the x-axis and the effectiveness of screening (true positives) on the y-axis (Fig. 1). Cost-effectiveness is the inverse of the slope of a line (data not shown) between the origin and the coordinates for a screening method, and the incremental cost-effectiveness is the inverse of the slope of the lines between the coordinates of the screening methods (20). Steeper slopes represent more cost-effective modalities.

Because the camera methods have relatively high fixed costs, the sensitivity of the results are examined for changes in the number of people screened. Because prevalence is an important determinant of the number of true positives and may vary across populations, the results are examined for alternative levels of prevalence. Finally, limited training may have resulted in a low sensitivity for the technician exam, and those results are examined under assumptions of improved performance.

Statistical analysis

The cost data were analyzed by two-tailed Student's t tests. The four techniques were compared to the reference standard of 30-degree seven-field stereoscopic photos read by the Fundus Photographic Reading Center. Measures of sensitivity and specificity were compared for significant differences with McNemar's test for comparing proportions of dependent samples (21).

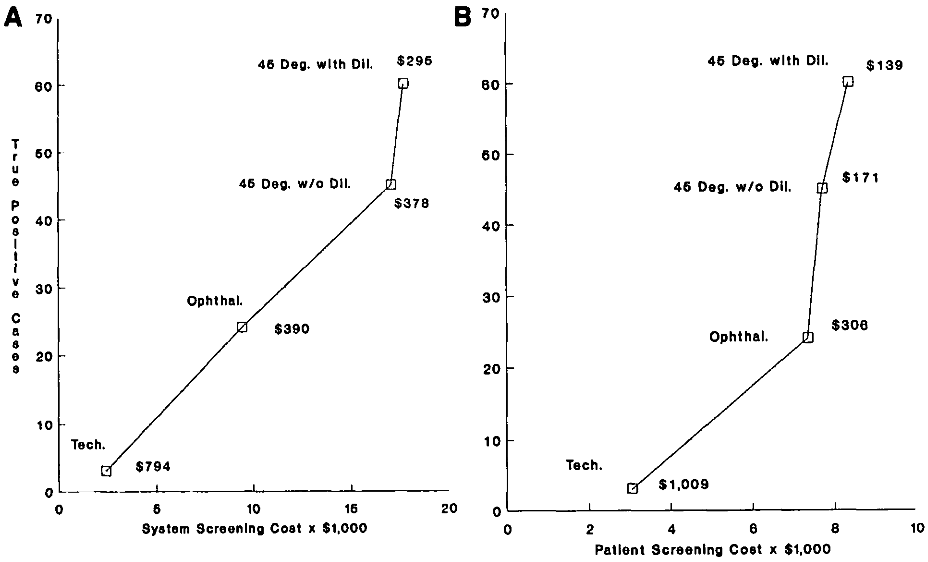

Figure 1—*Cost (x-axis) and effect (y-axis) of number of true-positive cases identified from medical system perspective (A) and patient's perspective (B). (45 Deg. with Dil.), 45-degree camera method with dilation; (45 Deg. w/o Dil.), 45-degree camera method without dilation; (Ophthal.), direct and indirect ophthalmoscopy by ophthalmologist; (Tech.), direct ophthalmoscopy by PA or nurse practitioner. Dollar figures represent cost-effectiveness ratios and are computed as inverse of slope of line from origin (not shown) to each coordinate. Inverse of slopes (not shown) of lines between points represent incremental cost-effectiveness ratios. Steeper slopes imply greater cost-effectiveness.*

RESULTS— The VA and Wilford Hall sites served slightly different clientele (Table 1). The VA group consisted of more Hispanics, was older, and had less education than the group studied at Wilford Hall. The VA patients also reported less employment, lower monthly earnings, and longer average distances from their home to the clinic. The mean age at which the two groups were first diagnosed as diabetic did not differ. However, consistent with their older age, the VA patients reported a longer duration of diabetes with a greater prevalence of moderate-to-severe nonproliferative and proliferative retinopathy, and a higher percentage was taking insulin (35 vs. 25%, respectively). Prevalence of moderate-to-severe nonproliferative retinopathy was 22% for VA and 16% for Wilford Hall patients. One case of proliferative retinopathy was identified among Wilford Hall patients compared with six for the VA. Additional details on the study populaton, including characteristics of respondents and nonrespondents are included in a companion paper that has been submitted for publication (J.A.P., J.J., W.A.J. Van Heuven, J.A. Walters, M. Tuley, D.R.L., R.J.L., A.S.K., R.V., "Screening for Diabetic Retinopathy: The Wide Angle Retinal Camera").

Effectiveness

Effectiveness results of the field study are presented in Table 2. Results are based on 351 cases for the camera methods, 347 cases for the exam by the ophthalmologists, and 172 cases for the technician exam (Wilford Hall site only). The technician exam was added midway through the study and therefore was not available for all patients. One patient was excluded entirely because the stereoscopic photographs were not gradable, and 4 other patients were excluded from the ophthalmologist evaluation because they were not examined by the ophthalmologist. Six patients at Wilford Hall were not examined by the technician.

The reference standard exam identified 74, 73, and 30 cases of disease in the populations screened by the camera methods, the ophthalmologists, and the technician, respectively. The 45-degree photo method with dilation had the highest sensitivity (0.81) (60 true positives and 14 false negatives). The 45-degree photo method with dilation is significantly more sensitive than all the other methods: ophthalmologist, ($P < 0.0001$; and 45-degree without dilation, $P < 0.002$). The ophthalmologist exam ranks first in specificity (0.99), lowest in false positives (1), and highest in true negatives (273). The ophthalmologist is more sensitive than the technician ($P < 0.02$) but equally specific ($P = 0.24$). The ophthalmologist is significantly more specific than the 45-degree photos with dilation caused by false positives from ungradable photos ($P = 0.011$). The 45-degree photos without dilation are less specific than the 45-degree photos with dilation ($P < 0.0001$), primarily because of the larger number of ungradable photos, 14.0 versus 3.7% for the method with dilation. The technician exam has low sensitivity, identifying only 3 of 30 cases of disease.

Costs

Costs by screening method are displayed in Table 3, and detailed estimates of personnel time and cost per minute are displayed in Appendix 2. The health-system cost was ~$50/exam for the 45-degree camera methods with and without dilation, $27 for the ophthalmologist exam, and $14 for the technician exam. Each of the three alternative method's costs was significantly different from the average ophthalmologist exam cost ($P = 0.001$). Including patient costs, the cost per patient screened by the 45-degree method without dilation was $70, with the 45-degree method with dilation being ~$4 more per case. In contrast, screening by an ophthalmologist cost about $48/case. The technician exam was considerably

Table 1—*Percentage distribution or means of patient variables in VA, Wilford Hall, and total sample*

	Population (%)		
	VA (N = 174)	Wilford Hall (N = 178)	Total (N = 352)
Racial/ethnic background*			
White	39.7	64.4	52.1
Hispanic	51.1	24.3	37.6
Black	9.2	11.3	10.3
Age (yr)			
<65	55.7	63.5	59.7
Education level*			
Less than high school	43.5	14.0	28.4
High school	28.2	37.6	33.0
More than high school	28.2	48.3	38.5
Employment status			
Full/part-time	27.0	35.4	31.3
Other	73.0	64.6	68.5
Monthly earnings ($)*†	1062 ± 806	1479 ± 998	1255 ± 922
Miles traveled*†	32 ± 44	16 ± 24	24 ± 36
Age at diagnosis (yr)†	50.2 ± 12.2	51.5 ± 11.4	50.9 ± 11.8
Duration of diabetes (yr)*†	10.7 ± 8.1	8.9 ± 8.3	9.8 ± 8.2
Taking insulin (%)*	35.6	25.3	30.4
Prevalence of retinopathy			
Moderate-to-severe nonproliferative*	21.84	15.73	18.75
Proliferative*	3.44	0.56	1.99

Missing values for these variables ranged from 0 to 8.5%. Monthly earnings had the highest percentage of missing values. All figures and test statistics excluded missing values. *$P < 0.05$, VA vs. Wilford Hall. †Values are means ± SD.

less expensive than the alternatives, averaging $31 when patient costs were included.

Because patients had the same transport expenses and time value by method, relatively small differences were observed in patient costs between methods. Because less time is required for return visits for verification, the ophthalmologist exam ($21) and the technician exam ($18) cost participants less than the 45-degree camera method without dilation ($22) and the 45-degree method with dilation ($24). Approximately 20–25% of patient costs were transport expenses, with the remainder being the value of patients' time.

Cost-effectiveness analysis

The costs and effectiveness of alternative screening methods are presented from the perspective of the VA health-care system (Fig. 1*A*). The technician exam is the lowest cost method and identified the fewest true-positive cases (partly because of implementation in only one site but also had the lowest sensitivity) and had the highest cost per true positive ($794). Examination by the ophthalmologists resulted in the second highest cost and CE ratio ($390), and the third highest number of true positives. The 45-degree method without dilation achieved more true positives at a higher cost compared to the ophthalmologist exam, with a slightly lower CE ratio ($378). In contrast, the 45-degree method with dilation achieved 33% more true-positive cases than the 45-degree method without dilation with only 4% additional cost, resulting in the lowest CE ratio ($295).

Similarly, from the patient perspective (Fig. 1*B*), the 45-degree method with dilation had the lowest average CE ratio ($139) compared to $171 for the 45-degree method without dilation, $306 for the ophthalmologist exam, and $1009 for the technician exam. The incremental CE ratios are much lower (slopes higher between the ophthalmologist exam and camera methods) because costs are similar, but there are substantial increases in the number of true-positive cases for the camera methods.

Sensitivity analysis

Findings were examined from the government medical system perspective for alternative levels of program size, prevalence of diabetic retinopathy, and sensitivity of the technician exam. Results are sensitive to program size. In contrast to the camera methods, the ophthalmologist exam includes little fixed cost, therefore the cost per exam changes little as program size increases. Simulation suggests the ophthalmologist exam is cost-effective to ~175 exams relative to the 45-degree method with dilation and up to ~340 exams relative to the 45-degree method without dilation. Beyond 175 exams, the 45-degree method with dilation is most cost-effective. Results are not sensitive to prevalence, which varied between 0.06 and 0.30. The CE ratios decline for each method as prevalence increases. For the 45-degree method, the CE ratio ranges from $917 for prevalence of 0.06 to $222 for prevalence of 0.30. Although the CE ratios draw somewhat nearer, they do not change ordinal rank as prevalence increases. The CE ratio for the technician exam is highly responsive to the sensitivity of the exam. An increase from 0.1 to 0.2 makes the technician exam as cost-effective as the 45-degree

Table 2—*Effectiveness of screening methods*

Method	45-degree photo: Without dilation (N = 351)	45-degree photo: With dilation (N = 351)	Exam: Ophthalmologist (N = 347)	Exam: Technician (N = 172)
Sensitivity	0.61	0.81	0.33	0.10
Specificity	0.85	0.96	0.99	0.99
True positive (N)	45	60	24	3
True negative (N)	236	267	273	140
False negative (N)	29	14	49	43
False positive (N)	41	10	1	2

Four patients failed to return for ophthalmologist's exam, and PA exam was evaluated in 1 site, Wilford Hall.

method with dilation. If sensitivity is 0.6, the cost per true-positive test is half the CE ratio for the 45-degree camera with dilation. Even if training costs increase fivefold (to $2500) to achieve a sensitivity of 0.6, the CE ratio for the technician exam is 66% of the CE ratio for the 45-degree method with dilation.

CONCLUSIONS— We compared efficiency of alternatives for achieving true-positive screening tests, an intermediate outcome, in preventing the consequences of diabetic retinopathy. Previous studies have provided evidence for the economic justification of diabetic retinopathy screening in terms of sight-years saved and net savings to government and society. They also have shown that the 30-degree camera method of screening with dilation is cost-effective relative to the 45-degree camera without dilation and the ophthalmologic exam (3).

By analyzing epidemiological and economic data on 352 patients in a VA and USAF population, this study found that, in this setting, medical care cost per true-positive case detected was lower for the 45-degree camera with dilation ($295) compared with the 45-degree camera without dilation ($378), the standard ophthalmologic examination ($390), and direct funduscopic examination by a PA or nurse practitioner ($794) for diabetic retinopathy screening. When patient costs were added, the relative rankings remained the same. Although the cost of false negatives is beyond the scope of our data (and would include disability and sight-yr lost), the relative ranking of the methods would remain the same if the cost of false negatives were included. A ranking of the methods by the number of false negatives showed the 45-degree photo method with dilation had the fewest false negatives, followed by the 45-degree technique without dilation (29) and the ophthalmologist exam (49).

Our findings differ from Dasbach et al.'s (3) simulation, which predicted the 30-degree photo method with dilation was only marginally more cost-effective than the 45-degree photo without dilation and the ophthalmoscopy exam (3). In that case, choice of method could be determined by local conditions of the delivery setting. This holds, in their analysis, if sensitivity of the latter two methods does not fall below 0.65. We found sensitivity below 0.65, and therefore the 45-degree photos with dilation are preferred for our population, an older population with more difficulty achieving adequate nonpharmacological dilation.

Our classification of positive cases included both moderate and severe stages of retinopathy. The former requires continued screening, and the latter may require immediate treatment to avoid sight loss. A review of the cases shows that 24 of 46 cases of nonproliferative disease missed by the ophthalmologists had soft exudates as the only advanced lesion beyond microaneurysm. These are difficult to identify, and their predictive value for progression to proliferative disease has been questioned (22). However, of the 7 cases of proliferative disease the ophthalmologists identified only 3. In 3 of 4 cases missed, the lesions were not on the optic disc and would be considered low risk for loss of vision.

This study applies data from only two sites, ones with special populations, veterans and retired and active-duty military personnel, and dependents of retired and active-duty personnel. The results, therefore, primarily apply to these groups. The Wilford Hall group was younger, better educated, had fewer ethnic minorities, and lived closer to the clinic. The same camera technicians were used at both sites, but the ophthalmologists differed. However, sensitivity and specificity of the screening methods varied little between sites. Time estimates of the activities were similar, although time required for the camera methods declined as the technicians gained experience with the equipment and moved from the VA to the Wilford Hall site. This probably was attributable to movement along the learning curve and the younger Wilford Hall population. The technician exam was conducted only at one site, and the technicians received limited training before the project, possibly resulting in the extremely low sensitivity. If this could be improved, even with a substantial increase in training costs, the technician exam would compete favorably with other methods on the basis of cost-effectiveness. Prevalence differed between the sites, but sensitivity analysis showed that relative cost-effectiveness was not affected as prevalence varied between 0.06 and 0.30.

Cost differences between the methods are primarily attributable to the relatively high capital cost of the camera methods. Although the ophthalmologist

Table 3—*Cost elements by screening method (in $)*

	45 Degree photos		Exam	
	Without dilation (n = 351)	With dilation (n = 351)	Ophthalmologist (n = 347)	Technician (n = 172)
Recurrent costs				
Personnel*	2608	2802	5771	963
Reading Center charge	1530	1801	—	—
Other†	597	1168	139	69
Verification of positives‡	4386	3570	1275	255
Training	405	405	—	598
System—capital and overhead				
Space§	941	941	179	90
Camera‖	3322	3322	—	—
Other Equipment¶	437	437	151	58
Overhead (rate 29.7%)**	2802	3136	1853	350
Total	17,028	17,672	9368	2383
System Cost Per Exam	49	50	27	14
Patient costs				
Transportation	1846	1846	1825	540
Transport time	2011	2011	1988	762
Screening time	548	1211	1183	526
Waiting time	1542	1851	1830	1099
Verification††	1744	1420	507	101
Total	7691	8339	7333	3028
Patient Cost Per Exam	22	24	21	18
Grand Total Cost	24,719	26011	16701	5411
Total Cost Per Exam	70	74	48	31

*See table 1, in appendix, for cost elements.
†Other costs include film, film processing, supplies, mailing, and camera maintenance.
‡All positive tests are verified with stereographic photographs at $51 per exam.
§Typical clinic space was priced at the market rental rate of $.78 per square foot per month. Space was utilized for camera storage, camera exams, fundoscopic exams, and prorated for the time actually used for that purpose.
‖The 45 degree Canon camera cost $12,000 and was amortized over an estimated 7 year life, assuming a discount rate of .0824 and a resale value of $1,500. The annual cost of $2,157 was multiplied by 1.54 (18.5/12) to represent the 18.5 month project period.
¶Small equipment items included pneumatic chairs, visulite base, Donaldson viewer, Visulite Viewer, and an external fixation device.
**VA accounting estimates that 29.7% of total ambulatory cost is indirect. This does not include depreciation of VA facilities. Space costs are estimated according to footnote 4 above.
††Patient verification costs include transport cost, transport time, screening time, and waiting time. The average cost was $20.28.

time is more expensive, the exam is shorter than that required for the camera methods. The current sites, with large central clinics, are particularly suited to screening projects requiring significant capital investment. Personnel can specialize, and fixed costs can be spread across many patients. Use of the camera methods in dispersed solo and small group practices may result in lower cost-effectiveness, as suggested by the sensitivity analysis of program size. To reduce patient costs associated with travel to central sites and to increase compliance, innovative methods are required to provide screening in remote sites. One option is the use of mobile screening units operated by traveling technicians, including nurse practitioners or PAs trained to conduct screening with a camera. This option should be evaluated in comparison with the centralized systems examined in this study.

Both technicians (12) and diabetologists (13) can be trained to provide exams with acceptable sensitivity and specificity. The barriers to primary-care physicians providing such exams clearly exist. First, these exams usually would be performed in the context of a routine visit with the cost (time, equipment, drugs for dilation) folded into the cost of the visit. They would not be reimbursed separately. This economic disincentive coupled with the multiplicity of other conditions for which the primary-care physician is being asked to screen (other diabetic complications, depression, alcoholism, other high-risk behaviors, living conditions for the elderly, nutrition, breast and colon cancer risk, etc.) make implementation of retinopathy screening by the primary-care physician unlikely. Second, the current recommendations specifically require an ophthalmologist's exam, assuming that primary-care physicians are not competent in this area. In contrast to the primary-care physician, the ophthalmologist is reimbursed a full office visit just for this exam. Finally, technicians who do not view screening as either reducing their income or as taking away from their primary function as a health-care provider, may in the long run be more successful at screening. However, their competence would have to be monitored just as the competence of the Reading Center staff is monitored.

The implementation of the 45-degree camera screening strategy would be constrained by the resources of the individual clinic or hospital using them and would have to be studied locally for quality control. Using the 45-degree camera, the screening could take place as an addition to a routine visit in a primary-care clinic or as a separate visit just for screening. The person taking the pictures could be a nurse's aid, a nurse, or a physician extender (PA or nurse practitioner). Most facilities would not need someone performing screening full time, so this would be only one of many duties. The photographs could either be read by a centralized reading center, or local personnel could be trained to read (each would require periodic reevaluation of competency). Cut-off points for referral would be set locally between the primary-care personnel and ophthalmologists. Frequency of screening should follow national guidelines. In VA and DOD facilities, this strategy has the potential of greatly increasing screening because current screening is limited by scarce ophthalmological resources.

Appendix 2—***Estimates of personnel time per case and cost per minute***

Activity	Person	Cost/min ($)*	Minutes (mean ± SD)
Preliminary			
Intake/history	Clerk	0.1655	4.41 ± 2.10
Physical exam†	PA/nurse practitioner	0.3914	6.99 ± 2.68
Dilation‡	PA/nurse practitioner	0.3914	2.00
Screening			
45-Degree photos without dilation	PA/nurse practitioner	0.3914	8.09 ± 4.17
45-Degree photos with dilation	PA/nurse practitioner	0.3914	7.26 ± 3.99
Ophthalmology exam	Ophthalmologist	1.9000	6.52 ± 5.07
Technician exam	PA/nurse practitioner	0.3914	3.44 ± 1.60
Interpretation			
45-Degree photos without dilation	Primary physician	0.6412	1.23 ± 0.92
45-Degree photos with dilation	Primary physician	0.6412	1.79 ± 1.30

*Determined by dividing annual salary plus fringe benefits by 2080 h.
†Physical exam consists of visual-acuity test; height, weight, and blood pressure measurements; and intra-ocular pressure test. Dilation is done for mydriatic photos and for exams by ophthalmologist and technician.
‡Dilation time was estimated by project staff. Individual time measurements were not taken.

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Appendix 1—***The following standard formula is used to determine annual cost of capital. The process is illustrated for wide-angle camera equipment (1)***

$$AC = [RC - (SV/(1 + R)^N)] \cdot A(R,N) \quad (1)$$
$$= [\$12{,}000 - (\$1500/(1 + 0.0824)^7] \cdot 0.1936$$
$$= \$2156$$
where $A(R,N) = [R(1 + R)^N]/[(1 + R)^N - 1]$
$$A(0.824,7) = [0.0824\ (1 + 0.0824)^7]/[(1 + 0.0824)^7 - 1]$$
$$A = 0.1936$$

AC, annualized cost; RC, replacement value; SV, scrap value; R, interest rate; N, useful life of capital. A(R,N), annuity factor (N yr at interest rate R)

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