Assessment of the Efficacy of Restoring Reading Performance After Refractive Lens Exchange With a Trifocal Intraocular Lens

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ABSTRACT

PURPOSE: To evaluate the efficacy of refractive lens exchange (RLE) with a trifocal intraocular lens (IOL) implantation by assessing reading performance and visual acuity at near and intermediate distances.

METHODS: This was a prospective interventional case series of 27 patients (54 eyes) at a university hospital who underwent a femtosecond laser–assisted RLE with Clareon PanOptix IOL (Alcon Laboratories, Inc) implantation. Visual acuity was tested before surgery and 6 months postoperatively and reading performance was evaluated using the Salzburg Reading Desk (SRD Vision) at near and intermediate distances. With a software-based simulator, the perception of halo and glare were quantified.

RESULTS: The uncorrected and distance-corrected near (40 cm) and intermediate (60 cm) visual acuities improved, with the mean (± standard deviation) postoperative binocular uncorrected visual acuity of 0.03 ± 0.08 logarithm of the minimum angle of resolution (logMAR) at 40 cm and -0.08 ± 0.06 logMAR at 60 cm. The surgery also improved uncorrected reading acuities, with the postoperative binocular uncorrected reading acuity of 0.05 ± 0.08 logMAR at 40 cm and 0.09 ± 0.10 logMAR at 60 cm. The postoperative uncorrected reading acuity matched the preoperative reading acuity with spectacle correction for near (0.04 ± 0.10 logMAR, P = .495). The near vision efficacy index was 0.75 ± 0.12 for conventionally measured visual acuity and 0.99 ± 0.35 for reading acuity. A total of 77.8% of patients reported halo and 14.8% reported glare, although none complained of bothersome photic phenomena.

CONCLUSIONS: The RLE surgery effectively restored good uncorrected near and intermediate vision in terms of visual acuity and reading performance. At high luminance and contrast levels, the postoperative uncorrected reading ability matched the preoperative spectacle-corrected performance for near.

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Refractive lens exchange (RLE) with multifocal intraocular lens (IOL) implantation can improve uncorrected vision at near, intermediate, and far distances in presbyopic patients.[1] The IOL divides the light energy into the near, intermediate, and far foci, with the superimposed images projected simultaneously onto the retina.[2,3] Typically, a multifocal IOL distributes the largest proportion of light energy to the far focus, thus improving distance vision.[4] The limited light energy available for the near and intermediate foci and the blur arising from the brighter far focus could negatively impact the near and intermediate vision.

In principle, researchers ought to compare postoperative with preoperative visual acuity to evaluate how multifocal optics affect vision. However, multifocal IOL studies usually analyze functional outcomes in patients with cataract, where comparing preoperative and postoperative visual acuity would not be informative, because the opaque cataractous lens significantly affects preoperative vision.[1] In contrast, the crystalline lenses in patients undergoing RLE are transparent, allowing for an intra-individual assessment of the impact of the multifocal IOL optics on visual function.

Conventional visual acuity, assessed by allowing the patient sufficient time to observe each optotype and encouraging guessing, could differ from real-world visual acuity. Fluent reading, for example, requires a quick recognition of words. A primary motivation for patients choosing multifocal IOLs is the desire to read without spectacles; thus, reading performance evaluation can play an important role in assessing the efficacy of the RLE procedure.[1,5,6] However, few studies analyzed reading performance in patients who have RLE. Furthermore, it remains to be determined if there is any negative effect on reading performance after a multifocal IOL implantation, when compared to the preoperative spectacle-corrected near vision.

Multiple factors, such as letter size, distance, and reading speed, must be considered when evaluating reading performance.[5] We used a computer-based testing system, the Salzburg Reading Desk (SRD Vision), which records these parameters in real time and allows for a variable testing distance. To assess the efficacy of the RLE procedure in restoring near and intermediate visual function, we evaluated visual acuity and reading performance in patients who had RLE implanted with the recently introduced Clareon PanOptix trifocal IOL (Alcon Laboratories, Inc) and compared it to the data obtained before the surgery.

PATIENTS AND METHODS

PATIENTS

We conducted a prospective interventional cohort study at a university hospital of patients who had femtosecond laser–assisted RLE bilaterally implanted with the Clareon PanOptix IOL. We included 27 patients (54 eyes) after excluding patients with clinically significant ocular comorbidities, relevant intraoperative complications, history of trauma or prior ocular surgery, elevated total higher order aberrations (root mean square exceeding 0.3 µm), irregular astigmatism, expected postoperative cylinder exceeding 0.75 diopters (D), uncooperative behavior, and those younger than 18 years. We calculated the sample size to determine the mean monocular corrected distance visual acuity (CDVA) with an accuracy of 0.02 logMAR using a two-sided 95% confidence interval, assuming a standard deviation (SD) of 0.072 logarithm of the minimum angle of resolution (logMAR).[7] We increased the required sample size from 25 to 27 patients to allow for expected drop-outs. We adhered to the tenets of the Declaration of Helsinki, and all participants provided a written informed consent. The Ethics Committee of the Medical Faculty of the University of Heidelberg approved the study and it was registered at the German Clinical Trials Register (Deutsches Register Klinischer Studien; reference number: DRKS00011251).

The IOL power was calculated with the Barrett Universal II formula using the optical biometer IOLMaster 700 (Carl Zeiss Meditec). We chose a toric version of the IOL if the Alcon toric online calculator (https://www.myalcon-toriccalc.com) indicated a lower predicted postoperative cylinder with a toric IOL. The RLE surgery was performed with the assistance of the LenSx femtosecond laser (Alcon Laboratories, Inc) to create capsulotomy and lens fragmentation. We used a digital marking system, the Zeiss Callisto (Carl Zeiss Meditec), for toric IOL alignment and to position the main incision at the steepest axis of the cornea in the case of non-toric IOLs.

IOL

The Clareon PanOptix is a hydrophobic acrylic diffractive trifocal IOL.[8] Although its optical design is based on the predecessor AcrySof IQ PanOptix lens, the Clareon PanOptix IOL is made of the manufacturer's newer Clareon material that minimizes glistening formation.[9] The diffractive structures are found in the central zone of 4.5 mm, directing 50% of the available light energy to the far focus, with the rest equally distributed between the near and intermediate foci.[8] The intermediate focus of the IOL is optimized for the 60-cm distance, whereas the near focus is designed for 40 cm.[8]

VISUAL ACUITY ASSESSMENT

Visual acuity was examined preoperatively and 6 months after the surgery. We tested at a 4-m distance

the uncorrected distance visual acuity (UDVA), manifest refraction, and CDVA. The uncorrected intermediate visual acuity (UIVA) and distance-corrected intermediate visual acuity (DCIVA) were tested at 60 cm. In addition, uncorrected near visual acuity (UNVA) and distance-corrected near visual acuity (DCNVA) were tested at both 40 and 33 cm. Preoperative examination also included corrected near visual acuity (CNVA) at 40 cm with the near addition in place. Visual acuity testing was performed in photopic conditions (approximately 85 cd/m^2), using the Early Treatment Diabetic Retinopathy Study (ETDRS) charts. The visual acuity values were recorded in logMAR notation.

Reading Performance Evaluation

The reading performance was assessed using the Salzburg Reading Desk, which has been used in previous studies to assess the reading performance of patients implanted with multifocal IOLs.[5,10] The Salzburg Reading Desk is a computer-based testing system consisting of a tablet screen, a laptop computer, two cameras, and a microphone. The tablet screen displayed logarithmically scaled Colenbrander sentences in German, the microphone recorded the voice to determine automatically the reading time, and the cameras enabled the measurement of reading distance in real time. The examiner then indicated any words which had been missed or read incorrectly, and the reading speed was calculated. The reading acuity was presented in logMAR values. All measurements were performed with the contrast and luminance set to 100%.

The reading performance was assessed preoperatively and 6 months postoperatively, monocularly and binocularly, both with and without distance correction, at 40 cm, 60 cm, and preferred near and intermediate distances. We also determined the preoperative reading performance with the near correction in place at 40 cm and at the preferred near distance.

Patient-Reported Outcomes

At the postoperative 6-month visit, visual disturbances were evaluated in an unprompted way asking the patients if they had any problems with their vision. Furthermore, the photic phenomena perception was evaluated using the software-based Halo & Glare Simulator (Eyeland Design Network GmbH). The patients could select between three types of halos (classic, starburst, or irregular) and two types of glare (classic or asymmetric). Patients could then adjust the size and intensity of halo and glare using the simulator's controls to create an image matching their subjective impression of a street at night. Each parameter could have values ranging from 0 to 100. In addition, the patients were asked to complete the Catquest-9SF questionnaire in German.[11]

Data Analysis

We used IBM SPSS Statistics Version 28 (IBM Corporation) and Microsoft Excel 365 (Microsoft Corporation) for data analysis. The testing for normality was performed using the Shapiro-Wilk test and confirmed by graphical analysis. We used the Wilcoxon test for paired samples for an explorative analysis comparing all preoperative and postoperative visual acuity and reading acuity data. We also compared the postoperative binocular UNVA and DCNVA with the preoperative binocular CNVA, as well as the postoperative binocular uncorrected and distance-corrected near reading acuity with the preoperative binocular corrected near reading acuity with near addition in place (all tested at 40-cm distance). One randomly selected eye per patient was used in monocular comparisons. The significance level of a P value less than .05 was used. We report the values of all quantitative parameters as mean ± SD.

RESULTS

The study included 11 women and 16 men, with a mean ± SD age of 55.2 ± 4.9 years. Toric IOLs were implanted in 13 eyes (24.1%). No one had to be excluded due to intraoperative complications and we recorded no adverse events at the 6-month follow-up visit. In the early postoperative period, 1 patient had a moderate dry eye and 2 patients required a short use of an intraocular pressure–lowering medication. At 6 months after the surgery, we observed no IOL glistening.

Visual Acuity and Refractive Outcomes

The mean ± SD preoperative manifest refraction spherical equivalent was +0.30 ± 2.50 diopters (D) (8 eyes with myopia of greater than -0.25 D, 9 eyes within ±0.25 D, 37 eyes with hyperopia of greater than +0.25 D), and the refractive cylinder was 0.50 ± 0.41 D. Postoperatively, they were +0.03 ± 0.32 and 0.27 ± 0.23 D, respectively. The targeted spherical equivalent using the Barrett Universal II formula was -0.21 ± 0.18 D. The visual acuity and refractive outcomes are presented in **Table 1** and **Figure A**. The surgery improved uncorrected and distance-corrected visual acuities, except for CDVA which remained similar (safety index of 1.04 ± 0.20). The efficacy index for distance vision was 0.84 ± 0.21. No secondary procedures to correct residual refractive error were performed.

The binocular UNVA at 40 cm improved from preoperative 0.67 ± 0.28 logMAR to postoperative 0.03 ±

TABLE 1

Preoperative and Postoperative Visual Acuity (Mean ± SD)

Visual Acuity (Testing Distance)	Preoperative, Monocular (logMAR)	Preoperative, Binocular (logMAR)	6 Months Postoperatively, Monocular (logMAR)	6 Months Postoperatively, Binocular (logMAR)	*P* (Preoperative vs Postoperative, Two-sided
UDVA (4 m)	0.42 ± 0.31[a]	0.30 ± 0.28[a]	0.03 ± 0.09	-0.04 ± 0.07	< .001[b,c]
CDVA (4 m)	-0.06 ± 0.08	-0.12 ± 0.08	-0.07 ± 0.06	-0.12 ± 0.05	.313[b]; .720[c]
UIVA (60 cm)	0.67 ± 0.27	0.54 ± 0.25	-0.03 ± 0.07	-0.08 ± 0.06	< .001[b,c]
DCIVA (60 cm)	0.33 ± 0.18	0.25 ± 0.19	-0.06 ± 0.07	-0.10 ± 0.06	< .001[b,c]
UNVA (40 cm)	0.75 ± 0.24	0.67 ± 0.28	0.09 ± 0.08	0.03 ± 0.08	< .001[b,c]
DCNVA (40 cm)	0.55 ± 0.18	0.44 ± 0.18	0.04 ± 0.07	-0.01 ± 0.05	< .001[b,c]
CNVA (40 cm)	-0.04 ± 0.06	-0.08 ± 0.05	N/A	N/A	N/A
UNVA (33 cm)	0.78 ± 0.24	0.70 ± 0.22	0.19 ± 0.09	0.13 ± 0.09	< .001[b,c]
DCNVA (33 cm)	0.60 ± 0.16	0.50 ± 0.17	0.15 ± 0.07	0.10 ± 0.07	< .001[b,c]

CDVA = corrected distance visual acuity; CI = confidence interval; CNVA = corrected near visual acuity; DCIVA = distance-corrected intermediate visual acuity; DCNVA = distance-corrected near visual acuity; N/A = not available; SD = standard deviation; UDVA = uncorrected distance visual acuity; UIVA = uncorrected intermediate visual acuity; UNVA = uncorrected near visual acuity

[a]Data from 26 patients (one patient had a preoperative UDVA worse than 1.3 logMAR, which was the first line on the chart.

[b]Monocular visual acuity.

[c]Binocular visual acuity.

0.08 logMAR ($P < .001$), and the binocular UIVA improved from 0.54 ± 0.25 to -0.08 ± 0.06 logMAR ($P < .001$). The preoperative binocular CNVA at 40 cm (-0.08 ± 0.05 logMAR) was slightly better than the postoperative binocular UNVA (0.03 ± 0.08 logMAR, $P < .001$) and DCNVA (-0.01 ± 0.05, $P < .001$) at 40 cm. The efficacy index for the near vision at 40 cm (postoperative monocular UNVA vs preoperative monocular CNVA) was 0.75 ± 0.12.

Reading Performance

Tables 2-3 summarize the results of the reading performance evaluation. Uncorrected reading acuity improved at all tested distances 6 months after the surgery, compared to preoperative values. Mean ± SD binocular uncorrected reading acuity at 40 cm was 0.53 ± 0.22 logMAR before and 0.05 ± 0.08 logMAR after the surgery. At 60 cm, it was 0.53 ± 0.22 logMAR before and 0.09 ± 0.10 logMAR after the surgery. The results at the preferred near and intermediate distances were similar to those at the set distances.

The preoperative binocular reading acuity at 40 cm with near correction in place (0.04 ± 0.10 logMAR) did not differ statistically significantly from the postoperative binocular uncorrected (0.05 ± 0.08 logMAR, $P = .495$) and distance-corrected (0.03 ± 0.09 logMAR, $P = .767$) reading acuity at 40 cm. The efficacy index for near reading acuity at 40 cm (postoperative monocular uncorrected vs preoperative monocular corrected reading acuity) was 0.99 ± 0.35.

Figures 1-2 present the cumulative visual acuity and reading acuity at near and intermediate distances.

Patient-Reported Outcomes

The classic halo type was chosen by 66.7% of the patients (n = 18), the starburst halo type was chosen by 11.1% (n = 3), and 22.2% of patients (n = 6) reported no halo. The mean ± SD halo size was 32.2 ± 24.6, and the intensity was 36.2 ± 25.7. Small (0 to 33), moderate (34 to 66), and large (67 to 100) halo size was reported by 51.9% (n = 14), 40.7% (n = 11), and 7.4% (n = 2) of patients, respectively. Low (0 to 33), moderate (34 to 66), and high (67 to 100) halo intensity was reported by 33.3% (n = 9), 55.6% (n = 15), and 11.1% (n = 3) of patients, respectively. Only 14.8% of patients (n = 4) reported glare, which was the classic type. The mean ± SD glare size was 3.9 ± 10.7, and the intensity was 4.4 ± 11.4. Moderate glare (34 to 66) was selected by one patient (3.7%), whereas the rest (n = 26, 96.3%) reported no glare or small glare size (0 to 33). Two patients (7.4%) reported moderate glare intensity (34 to 66), whereas all other patients (n = 25, 92.6%) reported no glare or low glare intensity (0 to 3). **Figure 3** presents the mean halo and glare values. No patients complained of bothersome photic phenomena when asked if they had any problems with their vision. In the Catquest-9SF questionnaire, 76.9% (n = 20) of patients indicated they were very satisfied with their vision and 69.2% (n = 18) reported their sight caused no difficulty in their everyday life (**Table A**; questionnaire data available from 26 patients). Most patients had no difficulty reading text in newspapers (84.6%, n = 22), recognizing faces (96.2%, n = 25), seeing prices of goods when shopping (88.5%, n = 23), seeing to walk on uneven surfaces (92.3%, n = 24),

TABLE 2

Preoperative and Postoperative Reading Performance Without Spectacle Correction (Mean ± SD)

Variable	Reading Acuity (logMAR)			Reading Speed (Words per Minute)		Reading Time (s)		Average Distance (cm)	
	Preoperative	Postoperative	*P*[a]	Preoperative	Postoperative	Preoperative	Postoperative	Preoperative	Postoperative
Monocular, uncorrected									
Near (40 cm)	0.63 ± 0.22 (n = 32)	0.14 ± 0.11 (n = 54)	< .001	128 ± 34	120 ± 32	8.0 ± 2.3	8.4 ± 2.0	40.2 ± 1.2	39.0 ± 2.2
Near (preferred)	0.61 ± 0.21 (n = 34)	0.14 ± 0.11 (n = 54)	< .001	118 ± 23	124 ± 36	8.3 ± 1.8	8.2 ± 2.1	40.1 ± 2.8	38.3 ± 2.9
Intermediate (60 cm)	0.61 ± 0.21 (n = 39)	0.19 ± 0.13 (n = 53)	< .001	108 ± 30	116 ± 23	9.0 ± 2.7	8.3 ± 1.6	60.3 ± 2.1	58.8 ± 3.0
Intermediate (preferred)	0.59 ± 0.22 (n = 40)	0.17 ± 0.12 (n = 53)	< .001	109 ± 33	116 ± 31	9.0 ± 2.5	8.7 ± 2.8	59.7 ± 2.8	57.3 ± 5.1
Binocular, uncorrected									
Near (40 cm)	0.53 ± 0.22 (n = 19)	0.05 ± 0.08 (n = 27)	< .001	132 ± 37	132 ± 35	7.8 ± 2.3	7.8 ± 2.0	40.4 ± 1.2	39.4 ± 1.5
Near (preferred)	0.53 ± 0.22 (n = 19)	0.05 ± 0.09 (n = 27)	< .001	125 ± 41	122 ± 32	8.0 ± 1.8	8.4 ± 2.2	40.0 ± 3.1	38.8 ± 2.5
Intermediate (60 cm)	0.53 ± 0.22 (n = 22)	0.09 ± 0.10 (n = 27)	< .001	112 ± 29	120 ± 31	8.6 ± 1.8	8.3 ± 2.0	60.3 ± 2.0	59.3 ± 2.0
Intermediate (preferred)	0.52 ± 0.24 (n = 22)	0.07 ± 0.10 (n = 27)	< .001	120 ± 34	129 ± 31	8.5 ± 2.0	7.8 ± 1.9	59.9 ± 3.7	57.6 ± 4.1

SD = standard deviation
[a]*Preoperative vs postoperative reading acuity, two-sided P value.*

doing handicrafts (76.9%, n = 20), reading subtitles (76.9%, n = 20), and engaging in hobbies (84.6%, n = 22).

DISCUSSION

The aim of the RLE procedure in presbyopic patients usually is to restore uncorrected near and intermediate vision while at the same time improving or maintaining good uncorrected distance vision. For this purpose, trifocal IOLs are usually selected because they can provide good uncorrected vision at near, intermediate, and far distances with high rates of patient-reported spectacle independence.[1,12,13] In a retrospective study, Fernández et al[12] presented outcomes after implanting the AT LISA tri 839MP IOL (Carl Zeiss Meditec) and reported the mean ± SD binocular uncorrected visual acuity of 0.08 ± 0.05 logMAR at near and 0.07 ± 0.06 logMAR at intermediate distances. A retrospective study by Fernández-García et al[13] evaluated the results after implantation of the FineVision IOL (PhysIOL) and found a mean UNVA of 0.04 ± 0.05 logMAR and UIVA of 0.22 ± 0.06 logMAR in patients who had binocular implantation. Our patients had a similar or slightly better mean UNVA, whereas the mean UIVA was two to three lines better, which could be due to differences in light distribution and the location of the intermediate focus.[14-16] It should be noted, however, that inter-study comparisons are limited by varying testing conditions and patient characteristics, and therefore any differences in results may not be solely due to differences between IOL models. In another retrospective study, Wallerstein et al[17] found a mean binocular UNVA of 0.00 ± 0.13 logMAR and UIVA of 0.01 ± 0.15 logMAR in patients who had RLE with AcrySof IQ PanOptix Toric IOL implantation. Although our results were generally comparable, we observed slightly better outcomes at intermediate distance. In a previous prospective study, we evaluated the outcomes after implantation of the TECNIS Synergy IOL (Johnson & Johnson Vision) and observed similar visual acuity values to the current study.[1] The RLE procedure with the TECNIS Synergy IOL improved uncorrected near and intermediate vision, but in that investigation we did not

TABLE 3

Preoperative and Postoperative Reading Performance With Spectacle Correction (Mean ± SD)

	Reading Acuity (logMAR)			Reading Speed (Words per Minute)		Reading Time (Seconds)		Average Distance (cm)	
Variable	**Preoperative**	**Postoperative**	***P*[a]**	**Preoperative**	**Postoperative**	**Preoperative**	**Postoperative**	**Preoperative**	**Postoperative**
Monocular, distance correction									
Near (40 cm)	0.44 ± 0.16 (n = 53)	0.11 ± 0.10 (n = 54)	< .001	113 ± 24	120 ± 27	8.8 ± 1.8	8.3 ± 1.9	40.3 ± 1.1	39.6 ± 1.4
Near (preferred)	0.42 ± 0.16 (n = 54)	0.11 ± 0.10 (n = 54)	< .001	118 ± 30	124 ± 35	8.5 ± 1.8	8.3 ± 1.8	40.1 ± 3.1	38.4 ± 3.0
Intermediate (60 cm)	0.29 ± 0.17 (n = 54)	0.21 ± 0.14 (n = 53)	.071	111 ± 27	113 ± 31	8.8 ± 1.7	8.6 ± 1.9	60.0 ± 2.5	59.7 ± 1.6
Intermediate (preferred)	0.28 ± 0.14 (n = 54)	0.18 ± 0.12 (n = 54)	.007	118 ± 25	119 ± 28	8.4 ± 1.7	8.5 ± 2.1	58.9 ± 5.0	57.9 ± 2.7
Binocular, distance correction									
Near (40 cm)	0.34 ± 0.15 (n = 27)	0.03 ± 0.09 (n = 26)	< .001	112 ± 25	128 ± 27	8.8 ± 1.7	7.7 ± 1.4	40.2 ± 1.3	39.7 ± 1.5
Near (preferred)	0.33 ± 0.15 (n = 27)	0.04 ± 0.07 (n = 27)	< .001	116 ± 22	138 ± 30	8.5 ± 1.7	7.1 ± 1.6	40.7 ± 3.8	39.3 ± 3.4
Intermediate (60 cm)	0.18 ± 0.11 (n = 27)	0.10 ± 0.10 (n = 27)	.005	119 ± 38	128 ± 38	8.3 ± 1.9	7.9 ± 1.9	59.9 ± 2.3	59.4 ± 1.6
Intermediate (preferred)	0.18 ± 0.10 (n = 27)	0.09 ± 0.10 (n = 27)	.012	120 ± 31	125 ± 35	8.4 ± 2.0	8.2 ± 2.0	58.7 ± 3.0	57.1 ± 4.1
Monocular, near correction									
Near (40 cm)	0.11 ± 0.14 (n = 54)	N/A	N/A	116 ± 29	N/A	8.6 ± 2.0	N/A	39.6 ± 1.7	N/A
Near (preferred)	0.09 ± 0.14 (n = 54)	N/A	N/A	120 ± 30	N/A	8.5 ± 2.1	N/A	37.9 ± 2.8	N/A
Binocular, near correction									
Near (40 cm)	0.04 ± 0.10 (n = 27)	N/A	N/A	117 ± 19	N/A	8.4 ± 1.5	N/A	39.2 ± 2.3	N/A
Near (preferred)	0.02 ± 0.11 (n = 27)	N/A	N/A	122 ± 32	N/A	8.5 ± 2.0	N/A	38.0 ± 3.0	N/A

N/A = not available; SD = standard deviation

[a]*Preoperative vs postoperative reading acuity, two-sided* P *value.*

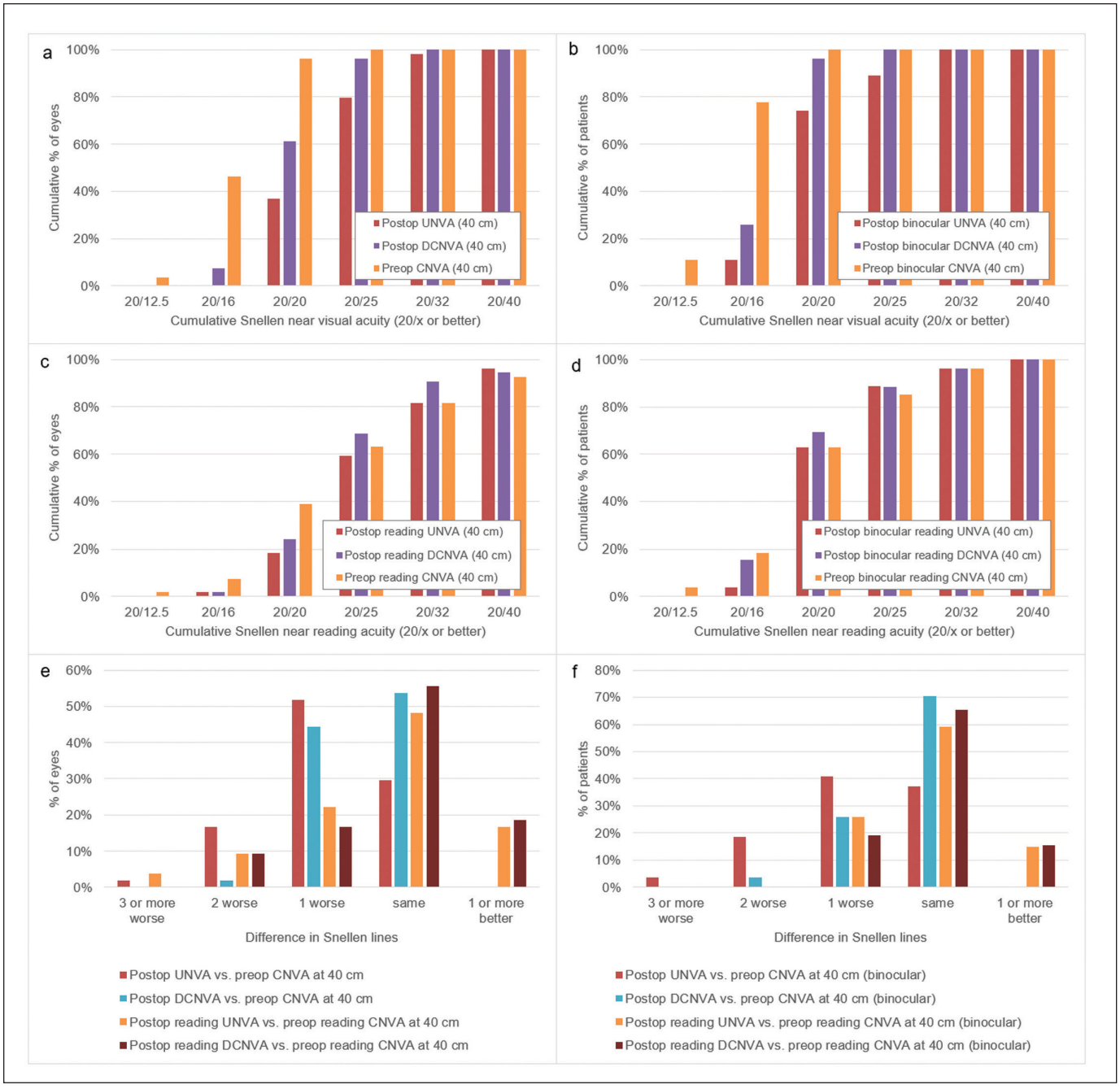

Figure 1. Postoperative uncorrected and distance-corrected near vision in comparison to preoperative near vision with spectacle correction for the near. (A) Monocular and (B) binocular cumulative near visual acuity; (C) monocular and (D) binocular cumulative near reading acuity; (E) monocular and (F) binocular Snellen line difference of postoperative uncorrected and distance-corrected near vision in comparison to preoperative corrected near vision. CDVA = corrected distance visual acuity; CNVA = corrected near visual acuity; DCNVA = distance-corrected near visual acuity; UDVA = uncorrected distance visual acuity

compare the postoperative outcomes with the preoperative CNVA.[1]

Unfortunately, the data on RLE outcomes after implantation of trifocal IOLs comes mostly from retrospective studies, limited by the non-standardized visual acuity testing performed in a routine clinical setting. For example, the mean preoperative CDVA in the above-mentioned retrospective studies ranged from 0.01 to 0.00 logMAR, but in no patient was it better than 0.00 logMAR.[12,13,17] Because all of these patients had clear lenses, one would expect to observe negative logMAR values in at least some patients. Most

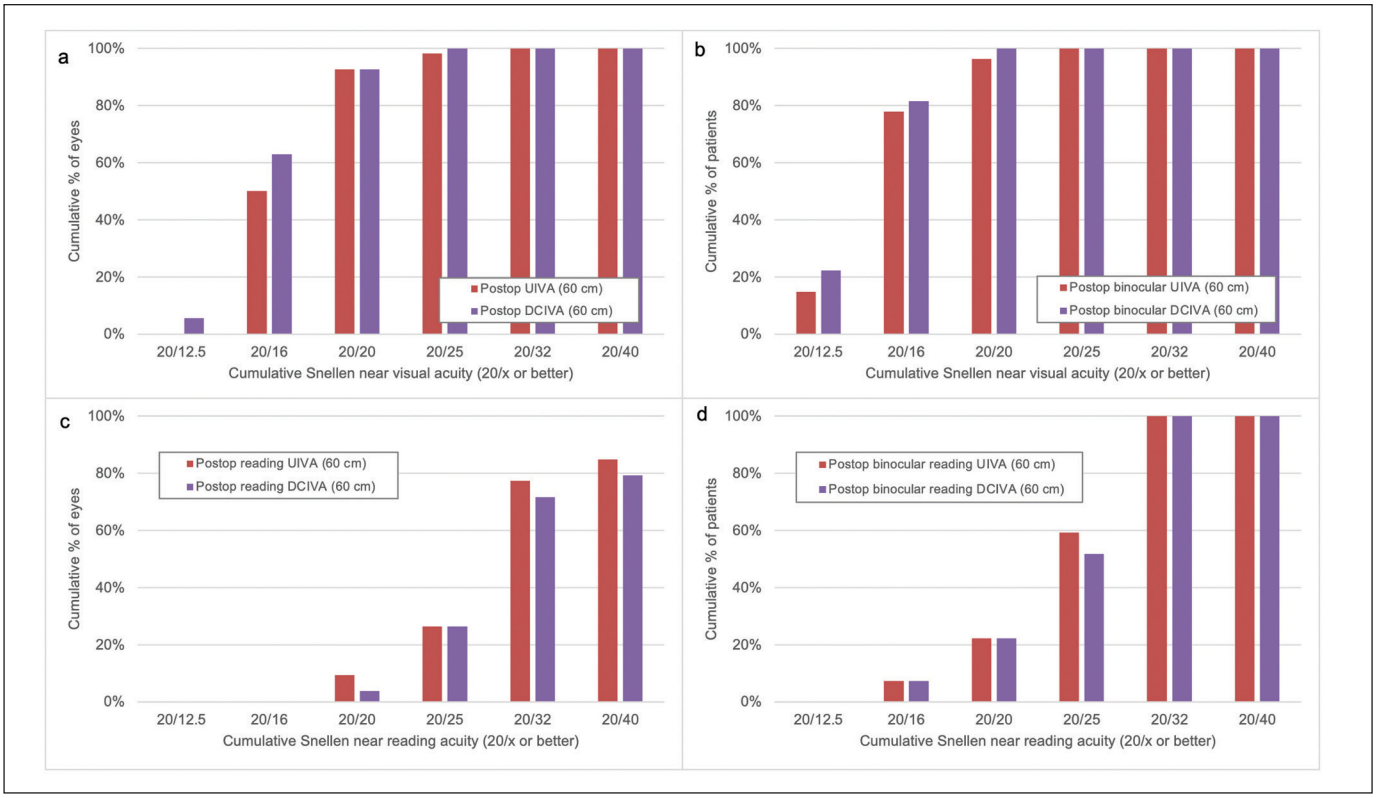

Figure 2. Postoperative uncorrected and distance-corrected intermediate vision. (A) Monocular and (B) binocular cumulative intermediate visual acuity; (C) monocular and (D) binocular cumulative intermediate reading acuity. DCIVA = distance-corrected intermediate visual acuity; UIVA = uncorrected intermediate visual acuity

Figure 3. Simulation of photic phenomena perception using the Halo & Glare Simulator (Eyeland Design Network GmbH). The image represents the mean halo and glare values selected by patients.

likely, the visual acuity was not tested beyond 20/20, which may not be critical in a routine clinical setting, but it distorts the safety and efficacy evaluation. If that is the case, one may considerably underestimate vi-

sual acuity, making the comparison of preoperative and postoperative data unreliable and potentially this would lead to a failure to identify patients losing lines of CDVA. This highlights the need of high-quality prospective studies on patients undergoing RLE.

Standard visual acuity testing may not fully represent the near and intermediate visual function. One could argue that carefully observing and separately guessing each letter of the visual acuity chart differs from a real-world situation, where patients need to recognize written words at a glance. Although reading performance evaluation is not a substitute for the conventional visual acuity testing, the assessment of reading performance under standardized conditions, in addition to the conventional visual acuity testing, allows a more comprehensive assessment of near and intermediate visual function. The Salzburg Reading Desk allows a highly repeatable and comprehensive reading performance evaluation and has been used in pseudophakic patients before.[5,18]

Rasp et al[18] compared reading performance after cataract surgery and the implantation of diffractive bifocal versus segmental refractive bifocal versus monofocal lenses. They found the diffractive bifocal models to provide superior reading performance compared to the monofocal and the segmental refractive bifocal IOLs.[18]

Attia et al[10] evaluated reading performance after cataract surgery and the diffractive trifocal FineVision IOL implantation. The median binocular uncorrected reading acuity was 0.11 logMAR at a distance of 40 cm, and 0.10 logMAR at both 60 and 80 cm.[10] With distance correction in place, the 40-cm binocular reading acuity improved to 0.01 logMAR.[10] The study demonstrated the ability of a trifocal IOL to provide functional near and intermediate vision, but the study was limited by a small sample size of 11 patients.[10] Furthermore, the preoperative reading performance was not assessed as those were patients with cataract.[10] In our results, we found slightly better uncorrected near reading acuity and slightly higher reading speed, which could be due to differences in implanted IOL models and a younger patient population in our patients with RLE.[10]

Baur et al[5] assessed reading performance in patients who had RLE implanted with the TECNIS Synergy IOL and found similar near and intermediate reading acuities to the ones we observed and report here. The authors reported a considerable improvement in uncorrected intermediate and near reading functions after the RLE procedure.[5] However, it remained to be seen how the postoperative uncorrected and distance-corrected reading performance compared to the preoperative reading performance with spectacle correction, because the latter one was not tested.[5]

In a real-world setting, presbyopic patients typically read with spectacles before the surgery and read without them after the surgery.[1] RLE is a refractive procedure, and to evaluate the efficacy of presbyopia correction in the same manner as it is done for evaluating the effectiveness of distance vision correction in refractive surgery, one should compare the corrected near vision before the surgery with the uncorrected near vision after the surgery.[19] In the current study, we observed that the postoperative UNVA and DCNVA were slightly worse than the preoperative CNVA. Interestingly, we did not observe the same effect when evaluating the reading acuity, where the postoperative uncorrected and distance-corrected near reading acuities were similar to the preoperative near reading acuity with near correction in place. Although the reason for this discrepancy remains unknown, a possible explanation could be the existence of other factors apart from optical quality, limiting the smallest readable text size. The other possible reason could be differences in testing conditions. Despite all testing being performed in photopic high-contrast conditions, visual acuity testing was done using printed ETDRS charts and reading performance was evaluated using texts shown on a screen. Discrepancy between visual acuity and reading acuity outcomes underlines the importance of complementing the conventional visual acuity testing with a reading performance evaluation. In general, reading acuity, which requires a quick recognition of words, tended to be lower than the conventionally measured visual acuity both before and after the surgery. Our results suggest that the RLE surgery with the implantation of the diffractive trifocal Clareon PanOptix IOL improved the uncorrected near reading performance to the level of the preoperative performance with spectacle correction for the near, indicating a high efficacy in restoring functional near vision. An unchanged CDVA further highlights the high safety of the RLE procedure in most patients and that in our study no patient lost two or more Snellen lines of CDVA.

The advantage of diffractive multifocal IOLs to provide uncorrected vision at a range of distances comes at the cost of increased dysphotopsia (ie, halo and glare).[2] The perception of these photic phenomena can be quantified using the Halo & Glare Simulator, as done in our study. Baur et al[5] presented the halo and glare simulation results in patients implanted with the TECNIS Synergy IOL. They reported higher mean values of the perceived halo and glare than we found in our study. It should be noted, however, that the per-

ception of photic phenomena varies considerably between individuals, as indicated by the relatively high SD values we report. It is not possible currently to predict the exact level of halo and glare a patient will perceive. Therefore, during the preoperative counseling, each patient has to be informed about the possibility of bothersome postoperative photic phenomena. Most patients tolerate these phenomena well, but the clinician should be cautious with patients who commonly perform visually demanding tasks at low light conditions such as driving long distances at night.[20] Another concern with multifocal diffractive IOLs is the possibility of reduced mesopic contrast sensitivity, although recent studies found it within normal range with modern multifocal diffractive models.[1,21,22] Patient satisfaction after multifocal IOL implantation also depends on personality traits as a study by Rudalevicius et al[23] demonstrated: patients with neuroticism as the dominant personality trait were least satisfied with the postoperative outcome, whereas those with agreeableness and conscientiousness had the highest satisfaction.

A strength of our study is that it included patients who had RLE only, enabling the assessment of the impact on patients' vision of the multifocal IOL implantation. In addition, we evaluated reading performance, which can differ from conventionally-assessed visual acuity. Furthermore, we analyzed the efficacy of near function restoration by comparing the postoperative uncorrected near vision with the preoperative spectacle-corrected near vision: this is of clinical relevance, because patients perceive and invariably compare their postoperative vision to the preoperative one. Finally, the prospective design of the study and standardized visual acuity assessment prevents distortion of the efficacy and safety analysis, which is often the case in retrospective studies.[24] A limitation of our study is that we assessed visual acuity and reading performance at high luminance and contrast only, which does not reflect some of the reading needs of patients, and do not include contrast sensitivity results. This was done to limit the already long duration of the study visit and prevent patient fatigue, which could potentially introduce bias. It needs to be emphasized that the findings of our study only apply to reading high-contrast well-lit texts, such as when using a reading light or reading from a computer screen. The reading performance in a low light setting may be worse, such as when reading a restaurant menu in a dim light. In addition to testing at lower levels of luminance and contrast, future studies could also include a preoperative corrected intermediate vision assessment for a more complete efficacy evaluation of intermediate vision.

CONCLUSION

The RLE surgery with a multifocal IOL implantation was effective in restoring uncorrected near and intermediate visual function. Although the postoperative UNVA was slightly worse than the preoperative spectacle-corrected near vision when assessed conventionally, this did not translate into a worse reading performance. At high luminance and contrast levels, the patients who have RLE are likely to achieve an uncorrected near visual function similar to the preoperative one with the spectacle correction for the near.

AUTHOR CONTRIBUTIONS

Study concept and design (RK); data collection (TN, OH, NH, ER, LC); analysis and interpretation of data (TN, GUA, IDB, GŁ, RK); writing the manuscript (TN); critical revision of the manuscript (GUA, IDB, OH, NH, ER, LC, GŁ, RK); statistical expertise (TN); supervision (GUA, RK)

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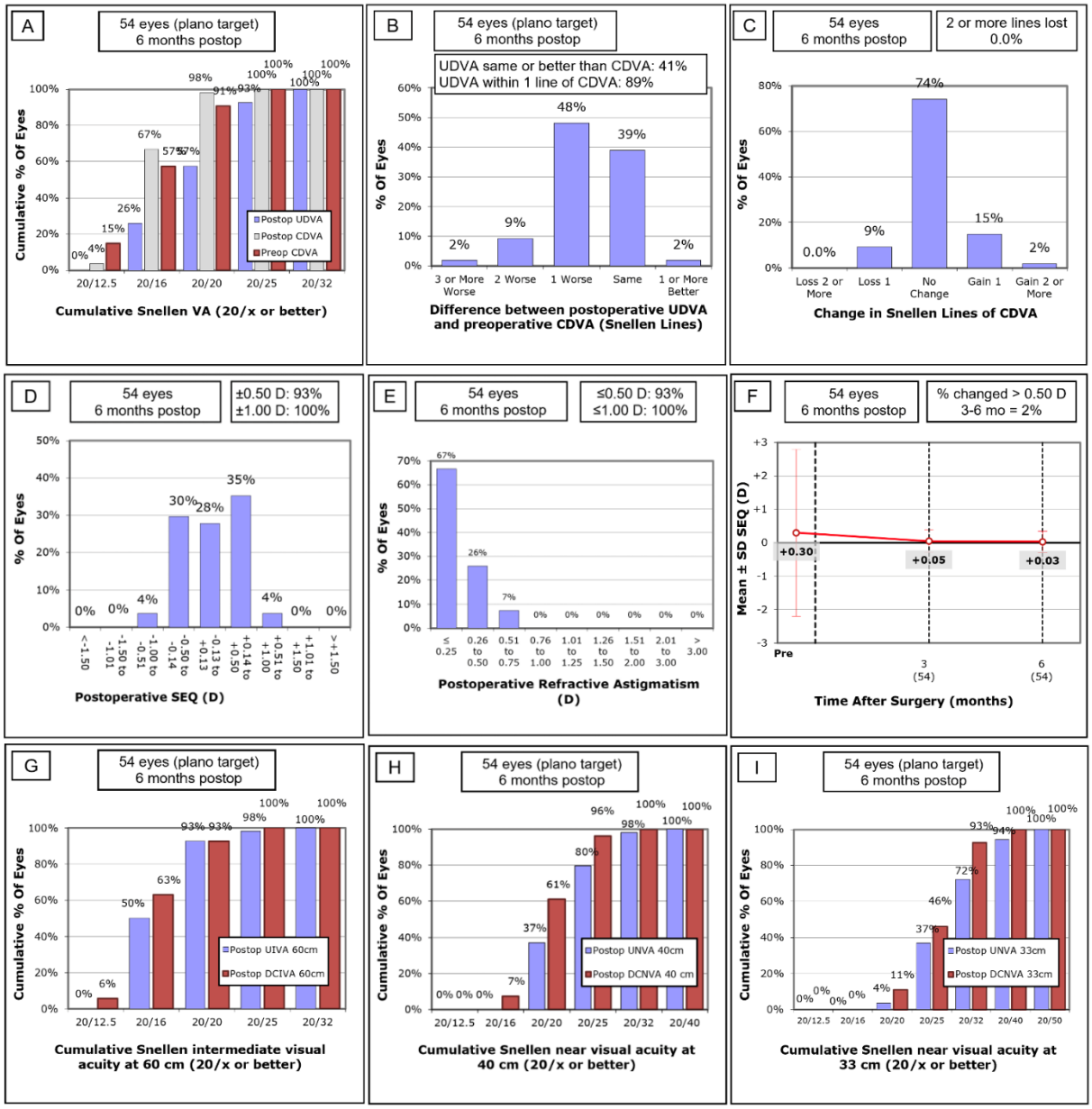

Figure A. (A) Cumulative preoperative corrected distance visual acuity (CDVA), postoperative uncorrected distance visual acuity (UDVA) and postoperative CDVA. (B) Difference between postoperative UDVA and CDVA. (C) Change in Snellen lines of CDVA. Distribution of (D) postoperative manifest refraction spherical equivalent and (E) postoperative refractive astigmatism. (F) Stability of manifest refraction spherical equivalent. Cumulative postoperative (G) uncorrected (UIVA) and distance-corrected (DCIVA) intermediate visual acuities and uncorrected (UNVA) and distance-corrected (DCNVA) near visual acuities at (H) 40 cm and (i) 33 cm.

Table A
Results of the Catquest-9SF questionnaire (the German version of the questionnaire used). Data from 26 patients

A. Do you find that your sight at present in some way causes you difficulty in your everyday life?					
	No difficulty	**Some difficulty**	**Great difficulty**	**Very great difficulty**	**Cannot decide**
	69.2% (n=18)	26.9% (n=7)	3.8% (n=1)	0% (n=0)	0% (n=0)
B. Are you satisfied or dissatisfied with your sight at present?					
	Very satisfied	**Fairly satisfied**	**Fairly dissatisfied**	**Very dissatisfied**	**Cannot decide**
	76.9% (n=20)	19.2% (n=5)	3.8% (n=1)	0% (n=0)	0% (n=0)
C. Do you have difficulty with the following activities because of your sight?					
	No difficulty	**Some difficulty**	**Great difficulty**	**Very great difficulty**	**Cannot decide**
Reading text in newspapers	84.6% (n=22)	11.5% (n=3)	3.8% (n=1)	0% (n=0)	0% (n=0)
Recognizing the faces of people you meet	96.2% (n=25)	3.8% (n=1)	0% (n=0)	0% (n=0)	0% (n=0)
Seeing the prices of goods when shopping	88.5% (n=23)	11.5% (n=3)	0% (n=0)	0% (n=0)	0% (n=0)
Seeing to walk on uneven surfaces, e.g. cobblestones	92.3% (n=24)	3.8% (n=1)	0% (n=0)	0% (n=0)	3.8% (n=1)
Seeing to do handicrafts, woodwork etc.	76.9% (n=20)	19.2% (n=5)	3.8% (n=1)	0% (n=0)	0% (n=0)
Reading subtitles on TV	76.9% (n=20)	19.2% (n=5)	3.8% (n=1)	0% (n=0)	0% (n=0)
Seeing to engage in an activity/hobby that you are interested in	84.6% (n=22)	11.5% (n=3)	0% (n=0)	0% (n=0)	3.8% (n=1)