Screening for glaucoma in populations at high risk: The eye screening New York project

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Cogent Medicine (2017), 4: 1367059
OPHTHALMOLOGY | RESEARCH ARTICLE

Screening for glaucoma in populations at high risk: The eye screening New York project

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Abstract: Purpose: To explore the yield and feasibility of glaucoma screening and the prevalence of glaucoma in high risk populations in New York City. Methods: A Community based glaucoma screening study was conducted in a high-risk population in NYC from 2007–2014 using fixed sites and mobile van. Participant underwent visual acuity testing, Tonopen intraocular pressure (IOP), frequency doubling technology (FDT), and optic nerve cup/disk ratio (C/D) by an ophthalmologist or optometrist. Glaucoma suspects (GS) were defined by IOP \( \geq 21 \) mm Hg, abnormal FDT, and cup/disc \( \geq 0.5 \). Results: 8,547 were screened between 2007–2014. 54% were Hispanics and 16% were African Americans. Of the 8,547 screened 2,118 (24.94%) had suspicions of glaucoma diagnosis. Of those who were followed up, glaucoma was confirmed in 52%. Our study suggests that glaucoma screening in high risk populations is feasible and has high positive yield. Furthermore, it highlights the importance of an active blindness prevention program in the context of population management.

Received: 04 June 2017
Accepted: 04 August 2017
First Published: 14 August 2017

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Reviewing editor: Udo Schumacher, University Medical Center Hamburg-Eppendorf, Germany

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Lama A. Al-Aswad is a glaucoma subspecialty with a strong interest in disease prevention and population health management. She is an Associate Professor of Ophthalmology at Columbia University Medical School and a Glaucoma research fellow. She received her medical degree from Damascus University Medical School and a Glaucoma research fellowship from Mass Eye and Ear Infirmary Harvard Medical School. She completed her residency in ophthalmology at SUNY Downstate and her Glaucoma fellowship at UT Memphis. Dr. Al-Aswad is the past president of the NY Glaucoma Society and the president elect for WIO. In 2015, she received her MPH in healthcare policy and management from Columbia University, Mailman School of Public Health.

Al-Aswad is a believer in blindness prevention as evident from her large-scale screening project in NYC where she screened 8,547 individuals for glaucoma. She recently launched the teleophthalmology screening project for the 4 leading causes of blindness utilizing cutting edge technology.

PUBLIC INTEREST STATEMENT

To study glaucoma screening in high risk populations, a study was conducted 2007–2014 in New York City, using multiple eye tests. 8,547 were screened. 54% were Hispanics and 16% were African Americans. Of the 8,547 screened 2,118 (24.94%) had suspicions of glaucoma diagnosis. Of those who were followed up, glaucoma was confirmed in 52%. Our study suggests that glaucoma screening in high risk populations is feasible and has high positive yield. Furthermore, it highlights the importance of an active blindness prevention program in the context of population management.
increase in RRR of being a GS [95% 1.79–2.19, \( p < 0.001 \)]. Follow up was available in 610 subjects. Glaucoma was confirmed in 52% of the individuals who followed up. 

**Conclusions:** Our data suggests the prevalence of positive screening is substantial in high risk populations. It establishes the feasibility of mobile screening as a method of facilitating access to care. Furthermore, it highlights the importance of an active blindness prevention program in the context of population management.

**Subjects:** Health and Social Care; Medicine, Dentistry, Nursing & Allied Health; Medicine; Ophthalmology

**Keywords:** glaucoma; glaucoma screening; access to care; prevalence of disease; population health management

1. **Introduction**

Glaucoma is the second leading vision-threatening disease worldwide (World Health Organization, 2004), and primary open-angle glaucoma (OAG) constitutes 74% of all cases (Quigley & Broman, 2006). Open-angle glaucoma is an insidious disease that often progresses with no symptoms until vision has been permanently damaged. Early diagnosis is of extreme importance, as continuous monitoring, and individualized treatment with agents that intraocular pressure (IOP), may reduce or minimize the risk of blindness (Collaborative Normal-Tension Glaucoma Study Group, 1998; Heijl, Leske, Bengtsson, Hyman, & Hussein, 2002; Kass et al., 2002). Unfortunately, large population-based studies have shown that 50 to 75% of individuals with glaucoma have never been diagnosed with the disease (Leske, Connell, Schachat, & Hyman, 1994; Mitchell, Smith, Attebo, & Healey, 1996; Tielsch, Sommer, et al., 1991; Varma, Ying-Lai, et al., 2004).

In the United States, there are currently an estimated 2.7 million cases of glaucoma among adults 40 years and older (Prevent Blindness America, 2012). The prevalence and severity of glaucoma vary widely among various racial and ethnic groups. Researchers who analyzed 1999–2008 data from the National Health and Nutrition Examination Survey found that non-Hispanic African-Americans had a significantly higher age- and sex-standardized prevalence of glaucoma (11.5%) compared with non-Hispanic Whites (6.9%; \( p < 0.001 \)) and Mexican Americans (6.5%; \( p = 0.006 \)) (Zhang et al., 2012). Glaucoma causes blindness in 19% of African-Americans and 11% of Hispanics/Latinos compared with 5% of non-Hispanic Whites, and it causes visual impairment in 11, 6, and 2% of those groups, respectively (Vajaranant, Wu, Torres, & Varma, 2012).

Many residents of northern Manhattan (a borough of New York, NY) are Hispanic/Latino or African-American, poor, and/or have a low education level. We hypothesized that these individuals in our area are at high risk of undiagnosed glaucoma and that it would be meaningful to make glaucoma-evaluating services readily accessible in these neighborhoods. The objective of this population-based study was to explore the efficiency and feasibility of community-based screening for glaucoma, outside the clinic, in northern Manhattan.

2. **Participants and methods**

From January 2006 to October 2014, the Edward Harkness Eye Institute of Columbia University Medical Center conducted a community-based glaucoma screening program in high risk communities in New York City. An operational definition was established for “population at high risk for glaucoma”. The high-risk population was a population with high participation of African Americans, Hispanics and areas known for low socio-economic status. The study adhered to the tenets of the Declaration of Helsinki and was approved by the Columbia University Institutional Review Board, which determined that the study qualified for a waiver of informed consent.
2.1. Participants
Study subjects were recruited from high-risk neighborhoods in northern Manhattan, where a large proportion of the population lives at or near the federal poverty level. In addition to being economically disadvantaged, many adults in these neighborhoods have little formal education and are not native English-language speakers. The only inclusion criterion for the study was age 20 years or older. There were no exclusion criteria and we did not turn anyone away who wished to be screened (67 individuals between the ages of 8-19 as a courtesy to their parents).

2.2. Procedures
The screening examinations were performed in 2 ways: (a) at 221 community sites in northern Manhattan, including the lobby of the Milstein Hospital at New York-Presbyterian/Columbia University Medical Center, the lobby of the Harkness Eye Institute, community centers, grocery stores, banks, and churches; and (b) via mobile screening performed in a specially equipped van or mobile satellite sites. Mobile screenings were organized approximately on a biweekly basis in proximity to churches, malls, and other community gathering places. Screening was offered only face-to-face, person-to-person. Spanish-speaking staff were employed in order to overcome language barriers. No flyers or other forms of advertisement were used for recruitment. Subjects were not compensated for participating in the study.

Participants were asked to complete a written questionnaire to report their age, race, gender, family and personal history of glaucoma, and personal history of diabetes mellitus or hypertension, and whether they had health insurance. It was made clear to participants that whether or not they had health insurance, the screening was free.

All participants underwent visual acuity testing, IOP measurements with a Tono-Pen (Reichert Technologies, DePew, NY), frequency-doubling technology (FDT, Carl Zeiss, Meditect, Inc., Dublin, CA) perimetry testing, and direct ophthalmoscopy for optic nerve evaluation focused on assessment of the vertical cup/disk ratio (VCDR). These evaluations were performed by a trained ophthalmologist or optometrist. An abnormal screening result for glaucoma (i.e. high risk for glaucoma) was defined if the subject had any of the following: IOP ≥ 21 mm Hg either eye, any significant FDT abnormality in either eye, or an enlarged VCDR (≥ 0.5) in either eye.

Subjects who had a positive glaucoma screening result were referred to the most geographically convenient ophthalmologist or the clinic of the Edward Harkness Eye Institute for a comprehensive in-office glaucoma evaluation and possible treatment. They were also advised for immediate follow-up when immediate follow up was imperative (e.g. individuals with very high IOP or severe glaucomatous damage). Alternatively, subjects were referred for a general ophthalmic evaluation if they were deemed to need further investigation of other ocular diseases other than glaucoma (e.g. cataract, retinal, or corneal disease) or they were advised to have a routine eye examination with an optometrist in 2 to 3 years if there were no ocular abnormality.

2.3. Statistical analysis
Multinomial probit regression was employed to test the association between predictors and the three nominal outcome variables: (a) glaucoma evaluation, (b) general ophthalmologic examination, or (c) routine eye care. A categorical, nominal dependent variable was used because it does not impose any hierarchy or ranking between levels. In other words, there is no underlying assumption that one level (e.g. general ophthalmic evaluation) has a higher importance or comes before the others (e.g. glaucoma evaluation). This is because patients referred to general ophthalmic evaluation, for example, could still present clinically-important conditions, such as diabetic retinopathy or age-related macular degeneration. Moreover, statistical tests using nominal outcome variables tend to be more conservative than continuous or ordinal ones. Robust cluster estimator of standard errors were used to adjust for the inclusion of both eyes given the inherently significant inter-eye correlations. Relative risk ratios (RRR) for each predictor and their corresponding \( P \)-values were used for statistical inference. Computerized statistical analyses were performed using STATA software (version14, StataCorp, College Station, TX). The alpha level (type I error) was set at 0.05.
3. Results
A total of 8,547 subjects in northern Manhattan were successfully screened. A substantial proportion of subjects, 12%, did not report their age; of those who did, the median age was 52. Females were represented in greater numbers than males: 55 to 45%. Most of the subjects (54%) were Hispanic/

| Parameter | N (%) |
|-----------|-------|
| **Age**   |       |
| 8–19      | 67 (0.78) |
| 20–39     | 1,294 (15.14) |
| 40–64 yr  | 4,651 (54.42) |
| ≥ 65 yr   | 1,529 (17.89) |
| Not reported | 1,006 (11.77) |
| **Gender** |       |
| Female    | 4,729 (55.33) |
| Male      | 3,802 (44.49) |
| Not reported | 16 (0.18) |
| **Race**  |       |
| African-American | 1,414 (16.54) |
| Asian     | 875 (10.24) |
| Hispanic/Latino | 4,647 (54.37) |
| White     | 1,247 (14.59) |
| Other     | 284 (3.32) |
| Not reported | 80 (0.94) |
| **Health insurance** |       |
| Yes       | 5,585 (65.34) |
| No        | 2,732 (31.96) |
| Not reported | 230 (2.69) |
| **Had ever seen eye doctor** |       |
| Yes       | 2,230 (26.09) |
| No        | 4,859 (56.85) |
| Not reported | 1,458 (17.06) |
| **Time of last eye exam** |       |
| 1 yr or less | 3,222 (37.70) |
| >1 yr but ≤ 2 yr | 1,659 (19.41) |
| >2 yr but ≤ 5 yr | 1,199 (14.03) |
| >5 yr but ≤ 10 yr | 369 (4.32) |
| >10 yr | 133 (1.56) |
| “Long time” or “many years” | 102 (1.19) |
| Othera | 1,863 (21.80) |
| **Glaucoma suspect**b |       |
| Yes       | 520 (6.08) |
| No        | 6,290 (73.59) |
| No response/don’t remember | 1,737 (20.32) |

(Continued)
Latino and 17% were African-American. Demographic characteristics and medical history are summarized in Table 1.

Nearly a third of the screened population, 2,732 participants (32%), reported that they had no health insurance. That subgroup included 1,742 of the 4,647 Hispanic/Latino subjects (20%) versus

| Parameter                                                                 | N (%)    |
|---------------------------------------------------------------------------|----------|
| Family history of glaucoma                                               |          |
| Yes                                                                       | 1,787 (20.91) |
| No                                                                        | 5,695 (66.63) |
| No response/don't know                                                   | 1,065 (12.46) |
| Personal history of glaucoma (not glaucoma suspect)                      |          |
| Yes                                                                       | 358      |
| No                                                                        | 7,379    |
| No response/don't know                                                   | 810      |
| Duration of glaucoma                                                      |          |
| 0–5 yr                                                                    | 74 (20.67) |
| 5–10 yr                                                                  | 102 (28.49) |
| 10–20 yr                                                                 | 31 (8.66)  |
| >20 yr                                                                   | 26 (7.26)  |
| No response/don't remember                                                | 125 (34.92) |
| Personal history of diabetes mellitus                                     |          |
| Yes                                                                       | 1,134 (13.27) |
| No                                                                        | 7,272 (85.08) |
| No response/don't know                                                   | 141 (1.65)  |
| Duration of diabetes                                                      |          |
| 0–5 yr                                                                    | 440 (38.80) |
| 5–10 yr                                                                  | 238 (20.99) |
| 10–20 yr                                                                 | 143 (12.61) |
| >20 yr                                                                   | 61 (5.38)   |
| No response or N/A                                                       | 252 (22.22) |
| Personal history of hypertension                                          |          |
| Yes                                                                       | 2,531 (29.62) |
| No                                                                        | 5,835 (68.27) |
| No response/don't know                                                   | 181 (2.11)  |
| Duration of hypertension                                                  |          |
| 0–5 yr                                                                    | 961 (37.97) |
| 5–10 yr                                                                  | 531 (20.98) |
| 10–20 yr                                                                 | 334 (13.20) |
| >20 yr                                                                   | 134 (5.29)   |
| No response or N/A                                                       | 571 (22.56) |

**“Never”, “don’t know”, “?”, “NA”, “don’t remember”, no response.**

**Told in the past that they had glaucoma.**

Laasow et al., Cogent Medicine (2017), 4: 1367059
https://doi.org/10.1080/2331205X.2017.1367059

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333 of the 1,414 African-American subjects (4%), 310 of the 875 Asian subjects (4%), and 220 of the 1,247 White subjects (3%). Sixty-five percent of subjects reported having health insurance and 3% of subjects did not answer the question.

More than half of all participants, 57%, reported that they had never seen an eye care provider (ophthalmologist or optometrist) (Figure 1). Hispanics/Latinos were more likely than other racial groups to report never having seen an eye care provider. 21% of all participants had 2 or more years elapsed since their last exam.

A total of 520 participants (6%) had been told at some point in the past that they might have glaucoma. Figure 2 shows the relationship between race and the likelihood of having been
previously deemed a glaucoma suspect. The proportion of glaucoma suspects was similar across racial groups. Remarkably 15 to 21% of subjects did not answer the question, mostly because they did not understand what glaucoma was.

Altogether, 2,118 subjects (25%) were referred for glaucoma evaluation, 1,243 (15%) were referred for an ophthalmic evaluation, and 5,133 (60%) were advised to have a routine eye examination in 2 or 3 years. Of the subjects who were referred for glaucoma evaluation, follow up was available in 610 subjects. Glaucoma was confirmed in 316 subjects at a rate of 52 and 9.2% remained glaucoma suspects. Figure 3 shows the number of referrals according to race. African-Americans were 2.5 times more likely to need a referral for glaucoma evaluation than for routine eye care, whereas Hispanics/Latinos and Whites were 1.6 times more likely. For Asians, the number of referrals for glaucoma evaluation and ophthalmic evaluation were approximately the same. African-Americans and Hispanic/Latinos were more likely to be referred for glaucoma evaluation than Whites ($p < 0.001$), although there was no significant difference between African-Americans and Hispanics/Latinos.

The multinomial probit regression analysis indicated that among African-Americans, the likelihood of referral for a glaucoma evaluation was increased by 78% ($p < 0.001$) compared with Whites, and the chance of referral to an ophthalmic examination was increased by 10% ($p = $NS). Among Hispanics/Latinos, those figures were 29% ($p = 0.001$) and 23% ($p = 0.03$), respectively. As expected, other factors that significantly increased the likelihood of referral for glaucoma evaluation were IOP ≥ 21 mm Hg in either eye, VCDR > 0.5 in either eye, abnormal FDT in either eye, older age, history of hypertension, longer duration of hypertension, history of diabetes, and longer duration of diabetes (Table 2). Each year of age increased the likelihood of referral to glaucoma evaluation by 1% ($p < 0.001$) and increased the chance of referral to ophthalmic examination by 2% ($p < 0.001$). Female gender was protective against the need for glaucoma evaluation (RRR = 0.83; $p < 0.001$) but not ophthalmic examination. Having health insurance was not significantly protective against the need for either glaucoma evaluation or ophthalmic examination.
4. Discussion

Our data suggest that our simplified, time-efficient glaucoma screening program was feasible for use in the low-income, poorly educated neighborhoods of northern Manhattan. Glaucoma screening in mobile satellite established clinics and mobile settings had a high yield, as a full 25% of subjects were referred for glaucoma evaluation and 15% were referred for evaluation of another ophthalmic problem. African-Americans and Hispanics/Latinos were significantly more likely than Whites to need referral for glaucoma evaluation, by 78% (\( P < 0.001 \)) and 29% (\( P = 0.001 \)), respectively. Our data also document low levels of access to eye care: 32% of subjects said they had no health insurance, and that subgroup included 20% of Hispanics/Latinos. In addition, more than half of all participants had never seen an eye care provider.

No single test or combination of tests has been defined as the gold standard for defining glaucoma in population-based research (Boland et al., 2016; Francis et al., 2011; Tielsch, Katz, et al., 1991). In the present study, we limited our examination to visual acuity testing, tonometry with a TonoPen was used because of its ease of use and portability. Although TonoPen has its limitations similar to all tonomtries that are currently available to measure intraocular pressure such as Goldman applation tonometry (GAT). Studies have shown depending on design of the study that TonoPen either measure lower or higher if IOP in low intraocular pressure or same or higher in high intraocular pressure (Bland & Altman, 1995; Frenkel, Hong, & Shin, 1988). Minckler found Tono-Pen-measured IOP on average 1.7 mm Hg higher than GAT within a GAT IOP range of 6–24 mm Hg (Minckler et al., 1987). When we started the study the icare tonometery was not available and even that has its limitations. FDT perimetry, and assessment of VCDR by a trained ophthalmologist or optometrist. We chose these tests because it is difficult to mobilize and carry a lot of equipment from one site to another and standardize it between the truck and the other sites, and because we wanted to minimize the length of the examination in order to screen more patients and prevent long waiting

### Table 2. Risk factors for referral

| Parameter                                | Referral for glaucoma evaluation | Referral for ophthalmic examination |
|------------------------------------------|----------------------------------|-------------------------------------|
|                                          | RRR (95% CI)         | \( P \) | RRR (95% CI)         | \( P \) |
| Age, each year                           | 1.01 (1.01–1.02)     | <0.001 | 1.02 (1.02–1.03)     | <0.001 |
| Female gender                            | 0.83 (0.75–0.91)     | <0.001 | 0.97 (0.86–1.10)     | 0.67   |
| Race (reference: White)                  |                     |        |                      |        |
| African-American                         | 1.78 (1.49–2.13)     | <0.001 | 1.10 (0.87–1.39)     | 0.43   |
| Asian                                    | 1.00 (0.80–1.24)     | 0.99   | 1.40 (1.10–1.79)     | 0.007  |
| Hispanic/Latino                          | 1.29 (1.10–1.50)     | 0.001  | 1.23 (1.02–1.49)     | 0.03   |
| Had health insurance                     | 1.04 (0.93–1.16)     | 0.47   | 0.92 (0.81–1.05)     | 0.23   |
| Glaucoma suspecta                        | 9.19 (7.41–11.42)    | <0.001 | 2.67 (1.96–3.64)     | 0.12   |
| Family history of glaucoma               | 1.71 (1.52–1.94)     | <0.001 | 0.97 (0.82–1.14)     | 0.71   |
| Personal history of diabetes mellitus    | 2.36 (2.03–2.74)     | <0.001 | 4.19 (3.57–4.91)     | <0.001 |
| Duration of diabetes                     | 1.61 (1.46–1.77)     | <0.001 | 2.05 (1.86–2.26)     | <0.001 |
| Personal history of hypertension         | 1.67 (1.50–1.87)     | <0.001 | 1.83 (1.60–2.08)     | <0.001 |
| Duration of hypertension                 | 1.27 (1.20–1.35)     | <0.001 | 1.26 (1.18–1.34)     | <0.001 |
| IOP ≥ 21 mm Hg either eye                | 36.27 (29.45–44.67)  | <0.001 | 5.31 (4.08–6.91)     | <0.001 |
| VCDR > 0.5 either eye                    | 23.63 (20.65–27.04)  | <0.001 | 1.97 (1.64–2.37)     | <0.001 |
| Abnormal FDT either eye                  | 1.98 (1.79–2.20)     | <0.001 | 2.43 (2.14–2.76)     | <0.001 |

Abbreviations: CI, confidence interval; FDT, frequency doubling technology perimetry; RRR, relative risk ratio; VCDR, cup/disk ratio.

*Told in the past that they had glaucoma.
periods. Standard achromatic perimetry (SAP), in particular, was not considered because it requires a dark room, more time, and patient training. Finally, we chose a C/D ratio of > 0.5 although it is on the conservative side but the rationale is to avoid missing glaucoma in the high-risk population of New York City.

Two other major population-based studies in the United States have examined the prevalence of glaucoma according to race/ethnicity: the Baltimore Eye Survey (BES) (Tielsch, Sommer, et al., 1991) and the Los Angeles Latino Eye Study (LALES) (Varma, Paz, et al., 2004; Varma, Ying-Lai, et al., 2004). The methodology of both was substantially more complex than that of our study. Recruitment in BES involved an in-home interview followed by a comprehensive ophthalmologic examination conducted at one of five screening centers established in east Baltimore, MD (Tielsch, Sommer, et al., 1991). The examinations at the neighborhood centers comprised refraction and visual acuity, visual field testing, applanation tonometry, stereoscopic fundus photography of the optic disc and macula, and a detailed personal interview. The Humphrey Field Analyzer (Carl Zeiss Meditec, Inc., Dublin, CA) was used for initial visual field testing, but a diagnosis of OAG required subsequent Goldmann perimetry.

In BES, 5,308 subjects aged 40 years or older underwent a screening examination (Tielsch, Sommer, et al., 1991). The researchers identified 100 cases of OAG (4%) among the 2,395 African-American residents and 32 cases (1%) among the 2,913 Whites. African-Americans had higher rates of OAG than Whites in every age group, and the overall age-adjusted relative prevalence of OAG was 4.3 higher among African-Americans than Whites. When only patients who met the most stringent diagnostic criteria were included, the difference between African-Americans and Whites in age-adjusted relative prevalence was 6.2. In the older age groups (70 years of age or older), the prevalence rates among Whites were greater than 1 in 50, whereas among African-Americans they were almost 1 in 10.

LALES was conducted in a Latino population in Los Angeles, predominantly Mexican or of Mexican ancestry (Varma, Paz, et al., 2004; Varma, Ying-Lai, et al., 2004). (The researchers defined Latinos as individuals born into or descended from a Spanish-speaking community, regardless of race.) Its design called for an in-home interview and a clinic examination, conducted by a glaucoma expert, which included visual field testing. Participants who did not undergo the clinic examination in addition to the in-home interview were excluded from their analyses. Of the 6,142 participants who were able to meet both expectations, 291 (4.7%) were diagnosed with OAG. By comparison, the rate among Whites in BES was 1% (Tielsch, Sommer, et al., 1991), and in the Blue Mountains Eye Study of a predominantly White population in Australia, the rate was 3% (Mitchell et al., 1996).

Other major population-based studies have been conducted in the United States for predominantly non-Hispanic White populations (Framingham Eye Study and Beaver Dam Eye Study) (Klein et al., 1992; Leibowitz et al., 1980), a mixed White and African-American population (Salisbury Eye Evaluation Study) (Friedman et al., 2004), and another Latino population (Proyecto VER [Vision and Eye Research]) (Quigley et al., 2001). However, comparisons are difficult given numerous differences in methodology. In the Framingham Eye Study, a screening examination was performed in only 10% of the sample, which might lead to underestimation of OAG prevalence (Leibowitz et al., 1980). Proyecto VER included only cases with structural and functional evidence in category 1 and advanced cases of structural damage with unproven visual field loss in category 2 (VCDR > 0.85) (Quigley et al., 2001). Therefore, it might have underestimated the prevalence of glaucoma. In the Beaver Dam Eye Study, diagnosis of OAG was based on IOP, which is not included in the current definition of OAG (Klein et al., 1992). Finally, the Salisbury Eye Evaluation Study was limited to participants 73 years of age or older (Friedman et al., 2004).

The relationship between OAG prevalence and race/ethnicity has also been examined in a systematic review of 81 population-based studies published worldwide between 1966 and 2014 (Kapetanakis et al., 2016). Per decade older, the risk of OAG was highest among Hispanics/Latinos (2.3 times
greater in adjusted analyses). However, of all racial/ethnic groups, Black/African/Caribbean populations had the highest absolute levels of OAG prevalence in each 5-year age band, starting at age 35, except above 80 years of age, where the prevalence was highest among Hispanics/Latinos.

In addition to examining the prevalence of OAG, it is important to consider rates of underdiagnoses of OAG and access to eye care. In LALES, over 75% \((n=220)\) of the 291 subjects who were ultimately diagnosed with OAG had not reported a previous history of glaucoma or treatment for glaucoma (Varma, Ying-Lai, et al., 2004). That figure is higher than in the Barbados Eye Study (51%) (Leske et al., 1994) or the Blue Mountains Eye Study (51%) (Mitchell et al., 1996). Similarly, in the Baltimore Eye Study, approximately 50% of all patients diagnosed with OAG, both African-Americans and Whites, were previously unaware that they had glaucoma (Tielsch, Sommer, et al., 1991). According to estimates based on US population-based studies and census data, the numbers of people with undetected OAG in 2011 were 0.54, 0.60, and 0.39 million among Hispanics/Latinos, non-Hispanic Whites, and African-Americans, respectively (Vajaranant et al., 2012). It is projected that in 2050 those numbers will be 2.72, 0.83, and 0.93 million, respectively, and Hispanics/Latinos will account for 50% of all cases (Vajaranant et al., 2012).

The BES investigators did not report on the use of eye care services (Tielsch, Sommer, et al., 1991), but in LALES, only 36% of subjects reported having an eye care visit in the past year, only 57% reported ever having a dilated eye exam, and only 19% reported having a dilated eye examination in the past year (Morales et al., 2010). These results are consistent with nationally representative data from the 2002 National Health Interview Survey: only 22% of Hispanic/Latino adults reported an eye care visit in the past year, and only 29% reported a dilated eye exam in the past year (Zhang, Saaddine, et al., 2007). Poverty and low education levels also influence access to eye care. An analysis of National Health and Nutrition Examination Survey data from 1999 to 2008 determined that individuals with lower education level (i.e. < high school vs > high school) or lower income (poverty income ratio < 1.00 vs ≥ 4.00) were consistently less likely to have had an eye care visit in the past 12 months compared with their counterparts \((P < 0.05\) for both comparisons) (Zhang, Cotch, et al., 2012).

Even so, it is astonishing that 57% of our study subjects said they had never seen an eye care provider. For Hispanics/Latinos, that figure was an astonishing 63%. The American Academy of Ophthalmology (AAO) recommends that people who have risk factors for glaucoma, which includes all African-Americans and Hispanics/Latinos, should have a comprehensive eye examination every 1 to 2 years when under 40 years of age, every 1 to 3 years when 40 to 54 years of age, and every 1 to 2 years when 55 years of age or older (Feder et al., 2016). By AAO standards, then, we documented that for many people in northern Manhattan, access to eye care that could potentially detect glaucoma is very poor.

One strength of our study – the fact that we did an extensive and prolonged community outreach – could also pose as a limitation. Since we did not examine subjects in an ophthalmology or optometry clinic, we were obviously limited in the types of testing we could do. In particular, we used FDT perimetry instead of the Humphrey SAP, and only one significant abnormality on the FDT test was required for a subject to be referred for glaucoma evaluation. In the Student Sight Savers Program, another initiative of the Friends of the Congressional Glaucoma Caucus Foundation, FDT was the best single screening test, demonstrating high specificity (98.6%) and moderate sensitivity (58.1%) (Salim, Netland, Fung, Smith, & Aldridge, 2009). However, in that program a stringent criterion was used: a subject was considered positive for screening only if there were 3 or more abnormal locations on the FDT printout.

Another limitation is that we do not know for sure whether we truly sampled the population of northern Manhattan in an unbiased fashion, or whether it was biased towards people who thought they might have an ophthalmic problem. Populations were reliably sampled in both the Barbados Eye Study (Leske et al., 1994) and the Blue Mountain Eye Study (Mitchell et al., 1996) (through a random selection of national registration numbers and a door-to-door census based on federal government maps, respectively), but our target population is considerably more mobile and less homogeneous than those.
Finally, our reliance on self-report of medical history and past eye care may have posed a risk of recall bias. For example, in LALES, 59 participants reported having a history of glaucoma, but they had no evidence of OAG based on the LALES examination (Varma, Ying-Lai, et al., 2004).

Despite these limitations, the high risk of undiagnosed glaucoma identified in this study, along with the documentation of poor access to routine eye care, highlights the need to develop better glaucoma screening strategies directed towards African-American, Hispanic/Latino, low-income, and poorly educated people. These programs will be increasingly important as the US population ages. Of note, the number of people with OAG is estimated to increase in the United States by 28% per decade, from 2.71 million in 2011 to 7.32 million in 2050 (Vajaranant et al., 2012).

We conclude that increasing access to glaucoma screening for populations with risk factors should be a priority for medical care providers and public health policy makers. Our study establishes the feasibility of community-based and mobile screening as methods of facilitating access to eye care. Furthermore, our results highlight the importance of an active blindness prevention program in the context of population health management. Our study was not designed to evaluate the cost effectiveness of glaucoma screening nor was it designed to study the prevalence of glaucoma in the general population. Our study was designed to study the prevalence of glaucoma in the high-risk population of New York City.

Acknowledgements
The authors thank George Cioffi, MD and Stanley Chang, MD for their outstanding academic guidance and support of this project, Ridwan Shabsigh, MD for his valuable input and advice in this project, specifically as it relates to population health management, Vipul Patel and Maribel Rodriguez for their help with the data management, the residents, the fellows of the Harkness Eye Institute and Vipul Patel for their help with conducting the screening, Joseph H Lee DrPH for his valuable input and advice on the genetics of aging and age-related disease and Faith Reidenbach, BA of Caley-Reidenbach Consulting, LLP provided medical writing assistance that was funded by the Friends of the Congressional Glaucoma Caucus Foundation.

Funding
This work was supported by The Friends of the Congressional Glaucoma Caucus Foundation (grant number PT-AAAD3355) and Research to Prevent Blindness.

Competing Interests
The authors declare no competing interest.

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6 Ophthalmology, 122, 6257–6264.

Citation information
Cite this article as: Screening for glaucoma in populations at high risk: The eye screening New York project, Lama A. Al-Aswad, Devon B. Joiner, Xinhui Wang, Carlos Gustavo de Moraes, Deborah Popplewell, Maria L. Amaro-Quireza, Muhammad Shabsigh & Nancy Taher, Cogent Medicine (2017), 4: 1367059.

Cover image
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