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Glaucoma

Presbyopia Progression From the Age of 40 to 79 Years in Glaucoma Patients Treated With Prostaglandin F Receptor Agonists

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Purpose: The aim of this study was to compare the near add power of glaucoma patients and controls between the ages of 40 and 79 years.

Methods: This was a cross-sectional study of 2724 bilateral phakic participants aged between 40 and 79 years, which included 1615 controls and 1109 patients with primary open-angle glaucoma who were using prostaglandin F (FP) receptor agonists. Participants were classified into eight age groups: 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, and 75–79 years of age. We compared the near add power and other ocular parameters between glaucoma patients and controls by age group.

Results: There was a significant difference between glaucoma patients and controls and in spherical equivalent, intraocular pressure, cup/disc ratio, ganglion cell complex thickness, peripapillary retinal nerve fiber layer thickness, and use of dry eye eyedrops across all or many of the age groups studied. The near add power of glaucoma patients was comparable to controls of the immediately older age group until 65–69 years, indicating that the advancement of near add power of glaucoma patients was approximately five years earlier than in controls until that age range.

Conclusions: There was an earlier progression of presbyopia determined by near add power in glaucoma patients treated with FP receptor agonists compared with controls.

Translational Relevance: Between ages 40 and 79 years, glaucoma patients treated with prostaglandin F receptor agonists had higher near add power than controls. This knowledge could contribute to informing better management of glaucoma patients with presbyopia.

Introduction

Presbyopia and glaucoma are common geriatric disorders and decrease the quality of life.[1–4] Presbyopia is an age-related progressive loss of focusing ability, leading to impaired near vision without proper near addition under full correction for distance vision.[5–7] Uncorrected presbyopia is a serious economic burden, reducing productivity and subjective happiness.[8,9] However, many people suffer from uncorrected presbyopia because of economic problems or a lack of willingness,[10] even though higher near vision is more important in the modern digital society than before.[11] Lens hardening and ciliary muscle dysfunction are believed to be major pathologies contributing to presbyopia progression; however, the exact mechanism of disease progression and the effect of prevention are still under investigation.[12,13]

Glaucoma is a major vision-threatening disease, with a prevalence of 5.0% in the Japanese population aged over 40 years.[14] It is an optic neuropathy leading to progressive visual field loss and is usually asymptomatic until the advanced stage.[15] Intraocular

pressure (IOP) may be elevated in glaucoma because of dysfunction of the drainage of aqueous humor in the trabecular meshwork and uveoscleral pathway. The only established treatment is to reduce IOP, and many topical medications are available, including prostaglandin F (FP) receptor agonists, which are a first-line therapy for primary open-angle glaucoma as recommended in European and American Society guidelines.[16,17] Pressure reduction with FP receptor agonists is achieved by facilitating uveoscleral flow and matrix metalloproteinase production, leading to the remodeling of the extracellular matrix of the ciliary muscle and sclera.[13]

Presbyopia in glaucoma patients treated with FP receptor agonists may be altered because the long-term use of FP receptor agonists may induce certain changes in the ciliary muscle. The contractile effect of FP receptor agonists on the ciliary muscle in organ culture experiments[18] and several clinical investigations are consistent with this finding.[19–22] One case report described accommodative spasm and pseudomyopia observed in a 47-year-old glaucoma patient after bimatoprost instillation,[20] and clinical studies have demonstrated earlier progression of presbyopia in glaucoma patients with medications.[21,22] One study involving 376 controls and 77 glaucoma patients aged 40 to 55 years compared the near add power of glaucoma patients and controls, and identified age, astigmatic errors, mean deviation, ganglion cell complex (GCC) thickness, and retinal nerve fiber layer (RNFL) thickness as significant risk factors for higher near add power.[22] However, it has not been demonstrated how the near add power progresses in glaucoma cases from the early presbyopic period to the age at which presbyopia stabilizes in comparison with controls. This aspect has been lacking in previous studies, yet it is crucial to determine age-related changes in presbyopia in glaucoma patients.

The aim of this study was to compare near add power in glaucoma patients and controls between 40 and 79 years of age, covering a sufficient population with presbyopia.[5–7] This study also compared refraction and glaucoma-related and dry eye–related ocular parameters to explore potential contributing factors for the differences between control individuals and glaucoma patients using FP receptor agonists.

Methods

Study Design and Participants

This was a clinic-based, cross-sectional study involving healthy individuals attending Otake Eye Clinic, Kanagawa, Japan. The Institutional Review Board and Ethics Committee of the Kanagawa Medical Association approved the study (approval date, November 12, 2018; permission number krec2059006), and it was carried out in accordance with the Declaration of Helsinki. The need for consent was waived by the Institutional Review Board of Kanagawa Medical Association since this study was conducted in an opt-out manner. The study involved retrospective chart review for consecutive patients visiting the clinic from December 2018 to April 2024. The Institutional Review Board and Ethics Committee of Keio University School of Medicine also approved this study (approval date, May 31, 2024; approval number 20241019) to permit authorship for authors (KN, AH, and MA) who were appointed at the Keio University School of Medicine. The protocol was registered with the UMIN Clinical Trials Registry (UMIN000051891) on August 15, 2023.

Inclusion and Exclusion Criteria

Participants aged 40 to 79 years with bilateral phakic eyes and best-corrected visual acuity above 20/30 were included. The exclusion criteria were a history of corneal or intraocular surgeries, including ocular laser treatment and refractive or cataract surgeries; moderate-severe cataract ($\geq$ Grade 2 nuclear cataract based on the World Health Organization cataract grading system)[23]; and severe dry eye disease (defined as positive symptoms of dry eye and diffuse keratoconjunctival staining on the fluorescein staining test) because severe dry eye disease significantly affects near vision.[24]

Ophthalmological Examinations and Diagnosis of Glaucoma

All participants received a complete ophthalmologic examination, including best-corrected visual acuity, a slit lamp examination, IOP measurement (Tonoref II; Nidek Co., Ltd., Gamagori, Japan), fundus examination, and standard automated perimetry with the Humphrey Visual Field Analyzer Swedish Interactive Threshold Algorithm–Standard 24-2 program (HFA 24-2; Carl Zeiss Meditec, Dublin, CA, USA). Primary open angle glaucoma was diagnosed if at least two reliable visual field examinations confirmed the presence of glaucomatous visual field defects consistent with glaucomatous optic disc changes with open angle observed with gonioscopy or slit lamp biomicroscopy. Patients were excluded if they had significant media opacity or other intraocular or neurological diseases affecting the visual field. Eyes

with unreliable visual field results (fixation loss > 33%, false-positive > 15%, or false-negative > 20%) were also excluded. Consequently, patients with primary open angle glaucoma were enrolled. The FP receptor agonists used were 0.005% latanoprost for 954, 0.0015% tafluprost for 82, 0.004% travoprost for 30, and 0.03% bimatoprost for 43 patients.

Binocular near add power was measured at a distance of 30 cm using a Bankoku near-acuity chart (Handaya Inc., Tokyo, Japan). After determining the patient's distance refractive correction, the minimal additional power required to achieve near acuity above 20/25 at 30 cm was measured in 0.25 D increments and was recorded as near add power. The prevalence of symptomatic presbyopia (near add power $\geq$ 1.50 D) was calculated. Ocular surface examinations consisted of tear break-up time (BUT) and a corneal staining test. BUT was defined as the time taken for the first black spot to appear on the stained ocular surface after the last complete blink observed using the cobalt-blue filter of the slit lamp. Three consecutive measurements were acquired, and the mean value calculated and recorded. A BUT measurement below or equal to five seconds was determined as a short BUT. Corneal staining was used to detect corneal epitheliopathy by grading the stain intensity (0–2) one minute after administering fluorescein dye in the eye using the slit lamp's cobalt blue illumination and a yellow barrier filter.

Optical coherence tomography (OCT; RS-3000; Nidek, Tokyo, Japan) was used to measure macular RNFL, ganglion cell layer (GCL) + inner plexiform layer (IPL) (GCL/IPL), and macular RNFL + GCL + IPL (GCC) of the maps based on macular cube scans of a 6 × 6 mm^2 area centered on the fovea. For peripapillary RNFL imaging, raster scanning over a 6 × 6 mm^2 area centered on the optic disc center was conducted at a scan density of 512 A-scans (horizontal) × 128 B-scans (vertical). Peripapillary RNFL measurements were performed along a 3.45-mm diameter circle automatically positioned around the optic disc.

Statistical Analysis

Participants were classified into eight groups based on years of age: 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, and 75–79 years. Participant demographics and ophthalmological parameters are presented as mean ± standard deviation for continuous variables and as percentages for categorical variables for each age group. The *t*-tests and χ^2 tests were used to compare parameters between the two groups at each age group. The near add power in patients with glaucoma and controls was compared separately for each refractive group (myopia < −0.50D, emmetropia from −0.50D to 0.50D, and hypermetropia> 0.50D). Normalized values of near add power, spherical equivalent, and astigmatic errors adjusted to the value of that of the 40–44 age group were calculated and compared using the Wilcoxon test. We performed all analyses using StatFlex (Atech, Osaka, Japan), with a P value < 0.05 (two-sided) indicating a significant difference.

Results

A total of 2724 participants were analyzed, including 1615 controls and 1109 glaucoma patients. There was a significant difference between glaucoma patients and controls in spherical equivalent, IOP, cup/disc ratio, GCC thickness, and peripapillary RNLF thickness across all or most age groups (Tables 1, 2). Specifically, near add power was higher in glaucoma patients than in controls from age group 40–44 to 70–74, and the percentage of participants with near add power $\geq$ 1.50 D was higher among glaucoma patients than controls from the age group 40–44 to 50–54. Regarding the results of near add power for each refractive group, near add power was higher in the myopic group for all age groups examined except group 75–79 (Table 3). There was no difference in the emmetropia groups from ages 40 to 64 years, although the number of cases was small in many of the age groups. The sample size for emmetropia and hypermetropia cases was enough in age groups 65–69 and 70–74 years where near add power was higher in glaucoma groups in all refractive groups compared with controls. The numbers for the hypermetropia groups were less than 10 in five of eight age groups, and a precise comparison was not possible. Regarding dry eye–related parameters, the use of dry eye medication was more prevalent in glaucoma patients than controls in the three youngest age groups, whereas BUT and corneal staining were not different between the groups except for BUT being shorter in glaucoma patients in the 75–79 age group.

Graphic representation of the near add power progression in glaucoma patients and controls by age group showed distinct differences in near add power between the two groups (Fig. 1). The near add power of glaucoma patients was comparable to that of controls of the immediately older age group until group 65–69, indicating that the advancement of near add power in glaucoma patients was approximately five years earlier than controls from the ages 40 to 69 years.

The normalized values for spherical equivalent and astigmatic errors are shown in Figure 2. Spherical equivalent values showed a hyperopic shift in glaucoma patients ($P = 0.015$), and changes in astigmatic errors

Table 1. Patient Demographics and Baseline Characteristics

	Age Group (Y)							
	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79
Number (% men)								
Cntr	103 (34.0)	205 (29.3)	246 (34.6)	278 (32.0)	234 (30.8)	230 (30.0)	202 (37.6)	117 (41.9)
Gla	60 (76.7**)	130 (66.2**)	175 (42.3)	161 (40.0)	140 (45.0**)	181 (50.0**)	147 (49.0*)	115 (42.6)
Mean age (y)								
Cntr	42.4 (1.3)	47.2 (1.3)	52.1 (1.3)	56.8 (1.4)	62.0 (1.3)	67.1 (1.4)	71.8 (1.4)	77.0 (1.1)
Gla	42.3 (1.4)	47.3 (1.4)	51.9 (1.3)	57.1 (1.3)	62.0 (1.4)	67.1 (1.4)	71.8 (1.4)	76.9 (1.4)
Spherical equivalent (D)								
Cntr	−3.17 (3.47)	−3.81 (3.52)	−4.21 (3.67)	−3.45 (3.84)	−2.47 (3.81)	−1.49 (2.78)	−0.78 (2.37)	−0.07 (2.21)
Gla	−4.64** (3.28)	−5.22** (3.34)	−5.65** (3.62)	−4.79** (3.30)	−4.11** (3.90)	−2.52* (3.06)	−1.71* (3.14)	−1.37** (1.89)
Astigmatism, D								
Cntr	0.45 (0.65)	0.55 (0.84)	0.58 (0.75)	0.75 (0.89)	0.69 (0.76)	0.95 (0.82)	0.89 (0.85)	1.07 (0.97)
Gla	0.37 (0.72)	0.59 (0.71)	0.63 (0.87)	0.52** (0.79)	0.83 (0.79)	1.02 (0.89)	1.03 (0.90)	0.86* (0.90)
Anisometropia (D)								
Cntr	0.46 (0.67)	0.67 (0.93)	0.67 (0.73)	0.49* (0.60)	0.58 (0.87)	0.71 (0.86)	0.66 (0.88)	0.82 (1.16)
Gla	0.47 (0.57)	0.48* (0.51)	0.84 (1.34)	0.60 (0.62)	0.88* (1.00)	0.94 (1.18)	0.73 (0.90)	0.67 (0.91)
Near add power (D)								
Cntr	0.93 (0.65)	1.40 (0.71)	2.10 (0.63)	2.46 (0.53)	2.77 (0.42)	2.81 (0.33)	2.84 (0.32)	2.92 (0.19)
Gla	1.43** (0.78)	2.14** (0.68)	2.43** (0.55)	2.75** (0.50)	2.89** (0.20)	2.95** (0.16)	2.98** (0.09)	2.91 (0.23)
Near add power $\geq$ 1.5 D (%)								
Cntr	16.0	58.3	90.4	97.5	98.3	99.1	99.0	100
Gla	66.0**	87.7**	96.6**	97.5	100	100.0	100	100

Cntr, controls; Gla, glaucoma patients.

Data are presented as mean and standard deviation in parentheses unless specified otherwise. †Worse eye. *$P < 0.05$, **$P < 0.01$, vs. controls; unpaired *t*-test or χ^2 test.

Table 2. Glaucoma and Dry Eye-Related Clinical Features

	Age Group (Y)							
	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79
Intraocular pressure (mm Hg)[†]								
Cntr	16.6 (3.5)	16.1 (3.0)	16.3 (3.0)	16.7 (3.9)	15.2 (3.6)	15.2 (3.3)	15.7 (3.3)	16.1 (4.7)
Gla	13.5** (3.0)	13.9** (3.1)	14.1** (2.8)	14.5** (2.8)	14.2** (3.2)	13.8** (3.2)	13.8** (3.4)	14.0** (2.6)
Mean deviation, dB[†]								
Cntr	−2.47 (4.68)	−2.19 (2.61)	−2.04 (2.99)	−2.70 (2.59)	−2.26 (2.93)	−4.31 (5.72)	−4.84 (5.58)	−5.71 (6.72)
Gla	−4.03* (4.06)	−5.29** (5.92)	−5.48** (5.84)	−5.12** (6.10)	−5.09* (7.08)	−6.40** (5.37)	−7.86** (5.61)	−8.34* (7.65)
Cup/disc ratio (%)[†]								
Cntr	65.7 (14.6)	61.3 (16.1)	63.9 (14.6)	64.6 (14.4)	68.9 (14.1)	67.1 (13.3)	65.3 (15.5)	67.6 (16.9)
Gla	77.4** (10.8)	73.3** (13.3)	72.9** (14.9)	71.3** (15.9)	76.1** (13.3)	76.9** (12.3)	75.9** (11.9)	74.5** (13.3)
GCC thickness (μm)[‡]								
Cntr	86.2 (13.2)	87.4 (12.8)	83.3 (12.2)	83.5 (12.0)	84.2 (10.8)	83.5 (11.6)	81.6.1 (10.1)	81.3 (14.1)
Gla	77.3** (9.5)	75.7** (10.0)	77.7** (12.1)	73.4** (11.1)	73.4** (10.5)	73.1** (10.3)	71.6** (10.6)	74.0** (10.9)
Peripapillary RNFL thickness (μm)[‡]								
Cntr	116.3 (24.8)	115.0 (20.3)	106.0 (19.3)	108.5 (21.0)	107.4 (20.8)	109.2 (21.4)	109.2 (17.8)	107.0 (22.3)
Gla	88.5** (14.4)	93.3** (17.1)	93.4** (19.3)	90.1** (19.6)	90.4** (30.3)	91.0** (22.6)	89.3** (15.6)	95.8** (19.2)
Tear break-up time (s)								
Cntr	3.9 (2.6)	3.9 (2.4)	3.6 (2.4)	3.5 (2.5)	3.3 (2.4)	3.4 (2.1)	3.5 (2.1)	4.0 (2.2)
Gla	3.0 (2.0)	3.2 (2.0)	3.5 (2.1)	4.1 (2.4)	3.9 (2.6)	3.7 (2.6)	3.0 (2.6)	3.2** (2.4)
Superficial punctate keratitis								
Cntr	25.6%	27.8%	25.3%	20.9%	19.8%	20.5%	22.6%	18.9%
Gla	36.8%	33.3%	27.7%	21.9%	26.0%	15.9%	16.4%	31.2%
Use of dry eye medication								
Cntr	8.7%	10.2%	9.3%	16.2%	14.1%	23.9%	21.3%	23.1%
Gla	35.0%**	31.5%**	20.0%**	13.7%	20.7%	17.1%	17.7%	27.8%

Cntr, controls; Gla, glaucoma patients.

Data are presented as mean and standard deviation in parentheses unless specified otherwise.

*$P < 0.05$ versus control; unpaired *t*-test or χ^2 test.

**$P < 0.01$ versus control; unpaired *t*-test or χ^2 test.

[†]Worse eye.

[‡]Mean of superior and inferior area.

Table 3. Mean Near Add Power in Refractive Group

Parameters and Refractive Group	Age Group (Y)							
	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75–79
Mean age (y)								
Myopia								
Cntr	42.3 (1.3) (n = 170)	47.2 (1.3) (n = 61)	52.0 (1.3) (n = 200)	56.8 (1.4) (n = 202)	61.8 (1.4) (n = 133)	66.9 (1.4) (n = 114)	71.7 (1.7) (n = 87)	76.6 (1.0) (n = 30)
Gla	42.3 (1.4) (n = 57)	47.2 (1.4) (n = 119)	51.9 (1.3) (n = 161)	57.1 (1.3) (n = 150)	61.9 (1.4) (n = 123)	67.0 (1.3) (n = 117)	71.6 (1.3) (n = 72)	76.7 (1.4) (n = 57)
Emmetropia								
Cntr	42.6 (1.3) (n = 26)	47.1 (1.3) (n = 37)	52.5 (1.2) (n = 31)	57.1 (1.3) (n = 45)	62.1 (1.3) (n = 39)	67.1 (1.3) (n = 36)	72.2 (1.3) (n = 32)	77.1 (0.9) (n = 27)
Gla	41.6† (2.0) (n = 3)	47.8 (1.6) (n = 11)	51.6 (1.6) (n = 13)	57.0 (1.2) (n = 17)	62.5† (1.3) (n = 8)	67.4 (1.4) (n = 32)	71.0 (1.4) (n = 49)	77.0 (1.7) (n = 52)
Hyperopia								
Cntr	43.0 (1.3) (n = 6)	46.8 (1.3) (n = 5)	52.4 (1.5) (n = 11)	56.9 (1.7) (n = 24)	62.2 (1.3) (n = 55)	67.3 (1.3) (n = 65)	71.7 (1.3) (n = 79)	77.1 (0.7) (n = 55)
Gla	44.0† (n = 1)	47.0† (n = 1)	51.0† (n = 1)	56.7†(1.7) (n = 4)	62.2†(1.6) (n = 9)	66.9 (1.4) (n = 30)	70.5 (1.4) (n = 21)	77.3†(2.0) (n = 3)
Mean SE (D)								
Myopia								
Cntr	−4.67 (1.38)	−4.87 (3.16)	−5.18 (3.27)	−4.82 (3.51)	−4.80 (3.35)	−3.40 (2.31)	−2.89 (2.00)	−3.10 (2.43)
Gla	−5.02 (3.13)	−5.68* (2.87)	−6.15 (2.84)	−5.20 (3.10)	−4.77 (2.49)	−4.14* (2.46)	−3.71* (3.24)	−2.59 (1.93)
Emmetropia								
Cntr	−0.02 (1.30)	0.03 (0.29)	0.00 (0.31)	−0.02 (0.29)	0.00 (0.20)	−0.02 (0.30)	−0.03 (0.26)	−0.06 (0.32)
Gla	−0.33†(0.14)	−0.30* (0.22)	−0.09** (0.19)	+0.01(0.04)	−0.01 (0.25)	−0.01 (0.30)	0.15* (0.28)	−0.01 (0.28)
Hyperopia								
Cntr	+2.22 (0.63)	2.25 (0.00)	1.50 (0.63)	1.31 (0.60)	1.40 (0.82)	1.35 (0.72)	1.61 (0.64)	1.58 (0.80)
Gla	+1.75†	0.87†	1.50†(0.55)	2.06* (0.87)	1.27 (0.49)	1.29 (0.45)	1.23* (0.67)	0.91 (0.14)
Mean near add power (D)								
Myopia								
Cntr	0.94 (0.60)	1.40 (0.73)	2.11 (0.66)	2.46 (0.53)	2.78 (0.41)	2.86 (0.72)	2.84 (0.33)	2.90 (0.28)
Gla	1.47** (0.77)	2.18** (0.69)	2.45** (0.60)	2.75** (0.44)	2.88** (0.23)	2.95** (0.45)	2.99** (0.07)	2.95 (0.13)
Emmetropia								
Cntr	0.79 (0.62)	1.40 (0.68)	2.07 (0.39)	2.45 (0.57)	2.87 (0.27)	2.82 (0.24)	2.81 (0.28)	2.90 (0.17)
Gla	1.42† (0.14)	1.70 (0.31)	2.27 (0.37)	2.50 (1.12)	3.00 (0.00)	2.98** (0.09)	2.96** (0.14)	2.88 (0.33)
Hyperopia								
Cntr	0.96 (0.93)	1.45 (0.11)	1.95 (0.77)	2.42 (0.42)	2.66 (0.52)	2.68 (0.35)	2.85 (0.34)	2.93 (0.16)
Gla	0.50†	2.50†	2.50†	3.00** (0.00)	2.94 (0.17)	2.90** (0.24)	2.99* (0.05)	3.00 (0.00)

Cntr, controls; Gla, glaucoma.

Data are presented as mean and standard deviation in parentheses.

*$P < 0.05$ vs. controls; unpaired *t*-test.

**$P < 0.01$ vs. controls; unpaired *t*-test.

†n < 10.

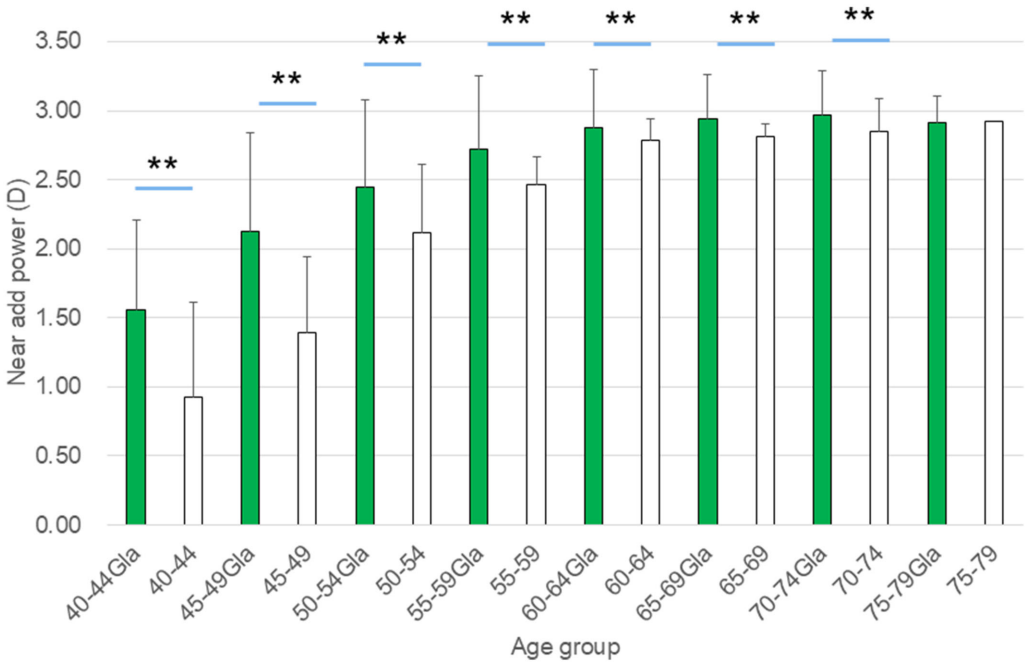

Figure 1. Near add power of glaucoma patients and controls by age group. Near add power was significantly higher in glaucoma patients (Gla, *green bars*) than in controls (*white bars*) from age group 40-44 to 70–74. $^{**}P < 0.01$, *t*-test.

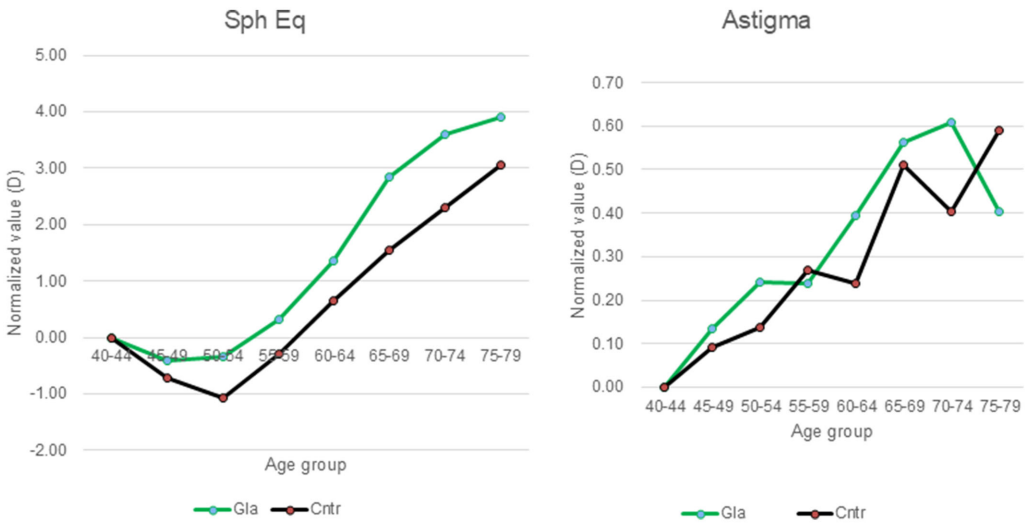

Figure 2. Normalized values of spherical equivalent (*left*) and astigmatic errors (*right*) adjusted to the values of the 40–44 age group. Spherical equivalent showed a hyperopic shift in glaucoma patients (*green line*) compared with controls (black line; $P = 0.015$), and the change in astigmatic errors was not different between glaucoma patients and controls ($P = 0.296$). Cntr, controls; Gla, glaucoma patients.

were not different between glaucoma patients and controls ($P = 0.296$). The increase of near add power was significantly greater in glaucoma patients ($P = 0.031$).

Discussion

The present study clearly demonstrates age-related differences in near add power between glaucoma patients and controls from ages 40 to 79 years. The results of near add power for each refraction indicated that the near add power for glaucoma groups was higher in most myopia groups compared with controls The current findings indicate early progression of presbyopia, especially in middle-aged glaucoma patients. Although the difference between the two groups decreased with aging, it is serious that between the ages of 40 and 59 years, glaucoma patients have greater near add power when productiv-

ity may decrease because of advanced presbyopia. This progression may also worsen presbyopic symptoms and decrease quality of life.[1,2] Presbyopia progressed earlier in glaucoma patients than in controls, even after the initiation of pressure reduction medication followed by successful pressure control, suggesting the presence of predisposed and/or continuous exacerbating factors in the presbyopia of glaucoma patients. Taken together, accommodation in glaucomatous eyes may be diminished and does not recover, even after pressure reduction.

Near add power linearly and differentially increased from 40 to 64 years of age in both glaucoma and control groups. Generally, accommodation amplitude becomes stable around the age of 55 years.[5–7] However, the current results suggest that some suppressive factor(s) on accommodation may play a role in actual near vision correction presented by near add power, leading to earlier progression of presbyopia in glaucoma patients. Spherical equivalent, pupillary function, lens elasticity, retinal sensitivity, and other tissue kinetics, including those of ciliary muscle and posterior segments, might contribute to near vision as suggested previously.[12,13] A comparison of changes in normalized values of ocular parameters adjusted for the value of the age group 40–44 revealed a more hyperopic shift in glaucoma patients. This might be partly due to the suppression of axial length elongation caused by pressure reduction with glaucoma medication.[25] It is reasonable that a more hyperopic shift in glaucoma patients may result in an exacerbation of presbyopia compared with controls. It is also notable that the glaucoma group exhibited higher near add power despite being significantly more myopic compared with controls since myopia generally needs less near add power.[26]

The proposed hypothesis of increased near add power in glaucoma patients treated with glaucoma medications is: FP receptor agonists contract the ciliary muscle, leading to a continuously forced restriction of mobility for accommodation. The ciliary muscle is one of the major components for accommodation, and a decline in its function may result in an increase of near add power in glaucoma patients treated with FP receptor agonists. There was no study of these patients and the function of the ciliary muscle and accommodation ability before glaucoma treatment. Consequently, another possibility may be also considered: the Kaufman group's studies suggest that open angle glaucoma may be a result of a more pronounced progression of presbyopia,[27,28] especially because the near add power requirement is higher in glaucomatous eyes as demonstrated in the present study. The Kaufman group's studies suggested that during accommodation there may be pressure and tension spikes on the optic nerve in the normal young eye.[12,13,27,28] These studies also suggest that these pressure and tension spikes increase with age and may be more pronounced in some people who then go on to exhibit glaucoma.

The strengths of this study include a wide range of age groups with a significant number of cases, providing convincing evidence. The glaucoma eye drops used were limited to FP receptor agonists, and the obtained simplified and controlled results provide useful information for glaucoma practice. This study has several limitations. Pupillary reaction may be diminished in glaucoma,[29,30] and it is crucial to perform pupillometry to evaluate factors for near vision in glaucoma patients treated with eye drops, although FP receptor agonists are not supposed to alter pupillary reaction.[28] The current study did not analyze anatomical factors (axial length, keratometry findings) and accommodation (amplitude of accommodation or near visual acuity with correction for distance). Further study with other glaucoma eye drops, including beta blockers and carbonic anhydrase inhibitors, would provide more information about presbyopia progression in glaucoma-medicated patients. Further studies involving patients under 40 years of age would detect specific effects of glaucoma and glaucoma medication on non-presbyopic eyes.

In conclusion, the current study clearly demonstrates age-related changes in near add power in glaucoma patients using FP receptor agonists. These results could be applied to the management of glaucoma, especially for patients aged 40 to 64 years, because the difference in near add power compared with controls was prominent in this productive population.

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