# Changes in Visual Acuity in a Population Over a 15-year Period: The Beaver Dam Eye Study

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**• PURPOSE: To describe the change in visual acuity in a 15-year period.**
**• DESIGN: Population-based study.**
**• METHODS: SETTING: Beaver Dam, Wisconsin. PARTICIPANTS: 4068 persons 43 to 86 years of age at the time of a baseline examination in 1988 to 1990, and with follow-up examinations every five years thereafter. OBSERVATION PROCEDURES: Best-corrected visual acuity after refraction, assessed by a modification of the ETDRS protocol. MAIN OUTCOME MEASURE: Doubling of the visual angle; incidence of visual impairment.**
**• RESULTS: Eight percent of the population developed impaired vision (20/40 or worse), 0.8% developed severe visual impairment (20/200 or worse), 7% had doubling of the visual angle, and 2% had improved vision. People 75 years of age or older at baseline were more likely to develop impaired vision (odds ratio [OR] 12.8, 95% confidence interval [CI] 9.6 to 17.1, *P* < .001), doubling of the visual angle (OR 7.8, 95% CI 5.6 to 10.7, *P* < .001), and severe visual impairment (OR 20.6, 95% CI 9.5 to 44.8, P<0.001) compared with people younger than 75 years of age.**
**• CONCLUSIONS: These data provide population-based estimates of the cumulative 15-year incidence of loss of vision over a wide spectrum of ages. In people 75 years of age or older the cumulative incidence of visual impairment accounting for the competing risk of death is 25%, of which 4% is severe, indicating a public health problem of considerable proportions as the US population in this age is expected to increase by 55% from 18 million in the year 2005 to 28 million by the year 2025. (Am J Ophthalmol 2006;142:539–549. © 2006 by Elsevier Inc. All rights reserved.)**


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THE PREVALENCE OF IMPAIRED VISION INCREASES markedly with age, especially in those 75 years of age or older.[1] Most population-based estimates of incidence of impaired vision are based on short term follow-up with few data describing the long term incidence of changes in vision, especially in persons in their 9th decade of life.[2–7] Such information is needed for defining etiologic relationships, assessing the effect of treatment of age-related eye disease, and anticipating resources required to meet the needs for eye care and vision-related services. The purpose of this report is to describe the change in visual acuity in a 15-year period in persons participating in the Beaver Dam Eye Study, a population-based study of older adults.

## METHODS

METHODS USED TO IDENTIFY THE POPULATION AND DEscriptions of the population have appeared in previous reports.[8,9] Written informed consent for the use and disclosure of protected health information was obtained from all subjects before being enrolled in the study. In brief, a private census of the population of Beaver Dam, Wisconsin, was performed from September 15, 1987 to May 4, 1988. Eligibility requirements for entry into the study included living in the city or township of Beaver Dam and being 43 to 84 years of age at the time of the census. There were 5924 eligible individuals; 4926 participated in the examination phase between March 1, 1988 and September 14, 1990. Ninety-nine percent of the population was Caucasian. Participation status is shown at follow-up examinations in Figure 1. Comparisons between participants and nonparticipants at the baseline and at the five- and 10-year follow-up examinations appear elsewhere.[4,9,10] Of the 2764 who were examined at the baseline and the five- and 10-year follow-up, 284 (10.3%) had died before March 31, 2003, the beginning of the 15-year follow-up examination. Of the 2480 surviving

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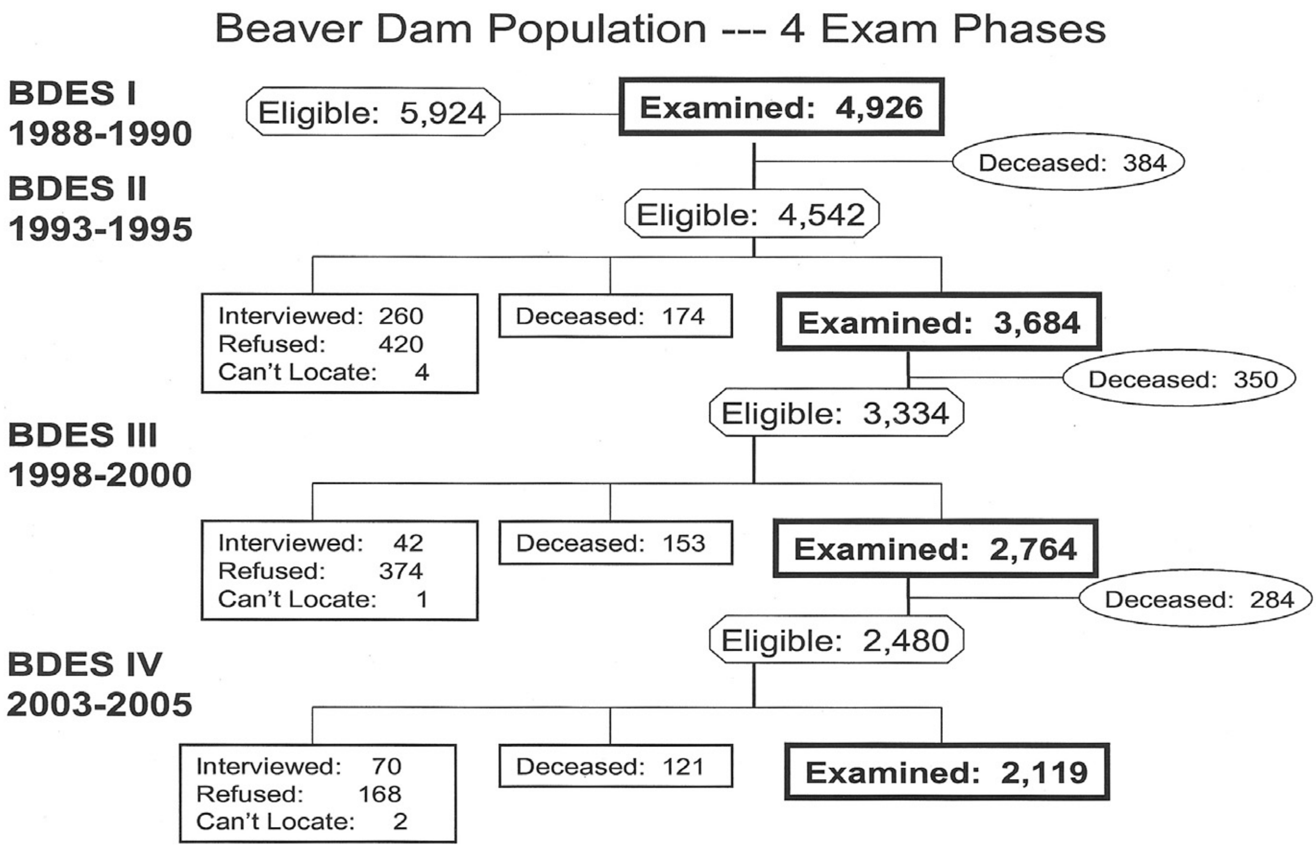


**FIGURE 1. Schematic showing participation status at follow-up examinations of the Beaver Dam Eye Study.**

persons who had participated in the baseline and five- and 10-year follow-up examinations, 2119 (85.4%) participated in the 15-year follow-up examination from March 31, 2003 through April 30, 2005 (Figure 1). One hundred twenty-one (4.9%) died after the start of the 15-year follow-up before being examined. Two (0.08%) could not be located. Seventy (2.8%) permitted an interview only, and 168 (6.7%) refused to participate. The mean and median times between the baseline and 15-year follow-up examinations were 14.9 years (standard deviation [SD] was 0.5 years) and 14.8, respectively.

Comparisons between the baseline characteristics of participants completing all four examinations and nonparticipants at 15-year follow-up are presented in Table 1. The 240 nonparticipants who were alive at the 15-year follow-up were more likely to be older than the 2119 participants completing all four examinations (Table 1). While controlling for age, these nonparticipants were more likely at baseline to be less educated and to have higher systolic blood pressure and higher intraocular pressure than persons who participated. There were no statistically significant differences in gender, visual acuity, the presence of central cataract, the presence of age-related macular degeneration, cardiovascular disease history, hypertension status, employment status, income level, cancer history, diabetes status, or heavy alcohol consumption at baseline between participants who completed all four visits and nonparticipants who were alive at 15 years. There were no statistically significant differences while controlling for age, in baseline visual acuity, age-related macular degeneration, or central cataract between those who participated at the 15-year follow-up and those who had died (n = 121, Table 1).

Included in the analyses were: 2119 people examined at all four visits, 645 people who were examined at baseline and at the five- and 10-year follow-up only, 920 people who were examined at baseline and at the five-year follow-up only, and 384 people who were known to have died before the five-year follow-up. Of these 4068 people, 280 (6.9%) were living in a nursing or group home at the time of their last examination.

Approval was granted by the Institutional Review Board at the University of Wisconsin, and informed consent was obtained from each participant at the beginning of the examination. The Tenets of the Declaration of Helsinki were observed.

At the 5-, 10-, and 15-year follow-up, before refraction, the participants were first asked to read the Early Treatment Diabetic Retinopathy Study (ETDRS) chart R modified for a 2-m distance with their current prescription without covering either eye. The number of letters correctly read was recorded. At all the examinations, the

**TABLE 1.** Comparison of Participants Completing All Four Examinations to Nonparticipants in the Beaver Dam Eye Study Among Those Seen Through 10-Year Examination and Alive as of March 30, 2005

| | Participants All Four Exams | | Nonparticipants* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Alive | | | Not Alive | | |
| Characteristic | Crude % | n | Crude % | n | Age-adjusted *P* Value† | Crude % | n | Age-adjusted *P* Value† |
| Age (yr) | | | | | | | | |
| 43–54 | 45.6 | 967 | 36.7 | 88 | <.001 | 14.0 | 17 | <.001 |
| 55–64 | 32.9 | 698 | 28.3 | 68 | | 18.2 | 22 | |
| 65–74 | 18.6 | 394 | 28.3 | 68 | | 45.5 | 55 | |
| 75+ | 2.8 | 60 | 6.7 | 16 | | 22.3 | 27 | |
| Gender | | | | | | | | |
| Female | 58.2 | 1234 | 56.3 | 135 | .28 | 57.9 | 70 | .11 |
| Male | 41.8 | 885 | 43.8 | 105 | | 42.1 | 51 | |
| Education | | | | | | | | |
| <High school | 15.5 | 328 | 22.1 | 53 | .03 | 34.7 | 42 | .06 |
| High school | 48.5 | 1027 | 50.8 | 122 | | 38.8 | 47 | |
| College | 17.0 | 360 | 12.9 | 31 | | 17.4 | 21 | |
| >College | 19.0 | 402 | 14.2 | 34 | | 9.1 | 11 | |
| Employment | | | | | | | | |
| Full-time | 51.8 | 1098 | 41.7 | 100 | .15 | 20.7 | 25 | .26 |
| Part-time | 12.8 | 271 | 8.3 | 20 | | 7.4 | 9 | |
| Retired | 23.3 | 493 | 35.8 | 86 | | 54.5 | 66 | |
| Other | 12.1 | 257 | 14.2 | 34 | | 17.4 | 21 | |
| Income ($) | | | | | | | | |
| ≤9000 | 7.5 | 156 | 13.4 | 31 | .48 | 16.9 | 20 | .28 |
| 10–19,000 | 22.6 | 469 | 23.4 | 54 | | 33.9 | 40 | |
| 20–29,000 | 21.4 | 443 | 22.5 | 52 | | 24.6 | 29 | |
| 30–44,000 | 26.0 | 538 | 20.8 | 48 | | 16.9 | 20 | |
| ≥45,000 | 22.5 | 465 | 19.9 | 46 | | 7.6 | 9 | |
| Best-corrected visual acuity, better eye | | | | | | | | |
| Better than 20/40 | 99.1 | 2091 | 99.2 | 236 | .53 | 96.7 | 117 | .74 |
| 20/40–20/160 | 0.7 | 15 | 0.8 | 2 | | 3.3 | 4 | |
| 20/200 and worse | 0.1 | 3 | 0.0 | 0 | | 0.0 | 0 | |
| Central cataract, worse eye | | | | | | | | |
| No | 90.5 | 1891 | 85.4 | 199 | .86 | 75.8 | 91 | .71 |
| Yes | 9.5 | 199 | 14.6 | 34 | | 24.2 | 29 | |
| Age-related macular degeneration, worse eye | | | | | | | | |
| None | 84.3 | 1767 | 83.1 | 196 | .58 | 71.4 | 85 | .24 |
| Early | 15.2 | 318 | 16.5 | 39 | | 26.1 | 31 | |
| Late | 0.5 | 10 | 0.4 | 1 | | 2.5 | 3 | |
| Hypertension | | | | | | | | |
| No | 59.6 | 1263 | 51.7 | 124 | .12 | 36.4 | 44 | .009 |
| Yes | 40.4 | 855 | 48.3 | 116 | | 63.6 | 77 | |
| History of cardiovascular disease | | | | | | | | |
| No | 89.6 | 1881 | 88.1 | 207 | .72 | 78.2 | 93 | .21 |
| Yes | 10.4 | 219 | 11.9 | 28 | | 21.8 | 26 | |
| History of cancer | | | | | | | | |
| No | 91.7 | 1943 | 90.4 | 217 | .99 | 84.3 | 102 | .37 |
| Yes | 8.3 | 175 | 9.6 | 23 | | 15.7 | 19 | |
| Diabetes status | | | | | | | | |
| No | 94.7 | 2001 | 95.4 | 226 | .58 | 90.9 | 110 | .18 |
| Yes | 5.3 | 111 | 4.6 | 11 | | 9.1 | 11 | |
| History of alcohol consumption | | | | | | | | |
| No | 10.9 | 231 | 11.3 | 27 | .90 | 17.4 | 21 | .32 |
| Yes | 89.1 | 1888 | 88.8 | 213 | | 82.6 | 100 | |

**TABLE 1.** Continued

| Characteristic | Participants All Four Exams | | Nonparticipants* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Alive | | | Not Alive | | |
| | Crude % | n | Crude % | n | Age-adjusted P Value† | Crude % | n | Age-adjusted P Value† |
| Heavy drinker | | | | | | | | |
| No | 84.7 | 1794 | 84.6 | 203 | .62 | 84.3 | 102 | .19 |
| Yes | 15.3 | 324 | 15.4 | 37 | | 15.7 | 19 | |
| Smoking status | | | | | | | | |
| Never | 47.4 | 1003 | 53.3 | 128 | .31 | 47.9 | 58 | 0.07 |
| Past | 34.7 | 735 | 32.1 | 77 | | 37.2 | 45 | |
| Current | 17.9 | 380 | 14.6 | 35 | | 14.9 | 18 | |
| | Mean (SD) | n | Mean (SD) | n | Age-adjusted P Value† | Mean (SD) | n | Age-adjusted P Value† |
| Age (yr) | 56.78 (8.82) | 2119 | 59.55 (9.74) | 240 | <.001 | 67.18 (9.47) | 121 | <.001 |
| Pack-years smoked | 14.16 (21.50) | 2110 | 12.62 (19.66) | 240 | .45 | 17.74 (27.88) | 121 | .01 |
| Systolic blood pressure (mm Hg) | 127.47 (17.91) | 2119 | 132.08 (19.31) | 240 | .005 | 134.43 (19.17) | 121 | .14 |
| Diastolic blood pressure (mm Hg) | 78.32 (10.15) | 2119 | 79.18 (9.86) | 240 | .05 | 76.32 (11.48) | 121 | .96 |
| Intraocular pressure (mm Hg) | 15.09 (3.16) | 2107 | 15.92 (3.10) | 239 | <.001 | 15.57 (3.61) | 120 | .85 |

SD = standard deviation.

*Nonparticipants at the fourth examination who had participated in all three previous examinations.

†Compared with participants. Characteristics were those ascertained at the baseline examination, and numbers at risk may vary as a result of missing data.

refraction from a Humphrey 530 refractor was placed in a trial lens frame and the best-corrected visual acuity was remeasured for each eye by means of the ETDRS protocol with charts R 1 and 2 modified for a 2 m distance.[9,11] If the best-corrected visual acuity was 20/40 or worse in either eye, an ETDRS refraction was performed for that eye and the visual acuity was measured. The inter-observer differences among the examiners for the refraction or the best-corrected visual acuity was low and not clinically appreciable (data not shown).

Three thousand nine hundred and forty two people had reliable event data (visual acuity or death) at consecutive examinations (71 right eyes only, 66 left eyes only, 3805 both eyes); 217 (5.5%) were in a nursing home by their last examination. Twenty-two percent of the 548 people aged 75 years or older at baseline were in a nursing or group home at the time of their last follow-up.

For each eye, the visual acuity was recorded as the number of letters correctly identified from either the 2 m chart (from 20/10 to 20/200 vision or 70 to 5 letters) or the 1 m chart (20/250 to 20/800 or 0 to −25 letters). The 1 m chart has 25 letters; if all were read correctly, the number of letters assigned is 0; if none can be read correctly, the number of letters assigned is −25. For eyes with vision poorer than 20/800, 1 of 3 levels of vision were recorded: hand motions, light perception, and no light perception. These levels were assigned arbitrary values on the visual acuity scale of −40, −55, and −70, respectively. Levels of impairment in visual function were defined by the best-corrected visual acuity in the eye, or, for a participant, in the better eye. The definitions were: no impairment, better than 20/40 (41 to 70 letters correct); any visual impairment, 20/40 or worse (40 or fewer letters correct); and severe impairment (legal blindness), 20/200 or worse (five or fewer letters correct).

Persons at risk for developing impaired vision were those with visual acuity better than 20/40 in at least one eye at baseline. Similarly, persons at risk for developing severe loss of vision were those with visual acuity better than 20/200 in at least one eye at baseline. Loss of vision over the 15-year period was defined as a doubling of the visual angle, a loss of 15 letters (for example, a change from baseline to follow-up from 60 to 45 letters read correctly corresponding to a change in visual acuity from 20/16 to 20/32). Only persons with better than no light perception at baseline were at risk to lose vision. Improvement in vision was defined as improving by 15 or more letters (half of the visual angle). People at risk for developing improvement in vision were those with ≤ 55 letters (visual acuity 20/20 or worse) in at least one eye. For an individual, loss and improvement were computed for visual acuity measured in the better eye.

For most analyses, age was defined as the age at the time of the baseline examination.

Comparisons of participants and nonparticipants were performed by type III SS in a two-way analysis of variance

(ANOVA) and the Cochran-Mantel-Haenszel test of independence to adjust for age groups with continuous (that is, blood pressure) and categorical (that is, visual acuity) characteristics, respectively. Student's paired *t* test and one-way ANOVA were used to compare the change in the number of letters read between eyes and age groups, respectively. This 15-year change was calculated as the difference among subjects seen at the baseline and 15-year examinations. Generalized estimating equations (GEE) were used to compute estimates of age- and gender-adjusted change.[12,13]

Cumulative 15-year rates were calculated accounting for the competing risk of death.[14] This is an adaptation of the Kaplan-Meier product limit method where time to the event of interest or death (competing event) is modeled. Persons eligible for analyses in this model include persons with information on either the event or death at consecutive examinations. Persons not examined at follow-up for reasons other than death are censored. Additional estimates of cumulative incidence were calculated for the event and for the event followed by death, which allowed us to calculate the proportion of survivors who had the event. Multivariable analyses and age-adjusted risk estimates were based on the discrete linear logistic model.[15] These analyses were run for subjects seen at consecutive visits. Because this method does not consider any data after an event occurs, analysis of improvement was done separately.

Analyses were also run for the five-year incidence among those participating in the 10- and 15-year examinations. Incidence of endpoints was defined in the same way. For analysis of vision loss or improvement with nursing home placement or cataract surgery, a time-dependent covariate analysis was run. For every five year period, incidence of vision loss/improvement, nursing home placement and cataract surgery was calculated. These values were updated for each consecutive five year period. Once a person developed an incident outcome, they no longer contributed to later five year periods. Unless noted, results were unadjusted for any confounders. SAS version 8 was used for all analyses.[16]

## RESULTS

THE MEAN AGE OF THE PARTICIPANTS AT BASELINE WAS 56.8 years; 58.2% were women (Table 1). The mean number of years of school completed was 12.8, and the median income was >$45,000. Other baseline characteristics of the participants are presented in Table 1.

The mean decrease in the number of letters read correctly over the 15-year period was smaller in the right (−5.4 [SD = 12.5]) compared with the left eye (−7.1 [SD = 13.7], $P < .001$) (Figure 2). For both men and women, there was a significant inverse relationship between the mean change in the number of letters read correctly between examinations and age such that those who were younger at baseline lost fewer letters during the 15-year period than those who were older. For the right eye, it varied from −2.7 letters (SD = 6.3) in people between 43 to 54 years of age to −17.4 (SD = 27.9) in people 75 years of age or older at baseline. For the left eye, it varied from −3.6 letters (SD = 7.4) in people between 43 to 54 years of age to −22.7 (SD = 32.6) in people 75 years of age or older at baseline. Women lost fewer letters (−5.3 vs −5.6, $P = .04$). A similar relation between age/gender and change in the number of letters read correctly between examinations was found in the left eye. The relationship to age is curvilinear. By fitting the quadratic relationship of change in the number of letters read correctly with age (continuously) and sex, we found that the change in letters in the right eye $= [-31.80 + 1.31\ \text{age} - 0.014\ \text{age}^2 - 1.10\ (\text{gender} = \text{male})]$. In people 55 years of age at baseline (42% male), a change of approximately 1 line in visual acuity score (right eye) was observed over the 15-year period (3.7 letters lost, 95% confidence interval [CI] −4.4 to −3.1). In persons 75 years of age at baseline, the visual acuity score diminished by approximately 3 lines (14.9 letters lost right eye, 95% CI −16.4 to −13.4).

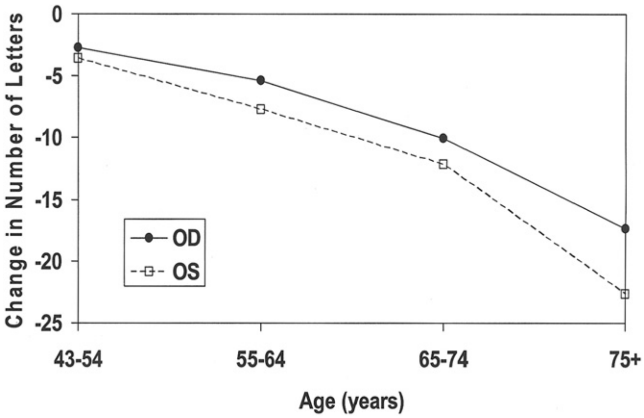


**FIGURE 2. Fifteen-year change in the number of letters read correctly in the right eye (solid) and left eye (dashed) by age at baseline in the Beaver Dam Eye Study.**

The cumulative 15-year incidence of visual impairment (right eye 15.2% vs left eye 15.6%, $P = .61$) was similar for both eyes while doubling of the visual angle (right eye = 10.6% vs left eye = 12.5%, $P = .03$) was greater in the left compared with the right eye.

On the basis of vision in the better eye over the 15-year period, 8.3% of the population at risk developed impaired vision, 0.8% developed severe impairment, and 7.2% had doubling of the visual angle. Improvement in the better eye occurred in 1.9% of the population. The 15-year incidence of any visual impairment, severe visual impairment, doubling of the visual angle, and improvement by age and gender are shown in Table 2. Death was accounted for as a competing risk. People who were 75 years of age or older at baseline were 12.8 times (95% CI 9.6 to 17.1, $P <$

**TABLE 2.** 15-Year Cumulative Incidence of Vision Changes in the Better Eye by Age and Gender in the Beaver Dam Eye Study

| | Doubling of Visual Angle* | | | Visual Impairment† | | | Severe Impairment‡ | | | Improvement (Half Angle)§ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age (yr) | No. of Participants at Risk | % | *P* Value‖ | No. of Participants at Risk | % | *P* Value‖ | No. of Participants at Risk | % | *P* Value‖ | No. of Participants at Risk | % | *P* Value‖ |
| Female | | | | | | | | | | | | |
| 43–54 | 668 | 1.1 | | 661 | 1.5 | | 667 | 0.2 | | 159 | 2.1 | |
| 55–64 | 579 | 6.8 | | 574 | 5.6 | | 578 | 0.2 | | 222 | 1.9 | |
| 65–74 | 599 | 10.9 | <.001 | 569 | 18.4 | <.001 | 598 | 0.9 | <.001 | 349 | 1.8 | .25 |
| 75+ | 336 | 17.0 | | 270 | 29.7 | | 327 | 5.0 | | 279 | 2.5 | |
| Total | 2182 | 7.3 | | 2074 | 10.2 | | 2170 | 1.0 | | 1009 | 2.1 | |
| Male | | | | | | | | | | | | |
| 43–54 | 588 | 2.9 | | 586 | 1.4 | | 588 | 0.2 | | 68 | 4.4 | |
| 55–64 | 510 | 4.8 | | 507 | 2.8 | | 510 | 0.0 | | 96 | 1.0 | |
| 65–74 | 448 | 14.9 | <.001 | 436 | 12.6 | <.001 | 447 | 1.6 | <.001 | 164 | 1.6 | .27 |
| 75+ | 213 | 10.9 | | 185 | 18.5 | | 211 | 1.8 | | 153 | 0.7 | |
| Total | 1759 | 7.1 | | 1714 | 6.0 | | 1756 | 0.6 | | 481 | 1.6 | |
| Age-adjusted | | | | | | | | | | | | |
| Male vs Female | | | .03 | | | .08 | | | .81 | | | .82 |
| Total | | | | | | | | | | | | |
| 43–54 | 1256 | 1.9 | | 1247 | 1.4 | | 1255 | 0.2 | | 227 | 2.8 | |
| 55–64 | 1089 | 5.9 | | 1081 | 4.3 | | 1088 | 0.1 | | 318 | 1.6 | |
| 65–74 | 1047 | 12.7 | <.001 | 1005 | 15.9 | <.001 | 1045 | 1.2 | <.001 | 513 | 1.8 | .67 |
| 75+ | 549 | 14.6 | | 455 | 25.1 | | 538 | 3.7 | | 432 | 1.9 | |
| Total | 3941 | 7.2 | | 3788 | 8.3 | | 3926 | 0.8 | | 1490 | 1.9 | |

*Incidence of doubling of the visual angle defined as a loss of 15 letters or more in visual acuity in better eye at follow-up.

†Incidence of impairment defined as development of visual acuity of 20/40 or worse in better eye at follow-up in an individual who had better than 20/40 visual acuity in both eyes at baseline.

‡Incidence of severe visual impairment defined as development of visual acuity of 20/200 or worse in better eye only at follow-up in an individual who had better than 20/200 in both eyes at baseline.

§Incidence of improvement in visual acuity defined as an improvement of 15 letters or more in visual acuity in better eye at follow-up.

‖Mantel-Haenszel test of trend.

.001) as likely to develop impaired vision, 7.8 times (95% CI 5.6 to 10.7, $P < .001$) as likely to have a doubling of the visual angle, and 20.6 times as likely (95% CI 9.5 to 44.8, $P < .001$) to develop severe visual impairment as people younger than 75 years of age at baseline. Although improvement in vision was 1.6 (95% CI 0.7 to 3.7, $P = .27$) times as likely in people 75+ years of age compared with those who were younger at baseline, the difference was not statistically significant. After controlling for age, doubling of the visual angle (OR = 1.4, 95% CI 1.0 to 1.8, $P = .03$) but not the incidence of visual impairment (OR = 0.79, 95% CI 0.6 to 1.0, $P = .08$) or improvement (OR = 0.9, 95% CI 0.4 to 2.2, $P \geq .82$) was statistically significantly different between men and women.

To provide estimates of burden of visual impairment in survivors, we reran the models as described in the Methods section so that only those surviving 15 years contribute information. The proportion of the survivors at the 15-year follow-up who had had an incident vision outcome (for example, doubling of the visual angle, visual impairment, severe visual impairment, or improvement) is presented in Figure 3 by age and gender. Incidence of doubling of the visual angle occurred in 7.4% of survivors and varied from 2.0% in those 43 to 54 years of age at baseline to 19.6% in those 75 years of age or older at baseline; for visual impairment it was 7.8% and varied from 1.4% in those 43 to 54 years of age to 37.2% in those 75 years of age or older at baseline; for severe visual impairment it was 0.7% and varied from 0.2% in those 43 to 54 years of age to 5.5% in those 75 years of age or older at baseline; and for improvement it was 2.0% and varied from 2.5% in those 43 to 54 years of age to 0.3% in those 75 years of age or older at baseline.

The relationship of improvement of visual acuity to cataract surgery was examined by time-dependent covariate analysis. In people 55 years of age or older, the incidence of improvement in vision over the next five-year period was consistently higher in eyes that had undergone cataract surgery in the same period compared with eyes that had not. Among the 119 right eyes that had undergone cataract surgery between the baseline and five-year examination, 27% of the eyes also had improved vision, whereas 1% of the 1188 eyes without cataract surgery also had improved vision. Similarly 9% of the 99 eyes with cataract surgery, vs 0.7% of the 562 eyes without cataract surgery between the five- and 10-year examinations had

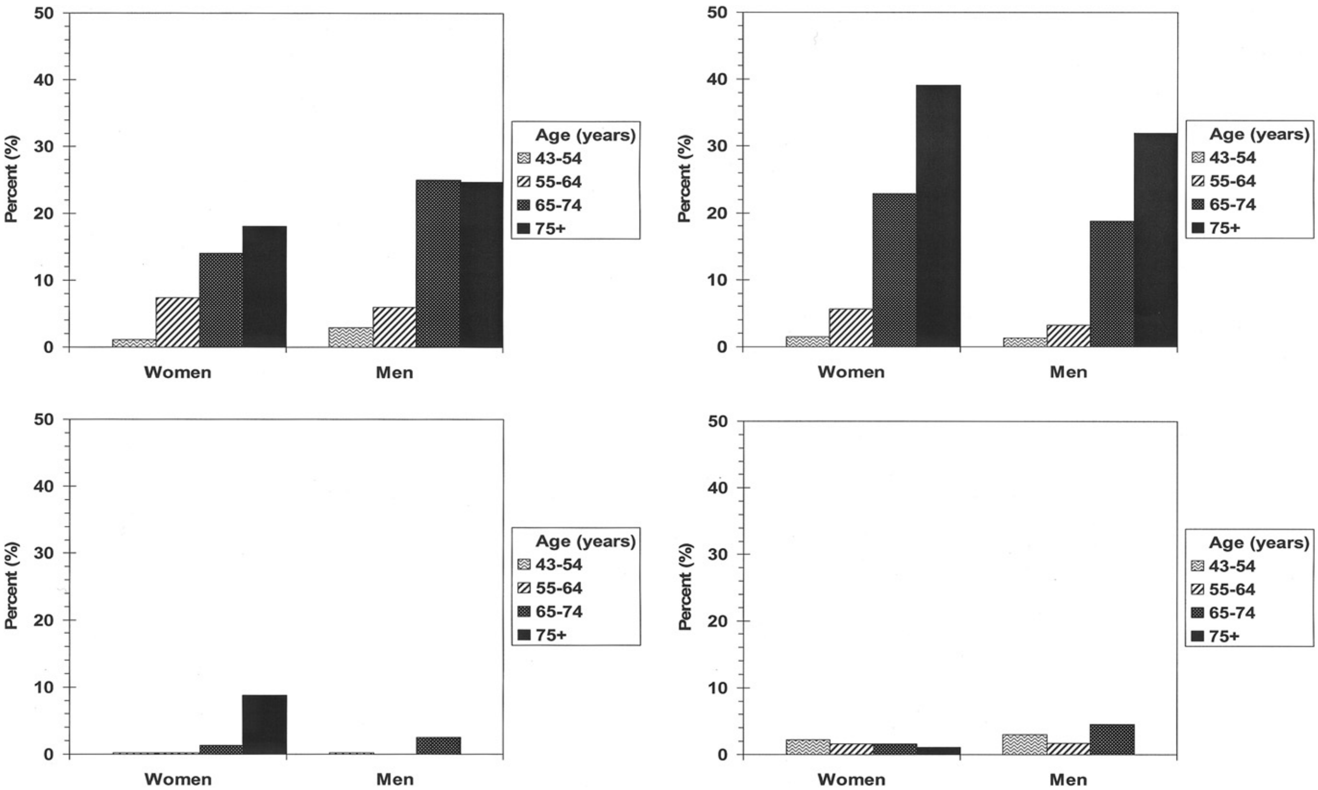


**FIGURE 3. Proportion of survivors to the 15-year follow-up who had developed (Top left) doubling of the visual angle; (Top right) visual impairment (20/40 or worse); (Bottom left) severe impairment (20/200 or worse); and (Bottom right) improvement (half of the visual angle).**

**TABLE 3.** 15-Year Incidence of Visual Impairment, Severe Impairment, Doubling of the Visual Angle, and Improvement by Baseline Visual Acuity in the Beaver Dam Eye

| | Level of Impairment at 15 Years | | | | Cumulative Incidence Doubling of Visual Angle (Better Eye) | | | Cumulative Incidence Improvement (Better Eye) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Visual Acuity in Better Eye at Baseline (Level of Impairment) | No. of Participants at Risk | None, n (%) | Moderate, n (%) | Severe, n (%) | No. of Participants at Risk | % | *P* Value | No. of Participants at Risk | % | *P* Value |
| Better than 20/40 (none) | 2229 | 2088 (93.67) | 127 (5.70) | 14 (0.63) | 3788 | 7.1 | | 1335 | 0.9 | |
| 20/40–20/60 (moderate) | 23 | 10 (43.48) | 10 (43.48) | 3 (13.04) | 138 | 6.5 | | 138 | 11.2 | |
| 20/200 or worse (severe) | 3 | 0 (0.00) | 0 (0.00) | 3 (100.00) | 15 | 40.0 | .006 | 17 | 11.8 | <.001 |

improved vision. Between the 10- and 15-year examinations, 4.4% (n = 92) vs 0.9% (n = 460) had improved vision. The time-dependent OR for improved vision in those with cataract surgery was 22.5 (95% CI 12.3 to 31.5, $P < .001$) compared with those without cataract surgery among persons 55 and older.

Among those persons without impaired vision at baseline and who were seen at the 15-year follow-up, incidence of moderately impaired vision (20/40 to 20/160) was 5.7% and for the development of severe visual impairment was 0.6% (Table 3). Of those who had moderately impaired vision at baseline, 43.5% were no longer visually impaired, while 13.0% had developed severe impairment at follow-up. The cumulative 15-year incidence (including people seen only at the five- and/or the 10-year examination) of doubling of the visual angle in people who did not have visual impairment at baseline was 7.1%; for those with moderate visual impairment it was 6.5%. Of eyes that were visually impaired and had improved by 15 or more letters, 75.0% (12/16) of right eyes and 33.3% (2/6) of left eyes had undergone cataract surgery.

One hundred and seventy-four (84.1%) of the 207 people who were not in a nursing home at baseline but who entered a nursing home at one of the follow-up examinations had a reliable visual acuity measurement at baseline and at a follow-up visit. In a time-dependent analysis of vision changes and nursing home placement, of those 75 years of age or older in whom visual acuity could

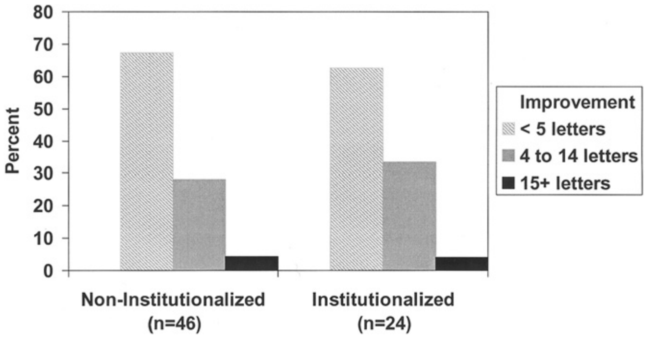


**FIGURE 4. Frequency of number of letters improvement in vision in the better eye by refraction compared with current prescription at 15-year follow-up in noninstitutionalized and institutionalized participants 75 years of age or older in the Beaver Dam Eye Study.**

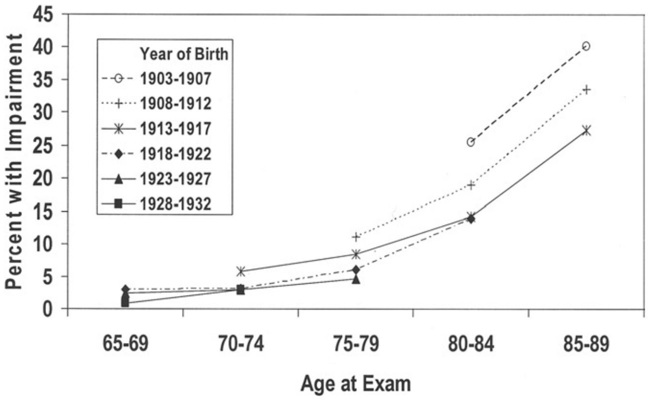


**FIGURE 5. Visual impairment rate by age at examination and year of birth. Each person contributes multiple times depending on his or her age at each of the examination phases he or she participated in.**

be measured, those entering a nursing or group home during a five-year period were 2.6 times (95% CI 1.6 to 3.4, $P < .001$) as likely to have developed impaired vision, 2.8 times (95% CI 1.0 to 4.8, $P = .04$) to have developed severely impaired vision, and 3.6 times (95% CI 2.0 to 4.9, $P < .001$) to have had a doubling of the visual angle during the same five-year period than those not entering a nursing or group home. The rate of improvement in visual acuity over a five-year period in those 75 years of age or older and institutionalized was similar to those who were not institutionalized (OR = 2.91, $P = .07$) during the same five-year period.

At the 15-year follow-up examination, a similar proportion of institutionalized (37.5%) and noninstitutionalized (32.6%) persons over 75 years of age had an improvement of five or more letters of visual acuity after refraction (Figure 4) compared with their current prescription. Among those who had this level of improvement and who were visually impaired with their current correction, 56% were no longer impaired after refraction. The rate of improvement of three or more lines was higher in those who were institutionalized (2.3%) compared with those who were not (1.0%, $P = .006$).

Birth cohort effects were examined for persons born in the same year (Figure 5). The prevalence of visual impairment for people aged 70 to 74 years at the time of the examination varied from 5.8% (18/313, 95% CI 3.2 to 8.3) in those born in 1913 to 1917 to 2.9% (12/419, 95% CI 1.3 to 4.5) for those born in 1928 to 1932. Similarly, for people aged 80 to 84 years at the time of the examination, prevalence varied from 25.5% (27/106, 95% CI 17.2 to 33.8) in those born in 1903 to 1907 to 13.9% (38/274, 95% CI 9.8 to 18.0) in those born in 1918 to 1922.

Of the 180 eyes that developed severe visual impairment over the 15-year period, late age-related macular degeneration was the primary cause in 52%, branch or central retinal vein occlusion in 12%, and cataract in 12%. Other less frequent causes of severe visual impairment included macular hole in 5%, diabetic retinopathy in 3%, retinal detachment in 3%, enucleation for choroidal malignant melanoma in 2%, glaucoma in 3%, and other optic nerve disease including ischemic optic neuropathy in 2%.

At the time of the 10-year follow-up, we had enough participants over the age of 80 years of age to examine vision loss. Twenty-three percent who had been ≥80 years of age at the 10-year examination had developed visual impairment and 3% developed severe impairment over the following five-year period.

At the time of the 15-year follow-up examination, there were 159 persons (7% of 2264) who were visually impaired including 20 who were severely impaired. The frequency of visual impairment and severe visual impairment, respectively, varied with age from 2% and 0.3% in those who were <70 years of age (n = 1050), 4% and 0% in those 70 to 79 years of age (n = 721), 20% and 2.4% in those 80 to 89 years of age (n = 421), to 38% and 9.7% in those ≥90 years of age (n = 72).

## DISCUSSION

THERE ARE VERY FEW POPULATION-BASED DATA AVAILable describing the long-term incidence of visual loss.[7] The current data build upon our previously reported population-based estimates of objectively measured change in vision over a five- and 10-year period.[4,10] This study is unique in that a large cohort, both institutionalized and noninstitutionalized, with a broad distribution of ages was reexamined after a 15-year interval. All visits used the same standardized protocols for measuring visual acuity. It reveals the high prevalence (38%) of visual impairment in persons in their $10^{th}$ decade of life and the relatively high (25%) 15-year cumulative incidence of visual impairment in persons aged 75 years at baseline. Furthermore, we found a high proportion

(37%) of those aged 75 years at baseline who survived 15 years had developed impaired vision.

These data show a curvilinear relationship in the overall change in visual acuity with age over the 15-year period, with a loss of approximately a line of vision in the youngest persons (43 to 54 years of age) and a loss of 3 lines of vision in persons aged ≥75 years. This latter age group was approximately eight times as likely to have a doubling of the visual angle and 12 to 13 times as likely to develop impaired vision as persons who were younger at baseline. The high incidence of loss of vision after 75 years of age is consistent with the higher frequencies of age-related macular degeneration, central and branch vein occlusion, and cataract in this age group.[17–21]

The overall 15-year cumulative incidence of severely impaired vision in the population was 0.8%. However, among persons >65 years at baseline, 2% had developed severe impairment in vision over the 15-year period. This group was approximately 20 times as likely to develop severe visual impairment as persons who were younger at baseline. There are no population-based United States data and few elsewhere for comparative purposes. In one such study in Italy, those who were aged ≥40 years at baseline, severe visual impairment developed over a 12-year period in 0.7%.[7] These estimates are similar to those we reported. Our findings have important implications for quality of life and cost of care. In the United States, for men aged 65 to 74 years of age in the year 2002, the life expectancy was 16.6 years, and for women, it was 19.5 years; for those aged 75 to 84 years, for men it was 10.3 years and for women it was 12.4 years.[22] If our estimates are extrapolated to the future, then a considerable number of people aged 65 to 84 years are at risk of developing visual impairment over their remaining lifetime. If the current rates from Beaver Dam are applied to the United States population estimates, approximately 6.6 million people who are aged ≥65 years will develop mild to moderate impairment with 0.9 million developing severe impairment at some point during a 15-year period.[22] Changes in care and exposures to protective and risk factors for age-related eye diseases associated with visual impairment could influence these estimates.

Those who entered a nursing or group home over a five-year period in Beaver Dam were approximately four times as likely to have doubling of the visual angle or to have developed visual impairment compared with those who did not enter a nursing or group home. This is consistent with the frequency of severe visual impairment in 20% of institutionalized subjects in Beaver Dam at baseline and with other population-based data that have described higher frequencies of loss of vision in people in nursing or group homes.[9,23–27] In the Blue Mountains Eye Study, visual impairment at baseline in older persons was also associated with a doubling of the risk of subsequent nursing home admission.[26,28] Reasons for admission to nursing or group homes (for example, stroke, dementia, fractures, and decreased vision) in Beaver Dam are not known. We speculate that decreased vision may act synergistically with loss of cognitive, motor, and other sensory abilities in precipitating institutional admission and perhaps in prolonging the stay. This speculation is consistent with our earlier observation of an association of poor visual acuity with incident falls and fractures.[29] Visual impairment has been shown to result in a nearly twofold increase in the odds of incident cognitive decline and functional decline in women aged ≥69 years followed for 4.4 years.[30] Self-reported impaired vision has been reported to be associated with poorer 10-year outcomes reflected in activities of daily living and instrumental activity of daily living.[31] Although data suggest that correcting vision impairment can lead to an improved quality of life and functional status, there is a need for data to show it maintains independence and reduces the risk of being institutionalized.[32,33]

Approximately 2% of the Beaver Dam population had an improvement in their visual acuity of 15 or more letters over the 15-year period. Sixty-four percent of right eyes and 62% of left eyes with improvement had undergone cataract surgery. Our data suggest that cataract surgery could improve vision by three or more lines in a quarter or more of the population 55 years of age or older.

Late age-related macular degeneration was the most important cause of incident severe visual loss, accounting for 52% of eyes with severe visual impairment. These findings are consistent with data from most, but not all, earlier studies.[1,2,4,5,34–40] The most common primary retinal vascular cause of severe visual loss in the Beaver Dam cohort was central and branch retinal vein occlusion (12%). It may reflect the lack of prophylactic and early diagnosis and treatment modalities for retinal vein occlusions. Diabetic retinopathy is associated with 3% of eyes with severe impairment. This may reflect the ability to prevent loss of vision by treatment of diabetic retinopathy with timely laser photocoagulation.[41] It may be that the higher mortality in persons with diabetes causes an underestimate of the toll of severe visual impairment related to this condition.[42]

We had previously described a birth cohort effect where the frequency of visual impairment was lower for more recent birth cohorts. This was not explained by a similar difference in rates of cataract surgery among the birth cohorts (Klein R, unpublished data, 2005). It is not explained by selective participation of those with less severe vision loss as suggested by differences in visual acuity that were similar in those who participated in the follow-up compared with those who did not. The cohort effect may be due to real differences in lifestyle exposures (for example, smoking, diet), the better control of diabetes, hypertension and lipids, and/or the greater frequency and the better outcomes of surgical interventions in the similarly aged persons with later birth dates compared with those with earlier birth dates.

Our findings differ from the National Health Interview Survey (NHIS) that showed no changes in 10-year trends in self-reported visual impairment within age groups from 1986 to 1995.[43]

We have previously reported cumulative incidences by using the product limit method.[10,44] In this report, we use a competing risks model to report cumulative incidence because of the increase in mortality with age. This model results in lower rates than the product limit method. For example, on the basis of the latter, the 15-year cumulative incidence for doubling of the visual angle, any visual impairment, and severe visual impairment in persons 65 to 74 years of age at baseline would be 19.1%, 23.5%, and 1.5%, respectively; for those 75+ years of age at baseline, it would be 34.6%, 49.4%, and 6.9%, respectively, which are higher than those determined by the competing risk method reported herein (Table 2).[14] We assume that the competing risk method is the appropriate measure when the burden of incident disease (for example, visual impairment) is of interest. The previously used product limit method represents a rate if there were no competing events such as death.

Our data may underestimate the true incidence of impaired vision if those who did not participate at the follow-up had lost vision at a greater rate than those who did participate. By the time of the 15-year follow-up, the persons who were alive and did not participate had a similar likelihood of having age-related macular degeneration, central cataract, or poor vision at baseline, so this supposition appears less plausible. There were 239 persons who were seen at baseline and the 15-year follow-up, but did not participate at either the five-year follow-up and/or the 10-year follow-up and thus were not included in analyses of cumulative incidence. Exclusion of these people might have caused an underestimate of the incidence of visual loss because these individuals were more likely to have decreased vision at baseline. However, we examined overall incidence as estimated without these people and with these people by using imputation methods (Klein R, unpublished data) and found the results to be similar for most outcomes. Because of the small number of those who missed either or both the five- or 10-year follow-up and the relative narrowness of the interval, we cannot adequately evaluate the possibility of bias introduced by nonparticipation.

In summary, the Beaver Dam Eye Study data provide estimates of the incidence of loss of vision over a 15-year period for a wide spectrum of ages. The high cumulative incidence (25%) and prevalence (15%) of visual impairment in people aged ≥75 years indicates a severe public health problem. This problem may grow because it is expected that those in the United Sates population this age will increase by 54% from 18 million this age in the year 2005 to 28 million people by the year 2025.[45]

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## Biosketch

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**Biosketch**

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