ORIGINAL ARTICLE

The Prevalence of Glaucoma in Young People

Findings of the Population-based Gutenberg Health Study

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SUMMARY

Background: Earlier information on the prevalence of glaucoma among children in Germany was based solely on estimates. Reported values for congenital glaucoma range from 1 in 10 000 to 1 in 68 000 depending on ethnic origin. The estimate for juvenile glaucoma is 1 in 44 000.

Methods: The Gutenberg Health Study is a population-based, prospective, monocentric cohort study with 15 010 participants aged 35 to 74. To determine the history-based prevalence of childhood glaucoma, participants were asked about the diagnosis of glaucoma, any operations for glaucoma that were performed, regular use of drugs for glaucoma, and the age of onset of glaucoma. The affected individuals were classified in four groups based on the age of onset: congenital (<2 years), juvenile (2 to <18 years), late juvenile (18 to <40 years), and early adult (40 to <45 years). In the identified glaucoma patients, the visual acuity, intraocular pressure, corneal thickness, visual fields, and optic discs were evaluated.

Results: 352 persons were identified from their medical history as having glaucoma. The weighted prevalences in the four groups were 0% in the congenital group, 0.01% (95% confidence interval [0, 0.03]) in the juvenile group, 0.16 % ([0.09; 0.23]) in the late juvenile group, and 0.17% ([0.15; 0.19]) in the early adult group. For participants over age 45, the weighted prevalence of glaucoma was 1.98% [1.7; 2.2].

Conclusion: In our cohort, the history-based prevalence of juvenile glaucoma was 0.01% (2 patients). The prevalence was an order of magnitude higher (0.16%) between the ages of 18 and 40, and two orders of magnitude higher at later ages (1.98%). The burden of disease seems to be markedly higher than previously assumed.

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Glaucoma in childhood is rare, and because of the long-term nature of the disorder, it necessitates frequent contact with doctors (1–5). Owing to the potential loss of visual functions, a child's development may be impaired and everyday life hampered, leading to great individual suffering.

A distinction is made between primary and secondary forms of childhood glaucoma. Primary congenital glaucoma is either already present at birth or develops as juvenile primary open-angle glaucoma into early adulthood. Depending on the timing it manifests, high intraocular pressure will cause bulbar growth, corneal opacity owing to folds in Descemet's membrane (Haab's striae), and/or optic nerve and visual field damage. Secondary childhood glaucoma may also be present at birth or manifest into young adulthood; it goes hand in hand with morphological changes—such as aniridia, Axenfeld-Rieger syndrome (dysgenetic changes in the anterior chamber angle [6]), or Sturge-Weber syndrome (1).

In the literature, estimates of the rates of childhood glaucoma differ widely. Some studies report incidence rates depending on ethnicity between 1:10 000 and 1:68 000 (1, 3, 7). For congenital glaucoma in Caucasian white persons in the US, incidence rates of merely 1:260 000 (3) have been reported, and for black persons in Africa, rates of up to 0.4%, which corresponds to 1:250 (8–13). The rates of congenital glaucoma are higher, especially in regions where consanguinity is the norm (1). Because of the low incidence of childhood glaucoma and the external signs, which are not always obvious—such as buphthalmos or corneal opacity—the diagnosis is often made late. Direct and immediate access to therapy is not possible everywhere, and consequently treatment is administered at an advanced stage (1, 4, 14). Late surgical treatment is then successful only to a limited extent as far as saving visual function is concerned. This causes great individual suffering and high socioeconomic costs (15, 16).

Worldwide, few studies exist on the epidemiology of congenital glaucoma (1, 3), and no data are available for Germany to date. Large epidemiological studies have

TABLE 1

Overview of groups (n = 14 700)

Group	Description	Age at onset of glaucoma	Sex m/f	Number of participants	Prevalence
1	Congenital glaucoma	<2 years	0	0	0
2	Juvenile glaucoma	2 to <18 years	0/100 %	2	0.01 %
3	Late juvenile glaucoma	18 to <40 years	54.17/45.83 %	24	0.16 %
4	Early adult glaucoma	40 to <45 years	52.17/47.83 %	23	0.17 %
5	Adult glaucoma	≥ 45 years	46.46/53.54 %	254	1.98 %

mostly investigated the prevalence of glaucoma in a study population without considering the age of the patients. For this reason, no conclusions can be drawn about the prevalence of glaucoma in childhood (17–21).

It was therefore the aim of our study to estimate for the first time the prevalence of childhood glaucoma in Germany—on the basis of data from a large population-based study—in order to create a basis for questions of healthcare and the burden of disease, among others.

Material and methods

We investigated the history-based prevalence of glaucoma in the Gutenberg Health Study (GHS), a population-based, prospective, monocenter cohort study.

In total, 15 010 persons from the city of Mainz and the rural district Mainz-Bingen were investigated (22). For 14 700 (97.9%) of participants, ophthalmological data were available for evaluation.

At the initial examination in 2007–2012, the study participants underwent a five-hour examination program. Ophthalmological data were collected by means of an extensive oral history of eye disorders, glaucoma medication, glaucoma surgery, and a detailed eye examination, including intraocular pressure measurements (22) (*eTable*). A change in data over the past years is not to be expected because of the lack of exogenous factors of influence.

The following criteria were considered in order to define glaucoma: glaucoma was reported in the medical history and, additionally, at least one glaucoma operation had already been undertaken and/or glaucoma medication was applied.

According to these selected inclusion criteria (glaucoma diagnosis, surgery, or medication), participants were identified as glaucoma patients and categorized into four groups by age at diagnosis:

- Group 1: Congenital glaucoma=age at diagnosis <2 years
- Group 2: Juvenile glaucoma=age at diagnosis 2–17 years
- Group 3: Late juvenile glaucoma= age at diagnosis 18–39 years
- Group 4: Early adult glaucoma= age at diagnosis 40–44 years.

We evaluated glaucoma-relevant data in the identified participants, such as visual acuity, intraocular pressure, corneal thickness, visual field, and optic disc (*eBox*).

Results

We identified 352 participants as glaucoma patients (weighted prevalence 2.02%, 95% confidence interval [1.79; 2.25]). Because the year of diagnosis was unavailable for some, 303 case patients were categorized into the different groups.

49 participants were younger than 45 years of age at disease onset. 0 participants were allocated to Group 1 (congenital), 2 to Group 2 (juvenile), 24 to Group 3 (late juvenile), and 23 to Group 4 (early adult) (*Table 1*).

The sex distribution in all groups was even (*Table 1*).

Regarding the weighting according to the standard population of the Mainz/Bingen district, the following prevalence rates were found for glaucoma (*Table 1*):

- Congenital: 0%
- Juvenile: 0.01% [0; 0.03]
- Late juvenile: 0.16% [0.09; 0.23]
- Early adult: 0.17% [0.15; 0.19].

The prevalence in participants older than 45 years at disease onset (adult glaucoma) was 1.98% [1.7; 2.2].

Of the participants who had been identified as glaucoma patients on the basis of their medical histories, 100% of participants in Group 2 (juvenile)—both participants—were taking one or more glaucoma drugs. In Group 3 (late juvenile), the rate was 95.8% [87.8; 100], and in Group 4 (early adult), it was 100%. In the group of participants aged 45 and older, the proportion treated with medication was 97.6% [95.7; 99.48] (*Figure 1*).

Glaucoma surgery in Group 2 had been performed in none of the participants, in Group 3 in 25% [7.7; 42.3], and in Group 4 in 21.7% [4.9; 38.6] of participants.

By comparison, 9.1% [5.5; 12.5] of patients ≥ 45th year of life had undergone one or several operations for their glaucoma (*Figure 2*).

Visual acuity in all three groups was very good (median 20/40 to 20/24). However, all groups also included patients with poor visual acuity of 20/100 (8 eyes), which correlated with advanced glaucoma (*Table 2*).

Proportional frequencies in the use of glaucoma drugs by number of effective substances (0–4) in the 3 age groups (Groups 3–5 according to *Table 1*), weighted according to the standard population of Mainz/Mainz-Bingen districts.

In participants with juvenile glaucoma, intraocular pressure (IOP, median) values of 15.5 mm Hg were measured in the right eye and of 16.4 mm Hg in the left eye. In the group of participants with late juvenile glaucoma, IOP in the right eye was 16.4 mm Hg and in the left eye, 16.3 mm Hg. In the group of participants with early adult glaucoma, IOP in the right eye was 15.5 mm Hg and in the left eye, 15.7 mm Hg (*Table 2*).

Median corneal thickness in participants with juvenile glaucoma was 567 µm for right eyes and 583 µm for left eyes; in participants with late juvenile glaucoma, it was 577 µm and 566 µm, respectively, and in participants with early adult glaucoma it was 547 µm and 548 µm, respectively.

In the group of participants with juvenile glaucoma, corneal thickness was found to be increased, but this had no clinical relevance (*Table 2*).

Visual field data were available for 42 participants (<45 years). The evaluation of the visual field examination did not provide any visual field abnormalities (according to the defined criteria) in either of the two participants (0%) in Group 2 (juvenile). In Group 3 (late juvenile), 27.27% and in Group 4 (early adult), 29.41% of the participants had relevant visual field defects (*Table 3*).

Photographs of the optic disc that had been taken in a state of miosis were available for 33 participants. In 12

participants, no photographs had been taken (9), or they were not usable (3).

The photographs of the optic disc in Group 2 showed changes typical for glaucoma in 50% of participants; in Group 3, in 46.66%; and in Group 4, in 87.5% (*Table 3*).

Discussion

Following the example of several authors (age 16 years old according to Childhood Glaucoma Research Network [CGRN], age 20 years old in the US literature), we decided to categorize our participants into four groups (*Table 1*) (26–28).

In the literature, prevalence or incidence rates are reported.

Most data are available for primary congenital glaucoma. The lowest reported incidence is 1:260 688 in a primarily Caucasian white population in the US; for Europe, it is 1:10 000–18 000 (3, 7, 15). The incidence is higher in ethnically mixed populations (1:18 500 in the UK, 1:30 200 in the Republic of Ireland) (1). The Sinti and Romany peoples in Slovakia have a very high incidence, namely 1:1250 (29). The incidence of childhood glaucoma is 1:43 575 in the primarily Caucasian white population of the US (*Table 4*) (3).

None of the 14 700 participants in our study had congenital glaucoma (age at onset <2 years). This is consistent with data from the literature, which report incidence rates of about 1:260 000 (US) and 1:357 000 (the UK). The prevalence in the UK is higher, but no data for the Caucasian white population are available (1, 3). It is the experience of glaucoma-specialized hospitals that in Germany, far more patients of a Caucasian white background undergo surgery. This means that the prevalence in Germany is likely to be higher. The incidence in the US if applied to Germany would translate into very few expected cases in a scenario of a live birth rate of 738 000/year (30).

It is possible that the population size of 14 700 participants is not large enough to identify affected persons in epidemiological cross-sectional studies. Furthermore, consanguinity and therefore the rate of genetically caused glaucoma was probably low in our study. Access to medical care in Germany is excellent, however, so that it would be possible to diagnose patients accordingly and hence, the captured prevalence would be high. Our study data were collected during a medical examination lasting several hours. For this reason, patients with congenital glaucoma might be under-represented as they might not have reacted to the invitation to join the study because of their often much poorer visual acuity (1, 31) and frequent necessary visits to the doctor; they may therefore be underrepresented in the study population. Furthermore, possibly healthy people do not perceive any benefit from a thorough examination. The prevalence rates may therefore be subject to selection bias. The response rate in the initial 5000 participants was 60.3% (32).

A certain recall bias will also need to be considered. If participants do not precisely remember the exact date of their diagnosis—for example, the 1st/2nd year of life

FIGURE 2

Proportional frequencies of participants who have had glaucoma surgery in the 3 age groups (Groups 3–5 according to Table 1), weighted according to the standard population of Mainz/Mainz-Bingen district

or 17th/18th year of life—they may be allocated to a different group according to the defined thresholds. The medical history-based imprecision in terms of naming diseases was vastly reduced by the fact that in addition to the diagnosis of glaucoma, the use of medication and/or past surgery were mandatory items, including the exact name of the medical drug and the surgical procedure. Patients who were not able to contribute these data were not registered as glaucoma patients.

Broken down by individual groups, the prevalence of juvenile glaucoma was 0.01% in the GHS. This concerned 2 female participants whose glaucoma had been diagnosed at ages 10 and 7, but who had not undergone glaucoma surgery. The visual field examination showed smaller defects in one female patient, but according to our criteria these were not classed as abnormal. In another female participant, the optic nerve showed changes that were typical for glaucoma. By comparison, the incidence in the US population was 2.29:100 000 (0.002%) (3). No prevalence data are available.

Further comparison data of the prevalence in this age group in Caucasian white participants are not available in the literature, which means our study has made these available for the first time.

To date, studies investigated older population groups, mostly >50 years of age, in much smaller cohorts. The prevalence of glaucoma was studied, but the duration of the illness or the age at onset were not considered (17, 19–21, 33). For this reason, it was not possible to draw any conclusion about the rates of childhood glaucoma in Germany.

In the Rotterdam Study, the prevalence in the age group ≥ 55 years was 1.10% (21) and thus lower than in our study. In the Baltimore Eye Survey, primary chronic open-angle glaucoma was diagnosed in 3% of the white and black population aged 40 or older (20), which is a slightly higher rate than in our study. In the Beaver Dam Eye Study, a subgroup of 43–54 year olds was evaluated, and the prevalence of open-angle glaucoma in this group was reported to be 0.9% (17). In the Egna-Neumarkt Study, the rates of glaucoma patients were 0.4% in female participants and 0.6% in male participants aged 40–49 years (33). If, in the GHS, consideration is given to all participants who were diagnosed before their 45th year of life, the prevalence is 0.37%. This prevalence rate includes all glaucoma types, not only primary open-angle glaucoma, and is notably below the prevalence of the participants in the Beaver Dam Study (who were a mean of 10 years

TABLE 2

Overview of parameters

	Juvenile glaucoma		Late juvenile glaucoma		Early adult glaucoma		Adult glaucoma	
	Right eye	Left eye	Right eye	Left eye	Right eye	Left eye	Right eye	Left eye
Visual acuity (decimal)								
Median	0.80	0.5	0.8	0.8	0.80	0.80	0.80	0.80
UQ	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Max	1.00	1.00	1.25	1.25	1.00	1.25	1.25	1.25
Min	0.63	0.05	0.00	0.00	0.03	0.05	0.00	0.00
LQ	0.63	0.05	0.63	0.63	0.40	0.63	0.63	0.63
Corneal thickness (µm)								
Median	567	583	557	559	547	548	554	557
UQ	585	605	587	593	585	586	580	579
Max	585	605	643	772	645	658	690	680
Min	549	560	499	513	464	474	455	449
LQ	549	560	543	543	521	524	531	534
Intraocular pressure (mm Hg)								
Median	15.5	16.4	16.4	16.3	15.5	15.7	15.7	15.3
UQ	16.3	17.0	17.4	17.9	18.0	18.0	18.0	18.0
Max	16.3	17.0	21.0	22.3	25.7	24.7	25.3	29.7
Min	14.7	15.7	10.0	6.0	9.0	7.0	5.7	6.0
LQ	14.7	15.7	15.2	15.1	12.7	12.7	14.0	13.3

Max, maximum; Min, minimum; UQ, upper quartile; LQ, lower quartile

TABLE 3

Overview of available case data

Description/Term	Number of participants	Visual field abnormality/ existing cases	Optic disc abnormality/ existing cases
Juvenile glaucoma (n = 2)	2	0/2	1/2
Late juvenile glaucoma (n = 24)	24	6/22	7/15
Early adult glaucoma (n = 23)	23	5/17	14/16

older), but matches the Egna-Neumarkt Study for the younger participants. It is obvious that the prevalence rises notably after the 50th year of life. In the group of 40–49 year olds in the Egna-Neumarkt Study, the prevalence was 2.0% for female participants and 2.1% for male participants (33). The US data are based on a retrospective analysis of patient files, which were examined by pediatricians. It is not clear whether all children also underwent an ophthalmological exami-

nation, and we can therefore assume that pediatric glaucoma cases are under-represented.

A special feature of our study is the fact that the focus was placed on the time of diagnosis of the disorder, which therefore allowed for a differentiated comment on the different groups of glaucoma.

Distinction needs to be made between history-based prevalence rates and prevalence rates after an examination had been undertaken. The GHS collected data on history-based prevalence. Participants were defined as glaucoma patients on the basis of their reported glaucoma diagnosis, surgery, and medication. By eliciting the exact medication history with details on glaucoma drugs and surgical procedures with their exact names, the validity of the data was improved and typical instances of confusion with, for example, cataracts were vastly avoided. These data from the medical histories were known to the investigators. However, it was not possible to avoid the inclusion of cases of ocular hypertension, although we identified only two participants by means of the optic disc and visual field results who had neither visual field nor optic disc abnormalities.

We assume that the actual prevalence is higher because, according to the literature, the rate of undiagnosed glaucoma cases, at least for open-angle glaucoma, in adulthood is 49–53% (18, 19, 21, 33, 34). In early childhood, glaucoma results in substantial

TABLE 4

Literature review of prevalence and incidence rates of glaucoma in young persons

Reference	Population size	Age at diagnosis	Ethnic origin	Congenital glaucoma	Juvenile glaucoma	Incidence	Prevalence	Study
Papadopoulos et al., 2007 (1)	99 glaucoma patients ≤ 16 years 2002, UK, IRE	≤ 1 year	Mixed	35 UK 2 IRE	n. a.	1 : 18 500 UK, 1 : 30 200 IRE	n. a.	All
Aponte et al., 2010 (3)	30 glaucoma patients <20 years diagnosed 1965–2004, US	<20 years	96 % Caucasian white	1 (≤ 1 year)	4 (13 to <20 years)	1 : 260 688	n. a.	All/files
Gencik et al., 1989 (29)	Population in 1950–1989, Slovakia	± 6 months	Sinti and Romany peoples	118	n.a.	1 : 2120	1:1250	Partly only history-based
Ellong et al., 2007 (27)	24 462 ophthalmology patients, of whom 1 343 with glaucoma 1991–2001, Cameroon	10–35 years	Black African	n. a.	94	n. a.	1:250	All/files

IRE, Republic of Ireland; n. a.; not available; UK, United Kingdom; US, United States of America

functional impairment and glaucoma is diagnosed proportionally more often than in adults, albeit with a delay (35, 36).

In order to validate the data from the medical history, we correlated these with the parameters visual acuity, intraocular pressure, corneal thickness, visual field analysis, and papillary findings. Data on corneal diameter or axial length were lacking. However, we did not identify any congenital cases; the data were therefore assumed to be within the normal distribution in the population.

Visual acuity and corneal thickness were found to be parameters of very little validity in terms of supporting the diagnosis, as corneal thickness in all groups corresponded to participants' average corneal thickness (37) and visual acuity was also in the upper range ($\geq 20/40$). Furthermore (Table 2) there were patients with very poor visual acuity and functional blindness, which corresponded to advanced glaucoma.

Intraocular pressure for all glaucoma patients was within the normal range and was therefore not used as an inclusion or exclusion criterion. Participants' good intraocular pressure level may have been achieved by means of successful treatment of the patients, who were adults already (Figure 1 and 2) (38).

66% of participants with childhood glaucoma had papillary changes typical for glaucoma, which supports the allocation of these participants to this diagnostic group.

Visual field analysis showed very small or no defects in 73% of cases. This is an astonishingly high proportion. Participants had either been treated very early and very effectively, so that the visual fields remained normal, or the examination method is not suitable for the purpose of screening (39).

The GHS is a non-interventional study; participants with abnormal or borderline findings can unfortunately not be re-invited.

KEY MESSAGES

- The study results enable for the first time an estimate of the history-based prevalence of juvenile glaucoma in Germany (<18th year of life), of 1:10 000.
- For persons who were diagnosed in young adulthood (18th to 40th year of life), the prevalence is 10 times higher (0.16%).
- Furthermore, the prevalence increases throughout life by more than the factor 10 (1.98%)
- In the past, to estimate rates of childhood glaucoma, incidence rates were used that as a rule related to congenital glaucoma and are very low: 1:260 000 (US) and 1:357 000 (Great Britain). The incidence for childhood glaucoma (<20th year of life) is 1:43 575 for the US population.
- This means that the burden of disease seems notably higher than estimated to date.

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Conflict of interest statement

Dr Marx-Gross has received travel expenses from Bayer. Prof Mirshahi has received funding for composing the present manuscript or thematically related ARBEITEN from Novartis Pharma. She has received study support (third party funding) from Bayer and Novartis Pharma. The remaining authors declare that no conflict of interest exists.

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Supplementary material

eBox, eTable:
www.aerzteblatt-international.de/17m0204

Supplementary material to:

The Prevalence of Glaucoma in Young People

Findings of the Population-based Gutenberg Health Study

by Susanne Marx-Gross, Dagmar Laubert-Reh, Astrid Schneider, René Höhn, Alireza Mirshahi, Thomas Münzel, Philipp S. Wild, Manfred E. Beutel, Maria Blettner, and Norbert Pfeiffer

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eTABLE

Eye examination in the Gutenberg Health Study at baseline (2007–2012)

Examinations	Equipment
Objective refraction (corrected visual acuity)	Autorefraktometer Humphrey 599 (Zeiss)
Pachymetry and keratometry	Pachycam (Oculus)
Visual field measurement	FDT Humphrey Matrix Perimeter (Zeiss)
Intraocular pressure measurement	Non-Contact-Tonometer Nidek NT-2000 (Nidek)
Photographic documentation of the fundus: 45° overview, 30° photo of optic disc and macula	Visucam Pro NM (Zeiss)

Extract from Mirshahi et al. (23)

FDT, frequency doubling technology

Material and methods: additional details

● Gutenberg Health study:

This study investigated 15 010 participants from Mainz City and the rural district Mainz-Bingen. From a population of 397 796 (Mainz City, $n=196\,425$; rural district Mainz-Bingen, $n=201\,371$), men and women aged 35–74 ($n=210\,867$) were defined as the target group. The random sample was stratified 1:1 by sex, 1:1 by place of residence (urban and rural area), and 1:1 for the four age decades (24). In order to determine the prevalence, we considered only those persons who were at risk. The cohort of the Gutenberg Health Study comprised persons aged 35–75, so that the entire cohort was studied only for the prevalence of congenital glaucoma and juvenile glaucoma. For the prevalence of late juvenile glaucoma, we studied persons from the cohort who were at least 40 years of age at the time of inclusion into the study (alternatively, the date of the examination) ($n=13\,510$). For the prevalence of early adult glaucoma, we studied persons who were at least 45 years old ($n=11\,724$).

We calculated the history-based prevalence of different subtypes of glaucoma for the population of Mainz/Mainz-Bingen on the basis of the data from Groups 1–4, and we weighted these according to the population structure (24).

We took an oral medical history at the time of the eye examination—among others, for pre-existing illnesses/disorders, surgical procedures, and medication, including details on dates. On the basis of these data, we categorized participants into groups if they had reported a diagnosis of glaucoma and/or had had surgery for glaucoma (the exact name of the procedure, so as to rule out confusion with other operations), and/or if glaucoma drugs had been used (with the exact name of the drug/effective substance). If it was not possible to establish the date of the initial diagnosis, the date/time of the first use of medication or glaucoma surgery were used to determine timings. Glaucoma operations included in particular goniotripanation, trabeculectomy, cyclophotocoagulation, laser iridotomy, argon laser trabeculoplasty, and the terms fistulating surgery and filtering bleb surgery were also included. Where a patient was not able to name their operation this information was not included in our evaluation. Furthermore, we also determined glaucoma drugs with trade names and frequency of application. The study protocol did not provide for checking with treating doctors and this was therefore not possible; neither were symptom-specific additional examinations.

We measured the bilateral intraocular pressure (IOP) by using a non-contact tonometer. We measured the pressure in the right eye first and calculated the mean of three measurements within a 3 mm Hg measuring interval.

We determined corneal thickness centrally by applying non-contact pachymetry, using Scheimpflug imaging.

We tested visual acuity according to objective refraction and used autorefractometry to determine refraction and Snellen's eye sign. If visual acuity was below 20/400 (0.05) these variables were determined at a distance of 1 meter by using a visual acuity chart up to 20/800. If visual acuity was lower, we used counting digits, hand movements, and light perception or no light perception for grading purposes. The visual field examination was done by using frequency doubling technology (FDT) (program N-30–5 screening). In participants with even identification numbers, we tested the right eye first and in participants with odd IDs, we tested the left eye first. Before the second eye was examined we undertook non-contact pachymetry, in order to grant the patient some rest and respite between visual field measurements. Refractive errors above 5 diopters were corrected by using lenses, otherwise the measurement was undertaken without refraction. If one sector showed a visual field defect with $P<1\%$ or two neighboring sectors showed defects with $P<5\%$, we immediately repeated the examination of the respective eye and classified it as abnormal if the finding was confirmed. The examination method did not allow for a differentiated diagnosis of the visual field in terms of glaucoma stage, as this would have been possible only after multiple visual field tests (reproducible defects) using specialized glaucoma programs. Re-invitation to further tests was not provided for by the study protocol and therefore was not an option.

Optic disc imaging was done by using a fundus camera. Participants were photographed in a darkened room, their pupils not enlarged. We always started with the right eye and took two photographs (30° and 45°) of the centered optic disc. In participants who met the glaucoma definition mentioned above, the photographic documentation was evaluated by an investigator and categorized into glaucomatous changes or no changes (22).

The study protocol and documentation were approved by the ethics committee of the Rhineland-Palatinate Medical Association (Reference number 837.020.07; original approval: 22 March 2007, latest update: 20 October 2015). The measures of Good Clinical Practice (GCP) and Good Epidemiological Practice (GEP), and the ethical principles of the Declaration of Helsinki were adhered to in conducting the study, and informed written consent was obtained from all study participants (25).

● Statistical evaluation

We used descriptive statistics to calculate measures of central tendency (medians, quartiles, means, standard deviations, and minimum and maximum values) for continuous variables (IOP, visual acuity (decimal), and corneal thickness). We determined weighted prevalence rates for the different glaucoma subgroups. The evaluation was weighted according to the standard population of the Mainz/Mainz-Bingen districts. Frequencies for the pathology for visual field tests and optic disc findings were recorded as yes/no.