Clinical Evaluation of Reading Performance Using the Salzburg Reading Desk With a Refractive Rotational Asymmetric Multifocal Intraocular Lens

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ABSTRACT

PURPOSE: To evaluate functional results and reading performance using the Salzburg Reading Desk after implantation of a sector-shaped near-embedded, rotational asymmetrical multifocal intraocular lens (IOL) and a multifocal toric IOL with a +3.00 diopter (D) near addition.

METHODS: In a prospective study, the LentisMplus and Mplus toric IOLs (Oculentis GmbH, Berlin, Germany) were implanted in 34 eyes of 18 patients at the University Eye Hospital of Heidelberg. Uncorrected and corrected distance visual acuity (UDVA, CDVA) and uncorrected and corrected near visual acuity (UNVA, CNVA) were evaluated using standardized visual acuity charts (ETDRS). The Salzburg Reading Desk was used to analyze unilateral and bilateral uncorrected and corrected reading acuity, reading distance, reading speed, and the smallest log-scaled print size that could be read effectively at a set (40 cm/80 cm) and subjective chosen near and intermediate distance.

RESULTS: Postoperatively, the median UDVA was 0.08 logMAR (20/25 Snellen) and the median CDVA was 0.01 logMAR (20/20 Snellen). The median UNVA was 0.12 logMAR (20/25 Snellen) and the median CNVA was 0.03 logMAR (20/20 Snellen). The median uncorrected reading acuity measured with the Salzburg Reading Desk for near distance at 40 cm was 0.18 logMAR (20/32 Snellen). The subjectively preferred near distance was 39 cm and revealed similar visual acuity results. The best reading acuity for intermediate distance with a median of 0.22 logMAR (20/32 Snellen) was achieved at a median distance of 62 cm.

CONCLUSIONS: Reading performance of the multifocal IOL corresponded for near standardized and individual distance, whereas reading function was better at the patient's preferred intermediate distance.

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The first multifocal lenses with a diffractive or refractive optical design were implanted in the 1980s.[1,2] More recently, with further developments in multifocal IOL technology, diffractive apodized and refractive rotational asymmetric optical designs have been introduced.[3,4] Several studies have revealed an improvement of functional results for near and far vision with the different types of multifocal IOLs.[5]

However, optical side effects such as halos, glare, and decrease of contrast sensitivity, which can significantly affect visual performance and patient satisfaction, have been described. These side effects are supposed to be reduced by a later concept of multifocality: a refractive rotational asymmetric IOL design developed by Oculentis GmbH, Germany (Lentis Mplus and Lentis Mplus toric). This IOL design minimizes the loss of light below approximately 7%, which ensures a higher contrast and retinal image quality. Moreover, near vision is less dependent on the pupil size and existing light conditions.[6-8] The concept of this IOL may offer balanced vision at any distance, but particularly for near and far with a high probability of spectacle independence.[6-8]

In most clinical trials, distance and near visual acuity are measured with standardized visual acuity charts at predefined distances of 40 cm (near visual acuity) and 4 m (distance visual acuity).[9,10] The provision of multifocal lenses for raising visual performance at individual chosen reading

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distances is an important indicator of physiological reading processes, especially for patients after refractive or cataract surgery. Therefore, the Department of Ophthalmology and Optometry of the University Hospital Salzburg has developed a standardized device that allows the evaluation of the reading performance at individual preferred reading distances.[11] The objective of this study was to evaluate the functional results of a refractive rotational asymmetric multifocal IOL with a surface-embedded near section, focusing on the functional results and examination of the visual performance at near and intermediate distance with the Salzburg Reading Desk.

PATIENTS AND METHODS

Patients

This prospective clinical study comprised 34 eyes of 18 patients who had phacoemulsification and implantation of a rotationally asymmetric multifocal IOL. Two of these patients were only analyzed for monocular reading performance due to posterior opacification of the second eye. Ten patients had cataract surgery and 8 patients had refractive lens exchange for presbyopia correction. In 10 eyes the Lentis Mplus IOL was implanted, whereas the Lentis Mplus toric IOL was implanted in 24 eyes. Patients with a postoperative expected corneal astigmatism greater than 1.00 diopter (D) received the toric multifocal IOL. Patients with bilateral cataract or presbyopic patients who requested refractive lens exchange were included in this study. Exclusion criteria were any active or chronic ocular disease that might affect the visual outcome after surgery, amblyopia, and previous refractive corneal surgery. All patients were adequately informed and signed the informed consent form beforehand. The study adhered to the tenets of the Declaration of Helsinki and was approved by the local ethics committee.

IOL

The Lentis Mplus and Mplus toric IOLs are both rotationally asymmetric multifocal IOLs combining an aspheric posterior distance vision zone and a +3.00 D anterior, sector-shaped, near vision zone.[6-8] Both foldable one-piece IOLs have an overall length of 11 mm and an optic size of 6 mm. They consist of an acrylic material with a hydrophobic surface. The 360° sharp optic edges reduce the risk of posterior capsule opacification. Moreover, the haptic design provides high rotational stability. The IOLs are always implanted vertically (haptic position 90° and 270°). In the toric version, the cylinder correction is implemented individually in the right axis and further IOL rotation is not necessary.

Preoperative and Postoperative Examination

Preoperatively, all patients had a full ophthalmologic examination including manifest refraction, visual acuity, biometry (IOLMaster; Carl Zeiss Meditec, Jena, Germany) anterior segment slit-lamp examination, tonometry, and dilated fundus evaluation. Postoperative follow-up visits were scheduled 12 months after surgery at the earliest (median: 24 months; range: 12 to 36 months). Examinations included the evaluation of the postoperative refraction, uncorrected (UDVA) and corrected (CDVA) distance visual acuity at 4 m, and uncorrected (UNVA), distance corrected (DCNVA) and corrected (CNVA) near visual acuity at 40 cm. Visual acuity was measured with an Early Treatment Diabetic Retinopathy Study (ETDRS) chart under photopic conditions.

The reading performance for near and intermediate distance was measured using the Salzburg Reading Desk. This device allows a measurement of the reading acuity at near and intermediate distance in a predetermined or subjectively preferred reading position. In the current study, the Salzburg Reading Desk version "SRD RDFD 1.0" was used for testing reading performance (**Figure A**, available in the online version of this article). It consists of a reading desk with a high-resolution monitor and a laptop computer where the operating software is displayed. Two infrared video cameras continuously measure the reading distance by stereo photometry. The reading speed and time are recorded with a microphone, which is incorporated into the Salzburg Reading Desk monitor. Log-scaled Colenbrander sentences are presented on the monitor in progressively smaller print sizes. A sentence is accepted if it can be read with a minimum speed of 80 words per minute.

At the end of each reading period, the following parameters are visualized at the user's interface: reading time in seconds, reading distance in centimeters, reading speed in words per minute, reading acuity in logMAR, inclination of the reading board in degrees, and the smallest print size. The reading performance in near and intermediate distance was evaluated considering a fixed prescribed distance at 40 cm and 80 cm, in addition to freely chosen reading distances for each task. Furthermore, the smallest log-scaled print size that could be read effectively (> 80 words per minute) was assessed. All examinations were performed under standardized conditions at a standard illumination of 500 lux according to the European norm DIN EN 12464-1.

Statistical Analysis

Statistical analysis was performed using Medcalc for Windows Software (version 12.3.0.0, Medcalc Soft-

TABLE 1

Preoperative and Postoperative Visual Acuity and Refraction

Parameter	Median (Range) Lentis Mplus IOL	Median (Range) Lentis Mplus Toric IOL	P^a
Preoperative			
UDVA (logMAR)	0.71 (1.00 to 0.30)	0.60 (1.30 to 0.40)	.756
CDVA (logMAR)	0.10 (0.70 to 0.00)	0.13 (0.50 to 0.00)	.5186
Postoperative			
UDVA (logMAR)	0.06 (0.24 to -0.08)	0.09 (0.24 to -0.02)	.4487
CDVA (logMAR)	-0.05 (0.14 to -0.20)	0.02 (0.14 to -0.10)	.1384
IOL power (D)	+20.25 (+14.50 to +35.00)	+20.54 (+0.75 to +29.91)	.6776
Achieved vs target refraction (D)	+0.33 (-0.58 to +0.94)	+0.13 (-1.75 to +1.13)	.1618

IOL = intraocular lens; UDVA = uncorrected distance visual acuity; CDVA = corrected distance visual acuity; D = diopters
[a]*Mann–Whitney U test.*
The Lentis Mplus and Mplus toric lenses are manufactured by Oculentis GmbH, Berlin, Germany.

ware, Ostend, Belgium). The Kolmogorov–Smirnov test showed that not all data samples were normally distributed; thus, the median, minimum, and maximum values were calculated for every parameter. The Mann–Whitney *U* test was used to analyze differences between the two IOL groups, whereas the Wilcoxon rank-sum test was applied to analyze changes within the group. For all statistical tests the same level of significance was used ($P < .05$).

RESULTS

A total of 34 eyes from 18 patients with a median age of 57 years (range: 45 to 78 years) were included in the study. This sample included a total of 5 (27.7%) men and 13 (72.2%) women. Between the two IOL models, there were no statistically significant differences in preoperative UDVA ($P = .756$) and CDVA ($P = .518$) and postoperative UDVA ($P = .448$), CDVA ($P = .138$), power of implanted IOL ($P = .677$), and achieved versus target refraction ($P = .161$; **Table 1**). Consequently, the IOLs were treated as a single combined group for further analyses of refraction, visual acuity, and reading performance.

Refraction

A median spherical IOL with a power of +20.30 D (range: +0.75 to +35.00 D) and a median cylindrical IOL with a power of +1.91 D (range: +0.97 to +5.63 D) were implanted. The median preoperative spherical equivalent was +1.25 D (range: -17.88 to +9.00 D), target spherical equivalent was 0.00 D (range: -0.40 to 0.00 D), and achieved postoperative spherical equivalent was +0.06 D (range: -1.75 to +1.13 D). No statistically significant difference was found between achieved and target refraction (Wilcoxon rank-sum test, $P \geq .05$). Twenty-two of 34 eyes (70.6 %) were within ±0.50 D and 32 of 34 eyes (94.1%) were within ±1.00 D of the intended value.

Visual Acuity

Table A (available in the online version of this article) shows the preoperative and postoperative visual acuity results. Postoperatively, a statistically significant improvement in monocular UDVA and CDVA was observed (Wilcoxon rank-sum test, $P \leq .05$). Eighty-eight percent of the eyes achieved a UDVA and UNVA of 0.20 logMAR (20/32 Snellen) or better (**Figure 1**).

Reading Performance

Figure 2 shows monocular and binocular uncorrected and corrected reading acuity for near and intermediate distance measured with the Salzburg Reading Desk. **Table 2** and **Table B** (available in the online version of this article) summarize the postoperative reading performance concerning reading speed and smallest print size outcomes.

Reading Acuity and Distance

There were no statistically significant differences regarding monocular and binocular uncorrected near reading acuity between the predetermined (40 cm) and the subjective chosen reading distances of 39 cm ($P = .4648$). The preferred intermediate distance with medians between 61 and 64 cm markedly deviated from the fixed intermediate distance of 80 cm (**Figure 2**). The median monocular uncorrected intermediate reading acuity increased significantly ($P = .05$) from 0.30 logMAR (20/40 Snellen), tested at 80 cm, to 0.22 logMAR (20/32 Snellen) at the individually preferred

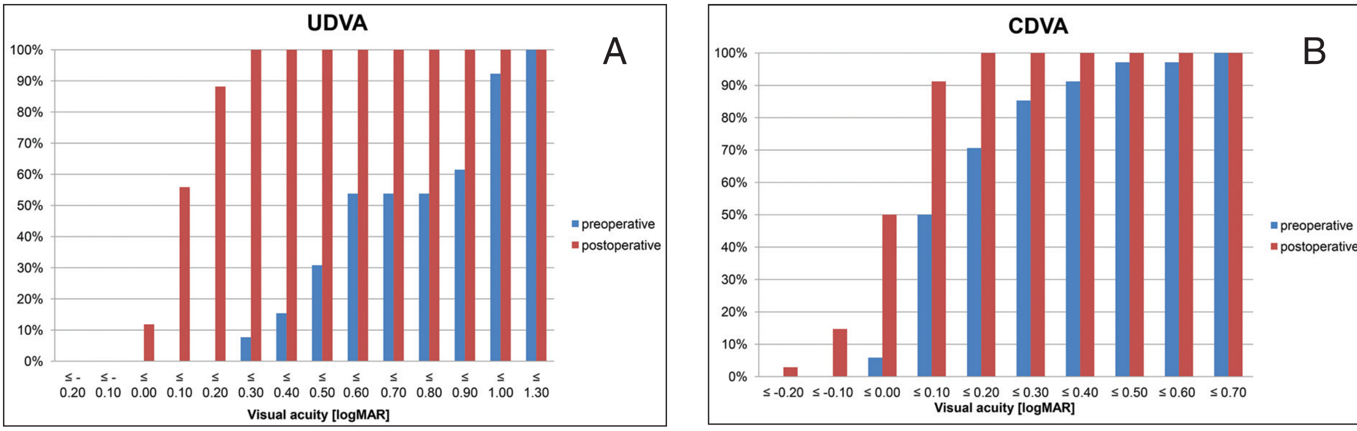

Figure 1. Preoperative versus postoperative cumulative visual acuity for near (A) uncorrected distance visual acuity (UDVA) and (B) corrected distance visual acuity (CDVA).

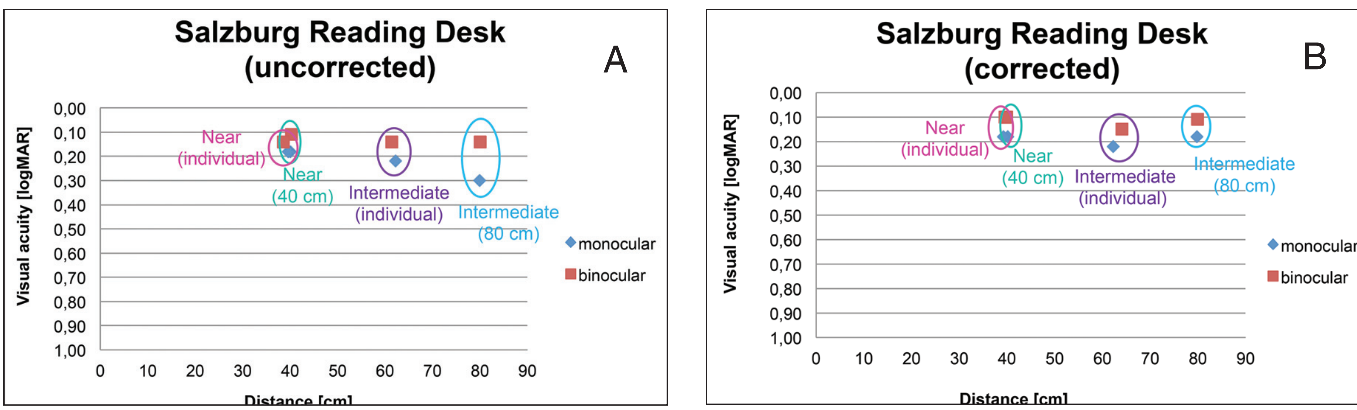

Figure 2. Postoperative results of the (A) uncorrected and (B) corrected monocular and binocular reading performance for a predefined near (40 cm) and intermediate (80 cm) distance and for individually chosen reading distance.

distance (median: 62.20 cm, range: 53.50 to 73.70 cm). For binocular intermediate reading acuity, no changes between both tested distances were observed. The corrected near and intermediate reading acuity remained stable between the fixed reading positions (40 and 80 cm, respectively) and the subjective reading positions of 39 and 62 cm.

Smallest Print Size and Reading Speed

The smallest print size for uncorrected visual acuity testing was significantly smaller at the predetermined intermediate reading distances ($P \leq .05$). **Table 2** shows that the letter size increased from the fixed intermediate distance to the preferred intermediate distance for the monocular uncorrected and corrected intermediate performance. The same applies to the results of binocular uncorrected and corrected letter size (**Table B**), whereas the reading acuity was only improved at the uncorrected subjectively chosen intermediate distance. The reading speed remained stable between the subjective reading positions and the fixed reading positions at all distances.

Discussion

In the current study, we evaluated the visual performance of the Lentis Mplus multifocal IOL, which is based on the concept of refractive rotational asymmetry, using standardized visual acuity eye charts (ETDRS, Precision Vision) and the Salzburg Reading Desk for measuring individual chosen reading distances. To our knowledge, this is the first study to compare the clinical outcomes of reading performance with the Salzburg Reading Desk after implantation of this IOL model.

The results of this clinical trial show that the outcomes of the Lentis Mplus multifocal IOL implantation after cataract surgery or refractive lens exchange are predictable, with a median spherical equivalent of +0.06 D (range: -1.75 to +1.13 D). As expected, the Lentis Mplus IOL provided a significant improvement in distance visual acuity related to the fact that the cataract was removed. The preoperative UDVA and CDVA increased from 0.60 logMAR (20/80 Snellen) and 0.10 logMAR (20/25 Snellen) to 0.08 logMAR (20/25 Snellen) and 0.01 logMAR (20/20 Snellen) postoperatively.

TABLE 2
Monocular Postoperative Reading Performance for Near and Intermediate Distance

	Median (Range)			
Parameter	Near Reading Acuity (40 cm)	Near Reading Acuity (Individual)	Intermediate Reading Acuity (80 cm)	Intermediate Reading Acuity (Individual)
Uncorrected				
Reading acuity (logMAR)	0.18 (0.47 to -0.03)	0.18 (0.47 to 0.00)	0.30 (0.40 to 0.09)	0.22 (0.41 to 0.07)
Reading distance (cm)	40.00 (37.60 to 42.80)	39.60 (28.60 to 44.50)	79.85 (75.20 to 81.90)	62.20 (53.50 to 72.70)
Reading speed (wpm)	103 (81 to 179)	100 (80 to 179)	92.50 (80 to 181)	97 (80 to 170)
Letter size	0.63 (0.32 to 1.00)	0.63 (0.32 to 1.00)	0.50 (0.40 to 0.80)	0.80 (0.5 to 1.25)
Corrected				
Reading acuity (logMAR)	0.18 (0.39 to -0.01)	0.18 (0.42 to -0.01)	0.18 (0.39 to 0.09)	0.22 (0.37 to 0.06)
Reading distance (cm)	40.20 (38.00 to 41.30)	39.20 (28.30 to 41.20)	79.80 (72.40 to 83.80)	62.45 (52.20 to 72.00)
Reading speed (wpm)	102 (80 to 176)	99 (80 to 183)	98 (80 to 152)	98.5 (80 to 226)
Letter size	0.63 (0.40 to 1.00)	0.80 (0.40 to 1.25)	0.63 (0.40 to 1.00)	0.80 (0.50 to 1.25)

wpm = words per minute

These results are consistent with findings from other studies of multifocal IOL designs and with our preliminary findings of the Lentis Mplus IOL model.[6-8,12-14] Several publications have confirmed good functional results for near vision, resulting in lower levels of spectacle dependence for near tasks.[6-8] We also observed an improvement in near visual acuity with a median UNVA of 0.12 logMAR (20/25 Snellen), which is a slightly better result compared to previous reports using the same IOL model.[15,16] However, no changes were detected in DCNVA. The CNVA outcomes improved to 0.03 logMAR (20/20 Snellen), with a median near addition power of +1.00 D. In addition, improvements of intermediate vision with a rotationally asymmetric IOL have been described in several studies.

Muñoz et al. evaluated 64 eyes of 32 patients after bilateral implantation of the Lentis Mplus IOL LS-312 MF30 IOL and found uncorrected intermediate visual acuity in decimal notation of at least 0.5 in 76% of eyes at three intermediate distances (70 cm, 1 m, and 2 m).[14] Alió et al. analyzed 135 eyes of 78 patients who received a Lentis Mplus IOL with either a C-loop haptic design or a plate-haptic design.[17] The results of the defocus curve revealed good vision for defocus values from -1.00 to -1.50 D, which corresponds with the visual function in intermediate distances.

Another prospective clinical trial compared the visual performance of the refractive rotationally asymmetric multifocal Lentis Mplus IOL and the apodized diffractive multifocal AcrySof ReSTOR SN6AD3 IOL (Alcon Laboratories, Inc., Fort Worth, TX).[16] The authors found significantly better results for intermediate vision in some levels of defocus, such as +1.00 and +1.50 D with the zonal refractive IOL. However, the diffractive multifocal IOL provided better uncorrected and distance corrected near visual outcomes, as previously reported in other publications.[18-20]

The comparison of the Lentis Mplus LS-312 MF30 with the diffractive multifocal Acri.Lisa 366D IOL (Carl Zeiss Meditec AG, Jena, Germany) also demonstrated a wider range of vision in the defocus of +1.00 to +2.00 D for the asymmetric refractive IOL design.[15] However, the UNVA and DCNVA were significantly better in the diffractive group. The comparison of different multifocal IOL designs for the same IOL type should be performed reservedly because of differences in measuring the visual acuity for near and intermediate distance. In most studies, conventional single character reading charts (Snellen, Jaeger, Zeiss, and ETDRS) are used to assess reading visual acuity only. For detailed testing of reading performance, modern log-scaled reading charts have been introduced that measure reading acuity, reading speed, and critical character size.[21] We believe it is important to evaluate near and intermediate function after multifocal IOL implantation because these are some of the major predictors of daily activity tasks, such as reading a newspaper and performing computer work.

One standardized tool for measuring the reading performance using sentences instead of single optotypes is the Salzburg Reading Desk.[11,22] This device reflects the physiological reading process by considering the reading speed, reading distance, and smallest print size that could be read effectively. In the literature there are only a few publications analyzing the reading performance of different multifocal IOLs with the Salzburg Reading Desk. Alió et al. compared bilateral reading performance of four IOL models (monofocal, apodized multifocal, diffractive multifocal and refractive multifocal) in terms of reading acuity, reading speed and distance.[23] The multifocal IOLs with diffractive optical design provided better near visual performance than the monofocal and refractive multifocal IOLs. Rasp et al. found similar results in a prospective randomized clinical trial comparing five different IOLs.[24]

We could not find peer-reviewed literature evaluating the reading performance of a zonal refractive multifocal IOL with the Salzburg Reading Desk. We observed a median monocular uncorrected near reading acuity of 0.18 logMAR (20/25 Snellen) at a predefined reading distance of 40 cm. The best results for monocular and binocular uncorrected and distance corrected reading acuity are achieved at an individual preferred reading distance of 39.6 cm, which corresponds to the standard viewing near distance with a +3.00 D near add multifocal IOL. Santhiago et al. compared the reading distance between the multifocal Restore IOL with a near addition of +3.00 and +4.00 D.[25] The reading acuity, speed and critical print size were significantly higher with the +3.00 D IOL at a fixed distance of 40 cm, which confirms our results. Regarding intermediate reading acuity, the situation appears different. The IOL performed well for intermediate vision with a median monocular uncorrected visual acuity of 0.30 logMAR (20/40 Snellen) at a fixed distance of 80 cm. After choosing a subjectively convenient intermediate distance, the monocular uncorrected reading acuity significantly improved to 0.22 logMAR (20/32 Snellen). Moreover, the patients were able to read a smaller print size after adjusting the reading distance. The best uncorrected and corrected reading distances were between 61 and 64 cm. However, with the exception of the letter size, there were no significant differences in terms of binocular uncorrected and corrected intermediate reading acuity and reading speed between the predefined distance of 80 cm and the individually preferred distance. We explain this finding with the fact that the reading acuity is dependent on the reading distance and speed. Therefore, diminishing the reading distance from 80 to approximately 60 cm can decrease or stabilize the visual acuity. Patients could read at the same speed but with a smaller print size at a closer distance. The results of the current study indicate the importance of reading performance testing at the subjectively convenient reading distance for several reasons.

Initial reading performance testing under fixed distances may lead to underestimation of potentially achievable results. Moreover, in everyday life patients adapt the reading distance according to their current circumstances, such as their body height, carriage, and individual preferences of reading. Simulating these everyday situations with the Salzburg Reading Desk allows more reliable results than with other conventional reading tests. Second, the diversity of various multifocal IOL designs with different near additions and the later generation of low add multifocal IOLs require different distances for the best achievable reading performance.

The Lentis Mplus IOL successfully restored distance and near visual function after cataract surgery and refractive lens exchange. Although it is a bifocal IOL, it provides functional satisfactory results at intermediate distances. Our results also indicate that at least the following four parameters are necessary to perform for the standardized evaluation of reading performance: reading acuity, reading speed, reading distance, and the smallest readable print size. Standardization of the reading performance is important for future studies to compare different types of multifocal IOLs after presbyopic correction.

AUTHOR CONTRIBUTIONS

Study concept and design (KL, MSAA); data collection (KL, MSAA, RK, TT, FTK, GUA); analysis and interpretation of data (KL, MSAA, RK, TT, FTK, GUA); writing the manuscript (KL, GUA); critical revision of the manuscript (MSSA, RK, TT, FTK); statistical expertise (KL); administrative, technical, or material support (KL, MSAA, RK, TT, FTK, GUA)

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Figure A. Salzburg Reading Desk version "SRD RDFD 1.0."

TABLE A

Refractive and Visual Outcomes Before and After IOL Implantation

	Median (Range)	
Parameter	**Preoperative**	**Postoperative**
UDVA (logMAR)	0.60 (1.30 to 0.30)	0.08 (0.24 to -0.08)
Sphere (D)	+2.00 (-17.75 to +9.50)	+0.50 (-1.00 to +1.50)
Cylinder (D)	-0.75 (-0.25 to -3.50)	-0.50 (-0.25 to -1.50)
CDVA (logMAR)	0.10 (0.70 to 0.00)	0.01 (0.14 to -0.20)
UNVA (logMAR)	–	0.12 (0.36 to -0.08)
DCNVA (logMAR)	–	0.12 (0.44 to -0.08)
Near add (D)	–	+1.00 (0.00 to +2.50)
CNVA (logMAR)	–	0.03 (0.32 to -0.14)

IOL = intraocular lens; UDVA = uncorrected distance visual acuity; D = diopters; CDVA = corrected distance visual acuity; UNVA = uncorrected near visual acuity; DCNVA = distance corrected near visual acuity; CNVA = corrected near visual acuity

TABLE B

Binocular Postoperative Reading Performance for Near and Intermediate Distance

	Median (Range)			
Parameter	**Near Reading Acuity (40 cm)**	**Near Reading Acuity (Individual)**	**Intermediate Reading Acuity (80 cm)**	**Intermediate Reading Acuity (Individual)**
Uncorrected				
Reading acuity (logMAR)	0.11 (0.29 to -0.10)	0.14 (0.29 to 0.02)	0.14 (0.31 to 0.04)	0.14 (0.22 to 0.00)
Reading distance (cm)	40.25 (38.10 to 43.80)	38.55 (30.40 to 41.20)	80.00 (77.10 to 86.50)	61.45 (54.50 to 72.80)
Reading speed (wpm)	108.5 (80 to 258)	108.5 (80 to 150)	102 (80 to 184)	105 (80 to 151)
Letter size	0.80 (0.50 to 1.25)	0.80 (0.50 to 1.25)	0.72 (0.50 to 1.00)	1.00 (0.8 to 1.25)
Corrected				
Reading acuity (logMAR)	0.10 (0.18 to -0.11)	0.10 (0.19 to -0.09)	0.11 (0.20 to 0.09)	0.15 (0.21 to 0.04)
Reading distance (cm)	39.90 (38.70 to 41.40)	39.60 (30.60 to 41.00)	79.90 (75.50 to 80.80)	64.05 (58.90 to 69.80)
Reading speed (wpm)	103 (80 to 172)	113 (81 to 156)	11 (80 to 163)	91.5 (81 to 158)
Letter size	0.80 (0.63 to 1.25)	0.80 (0.63 to 1.25)	0.80 (0.63 to 0.80)	0.90 (0.80 to 1.25)

wpm = words per minute