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ARTICLE

Effect of residual sphere on uncorrected visual acuity and satisfaction in patients with monofocal and multifocal intraocular lenses

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Purpose: To assess the effect of residual sphere on vision and satisfaction in pseudophakic patients.

Setting: Private clinics, United Kingdom.

Design: Retrospective case series.

Methods: A multivariate model evaluated the effect of 1-month residual sphere on outcomes of pseudophakic patients. Odds ratios (ORs) were calculated to assess the relative risk of not achieving ≥20/20 monocular uncorrected distance visual acuity (UDVA), ≥20/50 uncorrected near visual acuity (UNVA), and not being satisfied with vision. ORs were assessed for residual sphere −1.00 to +1.00 diopter (D) in quarter-diopter steps, using 0.00 D as a reference.

Results: The analysis included 38 828 multifocal and 11 571 monofocal intraocular lenses (IOLs). The residual myopic sphere ≤−0.25 D and hyperopic sphere ≥+0.50 D had a clinically meaningful effect on UDVA. Although monofocal IOLs had an improvement in UNVA with every additional 0.25 D of myopia, the change in ORs with increasing myopia was not significant for multifocal IOLs. The mean improvement in UNVA comparing eyes with 0.00 D and −1.00 D sphere was 0.26 logMAR for monofocal and 0.03 logMAR for multifocal IOLs. Low near-addition IOLs had a slightly higher gain in UNVA with increasing myopia, but the gain was not as substantial as with monofocal IOLs. The effect of ametropia on satisfaction was more pronounced for multifocal IOLs. For every 0.25 D of residual myopia, there was >25% increase in dissatisfied patients.

Conclusions: Although myopia improved UNVA in eyes with monofocal IOL, multifocal IOLs did not benefit from residual myopia. Multifocal IOL patients desiring distance vision should be targeted closest to emmetropia, even if it means targeting slight hyperopia.

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With a better understanding of ocular biometric measurements, the choice of new-generation intraocular lens (IOL) formulas, and the advent of high-precision optical biometers, the demands for accurate and predictable outcomes of cataract surgery are increasing.[1–3] In audits of refractive data, the percentage of eyes within ±0.50 diopter (D) or ±1.00 D of emmetropia is a commonly used benchmark to judge the success of cataract surgery.[4] However, in premium IOL candidates with high expectations for spectacle independence, the visual performance for distance and near vision can be considerably different at either end of the ±0.50 D or ±1.00 D range.

In one of our previous articles, we demonstrated how low amounts of residual astigmatism affect visual acuity (VA) after intraocular surgery.[5] These findings prompted us to investigate whether low levels of the residual sphere could have a similar impact on various outcome measures of refractive surgery, especially in pseudophakic eyes that have lost their accommodative ability. It is also possible that the sensitivity to residual hyperopia or myopia may be different among patients with a multifocal or monofocal IOL implant. To investigate such relationships, a large cohort of pseudophakic patients with various IOL types is required.

The aim of this study was, therefore, to examine the independent effect of the residual sphere on near and distance VA and patient-reported satisfaction in premium IOL candidates.

METHODS

This study is a retrospective analysis of clinical data of patients who underwent refractive lens exchange (RLE) or cataract surgery with a variety of premium IOL models. The study was deemed exempt from full review by the Institutional Review Board at the

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University of California, San Francisco, because it used only retrospective, deidentified patient data. All patients provided written informed consent before surgery and agreed to use their medical records for statistical analysis.

The data of patients were extracted from the electronic data set of a private IOL surgery provider (Optical Express). The criteria for inclusion in the study were intraocular surgery (cataract or RLE) performed between January 2014 and June 2022, attended a 1-month postoperative visit with the full record of refraction and VA on the electronic system, and completed a 1-month postoperative patient experience questionnaire. The extracted parameters included preoperative demographics and clinical data, surgery information (surgeon, surgical center, and IOL model), 1-month postoperative clinical data, and patient-reported outcomes.

Preoperative and 1-month postoperative VA measurements extracted from the data set included corrected distance visual acuity (CDVA), monocular uncorrected distance visual acuity (UDVA), and uncorrected near visual acuity (UNVA). Distance VA was measured at 3 meters with a logarithmic acuity chart (with refractions corrected to optical infinity based on the 3 m testing distance), and near acuity was measured with an early treatment diabetic retinopathy study reading chart normalized for 40 cm distance and recorded in Snellen distance equivalent.

Intraocular surgeries were performed either with the assistance of a femtosecond laser (Catalys Precision Laser System, Johnson & Johnson Vision) or with a standard phacoemulsification technique. Surgeries were performed by 28 surgeons in 22 surgical centers. Preoperative biometric measurements were determined by IOLMaster 500 or IOLMaster 700 (Carl Zeiss Meditec AG), and in most cases, the Haigis or Barrett Universal II formula was applied for IOL selection.

At the 1-month postoperative visit, patients were required to complete a questionnaire, which assessed the satisfaction and quality of vision after intraocular surgery. For the analysis of the residual sphere and satisfaction, the following question was used in the analysis: "Thinking about your vision during the last week, how satisfied are you with your vision? (Without the use of glasses or contact lenses)." The responses to this question were assessed on a 5-point discrete scale: 1 (very satisfied), 2 (satisfied), 3 (neither), 4 (dissatisfied), and 5 (very dissatisfied).

Statistical Analysis

Multivariate logistic regression analysis was performed to assess the independent effect of the residual refractive sphere on postoperative monocular UDVA, monocular UNVA, and satisfaction with vision. Identification of potential covariates was initially completed using univariate analyses, after which generalized linear models were constructed to estimate the relative impact of individual variables and their interactions. Using the 0.00 D residual sphere as a reference, adjusted odds ratios (ORs) were calculated to assess the impact of each additional quarter diopter of the myopic or hyperopic sphere within the range of ±1.00 D on studied variables.

The relationships were assessed for residual sphere in all eyes in the study (regardless of the amount of residual refractive cylinder) and for a subgroup of eyes with residual cylinder 0.00 D. In addition, the analysis was also performed to test the relationship between the residual manifest spherical equivalent and the study variables. The independent effect of sphere on postoperative outcomes in multivariate analysis was similar in all models. For that reason, only the ORs for the effect of the residual sphere in all eyes (regardless of the amount of residual cylinder) will be presented in this study.

The analysis was performed separately for eyes with monofocal and multifocal IOLs, considering both might have a different effect on studied variables, mainly on UNVA outcomes. Toric and nontoric versions of the same type of IOL showed a very similar trend and impact on outcomes, and for that reason, they were not analyzed separately. Similarly, patients with visually significant cataracts showed a similar change in VA with increasing ametropia than those who underwent RLE in the absence of cataract and will be presented as 1 group.

For the monocular UDVA vs residual sphere analysis, the ORs were calculated for the relative risk of not achieving 20/20 or better UDVA. The ORs were also assessed for the ≥20/16 VA level but showed very similar outcomes and will not be included in this study.

Monocular UNVA analyses were explored for various prints and font sizes, ranging between 20/32 (Jeager J4, very small print—not common in general use) and 20/80 (Jeager J9, standard newspaper journals or magazine print).[6] The relative risk of not achieving ≥20/50 UNVA was selected as the most meaningful to demonstrate the change in UNVA with increasing myopic and hyperopic sphere. The 20/50 (or Jeager J6) level represents the generally used "small print" (eg, classified ads, stock quotations, or pocket bibles).[6]

Although the relationship between monocular UDVA/UNVA and residual sphere was assessed for each eye of the patient, the relationship between satisfaction with vision and the amount of residual sphere was based on the amount of residual sphere in the dominant eye of each patient (using 1 eye per patient). The relationship was also assessed for nondominant eye and was found to have a weaker effect on satisfaction than the residual refraction in the dominant eye. The ORs were explored at 2 levels: the likelihood of not being "satisfied" with vision (the sum of patients who reported to be either "satisfied" or "very satisfied") and the patients who reported to be "very satisfied." Both showed very similar outcomes, and the ORs in this study will be presented only for the relative risk of not being "satisfied" with vision.

All analyses were based on refractive error recorded in minus cylinder form. Data tabulation and statistical operations were performed with SAS 9.3 (SAS Institute, Inc.).

RESULTS

The analysis included a total of 50 399 eyes of 26 705 patients. Of all eyes, 38 828 (77.0%) had a multifocal IOL and 11 571 (23.0%) had a monofocal IOL. The summary of lens types included in the data set is presented in Supplemental Table 1 (available at http://links.lww.com/JRS/B100). Of the multifocal lenses, the lens types included diffractive multifocal IOLs (Tecnis ZKB00 and ZLB00, Johnson & Johnson Vision), extended depth-of-focus IOLs (Tecnis Symfony ZXR00 and ZXT, Johnson & Johnson Vision and AT Lara 829MP, Carl Zeiss Meditec AG), and refractive segmented bifocal IOLs (Lenstec SBL-2, Lenstec, Inc., and Lentis Mplus/Mplus^X MF30, Teleon Surgical B.V.; formerly manufactured by Oculentis GmbH). Most of the patients underwent a RLE with none or minimal cataract changes. The percentage of eyes with visually significant cataract and poor preoperative CDVA (<20/40) was small (3.2% or 1624/50 399 eyes).

Preoperative and 1-month postoperative data of our population are summarized in Supplemental Table 2 (available at http://links.lww.com/JRS/B101). The mean age of the study group was 58.5 ± 8.3 years. Of all multifocal IOL eyes, 82.2% (31 930/38 828) had postoperative refractive sphere within ±0.50 D and 97.1% (37 696/38 828) had postoperative refractive sphere within ±1.00 D. In eyes with a monofocal IOL, 71.6% (8280/11 571) and 87.9% (10 167/11 571) had postoperative refractive sphere within ±0.50 and ±1.00 D, respectively (patients with monofocal IOLs were more likely to be targeted for monovision).

Table 1. Odds ratios for not achieving monocular UDVA 20/20 or better, stratified by residual refractive sphere

Residual sphere (D)	Monofocal IOLs Odds ratio (95% CI); *P* value	Multifocal IOLs Odds ratio (95% CI); *P* value
−1.00	92.9 (47.6, 181.3); <.0001	162.2 (98.4, 267.2); <.0001
−0.75	27.7 (18.6, 41.0); <.0001	40.5 (33.2, 49.3); <.0001
−0.50	7.7 (6.3, 9.4); <.0001	9.9 (9.0, 10.9); <.0001
−0.25	2.3 (2.0, 2.7); <.0001	2.8 (2.6, 3.1); <.0001
0.00	1.0	1.0
+0.25	1.1 (0.9, 1.2); .4172	1.1 (1.0, 1.2); .0031
+0.50	2.0 (1.8, 2.3); <.0001	2.1 (2.0, 2.3); <.0001
+0.75	4.1 (3.5, 4.8); <.0001	5.1 (4.7, 5.5); <.0001
+1.00	9.5 (7.5, 11.9); <.0001	10.5 (9.3, 11.8); <.0001

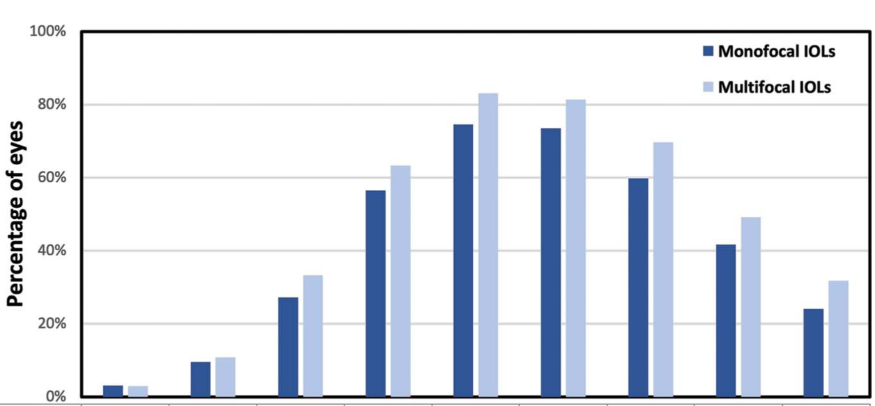
Effect of Residual Sphere on Distance VA

Table 1 summarizes ORs for the relative risk of not achieving monocular UDVA 20/20 or better according to the residual sphere. Postoperative residual sphere as low as −0.25 D significantly affected visual outcomes. Compared with the eyes with 0.00 D residual sphere, the odds of not achieving ≥20/20 UDVA with −0.25 D myopia increased by a factor of 2.3 (CI, 2.0-2.7; $P < .0001$) for eyes with monofocal IOLs and 2.8 (CI, 2.6-3.1; $P < .0001$) for eyes with multifocal IOLs. In eyes with −0.50 D residual sphere, the change in OR was substantial: the OR increased by a factor of 7.7 (CI, 6.3-9.4; $P < .0001$) and 9.9 (CI, 9.0-10.9; $P < .0001$) for eyes with monofocal and multifocal IOLs, respectively. As expected, there was a further sharp increase in ORs with increasing residual myopic sphere between −0.50 D and −1.00 D.

Increasing residual hyperopic sphere had a more moderate effect on acuity (Table 1). A residual sphere of +0.25 D had only a minimal effect on VA (albeit statistically significant for multifocal IOLs), which is likely clinically insignificant. A residual sphere of +0.50 D already had a significant effect, with the odds of not achieving ≥20/20 UDVA increasing by a factor of 2.0 (CI, 1.8-2.3; $P < .0001$) for monofocal IOLs and 2.1 (CI, 2.1-2.3; $P < .0001$) for multifocal IOLs. Thereafter, the OR of not achieving ≥20/20 approximately doubled for every additional quarter diopter of residual hyperopia.

Figure 1 shows the percentages of eyes with ≥20/20 UDVA stratified by residual sphere and the mean UDVA for each level of residual sphere. The percentage of eyes achieving ≥20/20 UDVA dropped by approximately 20% between the group of eyes with 0.00 D and −0.25 D residual sphere and by a further 30% between eyes with −0.25 D and −0.50 D residual sphere. Consistent with the OR findings, the residual sphere of 0.00 D and +0.25 D had very similar percentages of eyes achieving ≥20/20 UDVA, but these percentages gradually decreased for the residual hyperopic sphere from +0.50 to +1.00 D.

As compared with eyes with 0.00 D residual sphere, eyes with −1.00 D of residual sphere had a decrease in mean UDVA by 0.36 logMAR and 0.32 logMAR (more than 3 Snellen lines) for eyes with monofocal and multifocal IOLs, respectively (Figure 1). For residual hyperopia, the decrease in acuity was less pronounced. As compared with eyes with 0.00 D residual sphere, eyes with +1.00 D residual sphere had a mean UNVA decrease of 0.14 logMAR for monofocal IOLs and 0.13 logMAR for multifocal IOLs (more than 1 Snellen line). In eyes with multifocal IOLs, the multifocal lens model had no independent effect on UDVA outcomes; all lens models were similarly affected by increasing



Residual Sphere [D]	-1.00	-0.75	-0.50	-0.25	0.00	+0.25	+0.50	+0.75	+1.00
Monofocal IOLs:									
Number of eyes	293	304	573	954	3110	1985	1658	833	457
Mean UDVA [logMAR]	0.37	0.24	0.15	0.06	0.01	0.01	0.04	0.09	0.15
Multifocal IOLs:									
Number of eyes	546	1080	2377	3840	13010	7058	5645	2766	1374
Mean UDVA [logMAR]	0.30	0.21	0.11	0.03	-0.02	-0.01	0.02	0.06	0.12

Figure 1. The percentage of eyes achieving monocular UDVA 20/20 or better stratified by residual refractive sphere.

Table 2. Odds ratios for not achieving monocular UNVA 20/50 or better, stratified by residual refractive sphere

Residual sphere (D)	Monofocal IOLs Odds ratio (95% CI); *P* value	Multifocal IOLs Odds ratio (95% CI); *P* value
−1.00	0.07 (0.05, 0.09); <.0001	0.7 (0.4, 1.1); .1101
−0.75	0.1 (0.1, 0.2); <.0001	1.0 (0.7, 1.3); .8413
−0.50	0.3 (0.2, 0.3); <.0001	1.0 (0.8, 1.2); .9668
−0.25	0.5 (0.5, 0.6); <.0001	1.1 (0.9, 1.2); .4549
0.00	1.0	1.0
+0.25	1.6 (1.4, 1.8); <.0001	1.3 (1.2, 1.5); <.0001
+0.50	2.2 (1.8, 2.6); <.0001	2.1 (1.9, 2.4); <.0001
+0.75	2.3 (1.9, 2.9); <.0001	4.0 (3.5, 4.5); <.0001
+1.00	2.6 (2.0, 3.6); <.0001	7.3 (6.3, 8.4); <.0001

ametropia. Supplemental Tables 3 and 4 (available at http://links.lww.com/JRS/B102 and http://links.lww.com/JRS/B103) present the change in mean logMAR UDVA and the percentages of eyes achieving ≥20/20 UDVA for the most commonly implanted multifocal IOLs in our data set.

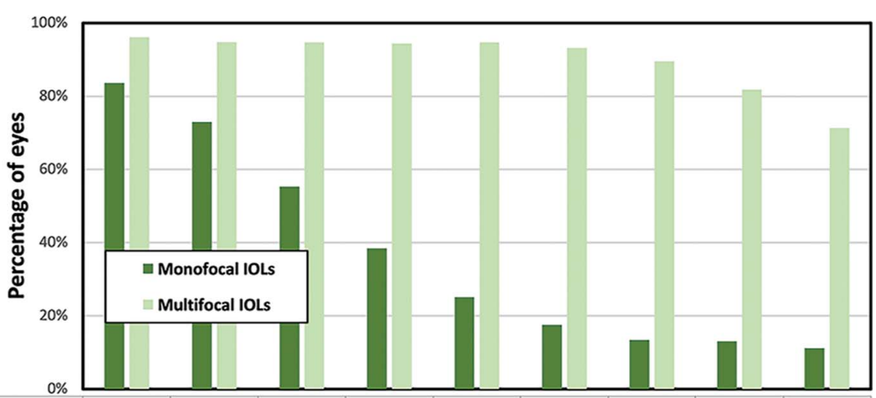
Effect of Residual Sphere on Near VA

The multivariate logistic regression model of not achieving a monocular UNVA of ≥20/50 is presented in Table 2. Eyes with monofocal and multifocal IOLs showed very different trends in UNVA change. There was only a subtle nonsignificant change in the ORs of not achieving ≥20/50 UNVA with increasing myopia in eyes with multifocal IOLs. By contrast, monofocal IOLs demonstrated a significant decrease in OR with increasing myopia. This means eyes with multifocal IOLs maintained almost the same level of UNVA for all presented levels of myopia, while monofocal IOLs had a significant improvement in UNVA with increasing myopic sphere.

Increasing hyperopic sphere degraded near VA for both monofocal and multifocal IOLs. The ORs for not achieving ≥20/50 UNVA were statistically significant at the lowest level of residual hyperopia of +0.25 D (OR, 1.6, CI, 1.4-1.8; $P < .0001$ for monofocal IOLs and OR, 1.3, CI, 1.2-1.5; $P < .0001$ for multifocal IOLs) and increased further with increasing hyperopia. However, for the higher amounts of the residual hyperopic sphere (+0.75 D and +1.00 D), the likelihood of not achieving 20/50 or better UNVA was much higher in eyes with multifocal IOLs than in monofocal IOLs. In other words, eyes with multifocal IOLs had a greater decrease in percentages of eyes achieving ≥20/50 UNVA with increasing hyperopia than eyes with monofocal IOLs.

Figure 2 shows the percentages of eyes with ≥20/50 UNVA stratified by residual sphere. This demonstrates a sharp increase in the percentages of eyes achieving ≥20/50 UNVA in eyes with monofocal IOLs with increasing myopic residual sphere, while the percentages are almost the same for every quarter-diopter step of residual myopic sphere for eyes with multifocal IOLs. On the other hand, the decrease in the percentage of eyes achieving ≥20/50 UNVA with increasing hyperopia is more pronounced in eyes with multifocal IOLs.

Figure 2 also shows the mean logMAR values of UNVA stratified by the residual sphere. Eyes with monofocal IOLs had a 0.26 logMAR improvement in the mean UNVA (almost 3 Snellen lines) between 0.00 D and −1.00 D residual sphere, while the eyes with multifocal IOLs had only a 0.03 logMAR improvement for the same change in the residual sphere (approximately 1 letter of a Snellen line). There was a slight variation in the effect of residual myopia



Residual Sphere [D]	-1.00	-0.75	-0.50	-0.25	0.00	+0.25	+0.50	+0.75	+1.00
Monofocal IOLs:									
Number of eyes	293	304	573	954	3110	1985	1658	833	457
Mean UNVA [logMAR]	0.31	0.38	0.45	0.51	0.57	0.60	0.63	0.66	0.70
Multifocal IOLs:									
Number of eyes	546	1080	2377	3840	13010	7058	5645	2766	1374
Mean UNVA [logMAR]	0.22	0.23	0.24	0.25	0.25	0.26	0.29	0.33	0.38

Figure 2. The percentage of eyes achieving monocular UNVA 20/50 or better stratified by residual refractive sphere.

Table 3. Odds ratios for not being satisfied[a] with postoperative vision stratified by residual refractive sphere		
Residual sphere (D)	Monofocal IOLs Odds ratio (95% CI); *P* value	Multifocal IOLs Odds ratio (95% CI); *P* value
−1.00	2.1 (1.0, 4.2); .0365	2.8 (2.0, 3.9); <.0001
−0.75	2.5 (1.4, 4.4); .0024	2.2 (1.7, 2.8); <.0001
−0.50	2.6 (1.7, 3.8); <.0001	2.0 (1.7, 2.4); <.0001
−0.25	1.1 (0.7, 1.6); .6951	1.3 (1.1, 1.6); .0007
0.00	1.0	1.0
+0.25	0.9 (0.7, 1.2); .5261	1.2 (1.0, 1.3); .0434
+0.50	1.0 (0.7, 1.4); .8684	1.2 (1.1, 1.4); .003
+0.75	1.2 (0.8, 1.8); .292	1.6 (1.4, 1.9); <.0001
+1.00	1.6 (1.0, 2.5); .0393	2.2 (1.8, 2.7); <.0001

[a]Satisfied refers to the number of patients who reported to be "satisfied" or "very satisfied" with postoperative vision on a 5-point scale (very satisfied, satisfied, neither, dissatisfied, or very dissatisfied)

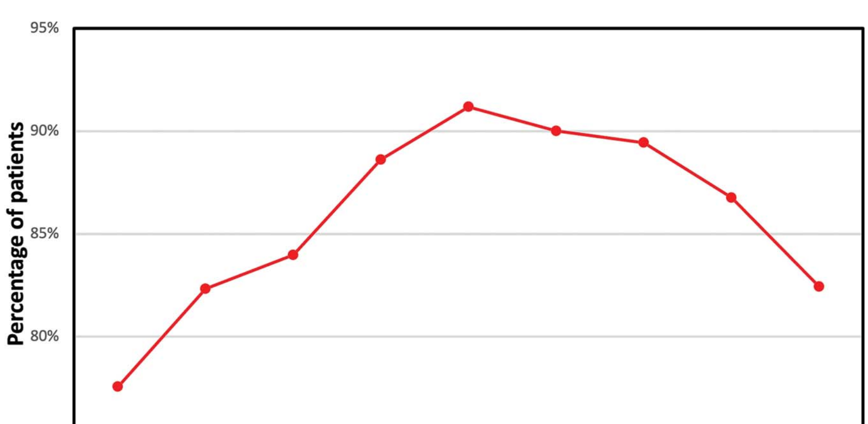
on UNVA among different multifocal lens types, depending on their near vision addition, but no multifocal lens model had near vision improvement with increasing myopia as substantial as monofocal lenses. Supplemental Tables 5 and 6 (available at http://links.lww.com/JRS/B104 and http://links.lww.com/JRS/B105) present the change in mean logMAR UNVA and the percentages of eyes achieving ≥20/50 UNVA for the most commonly implanted multifocal IOLs in our data set. The greatest improvement in near vision with increasing myopia was observed for an IOL with a lower near addition (Tecnis Symfony, Johnson & Johnson Vision), but the improvement (0.08 logMAR or 4 letters of a Snellen line comparing 0.00 D and −1.00 D residual sphere) was still not as significant as with monofocal IOLs. On the other hand, IOLs with higher near addition (3.0 D or more), such as Lentis Mplus^X MF30, Lentis Mplus MF30 and their toric versions (Teleon Surgical B.V.), or Tecnis ZLB00 (Johnson & Johnson Vision), showed no improvement or even worsening of UNVA with increasing myopia (Supplemental Table 5, available at http://links.lww.com/JRS/B104).

Increasing hyperopia had a very similar effect on the deterioration of near acuity for monofocal and multifocal IOLs. The mean UNVA worsened by 0.13 logMAR between 0.00 D and +1.00 D residual sphere for both monofocal and multifocal IOLs (more than 1 Snellen line decrease). However, when comparing different models of multifocal lenses, it seemed that UNVA was less affected by increasing hyperopia in patients with higher near-addition IOLs, such as Lentis Mplus^X MF30, Lentis Mplus MF30, or Tecnis ZLB00 (Supplemental Table 5, available at http://links.lww.com/JRS/B104).

Effect of Residual Sphere on Postoperative Satisfaction

We developed a multivariate logistic regression model of not being satisfied with postoperative vision based on the residual sphere in the dominant eye of each patient (Table 3). The analysis was performed only for patients who had either bilateral implantation of a monofocal IOL (5086 patients) or bilateral implantation of a multifocal IOL (18 493 patients).

For patients with monofocal IOLs, the effect of the residual myopic sphere in the dominant eye on satisfaction was statistically significant for residual myopia between −0.50 D and −1.00 D. However, the number of patients with residual sphere of −0.75 D or −1.00 D in the dominant eye was



Residual Sphere [D]	-1.00	-0.75	-0.50	-0.25	0.00	+0.25	+0.50	+0.75	+1.00
Multifocal IOLs:									
Number of patients	205	464	1011	1792	6385	3425	2747	1277	666
Percentage of patients Satisfied/Very Satisfied	77.6%	82.3%	84.0%	88.6%	91.2%	90.0%	89.4%	86.8%	82.4%

Figure 3. The percentage of patients satisfied or very satisfied with postoperative vision after multifocal IOL implantation stratified by residual refractive sphere.

small (less than 100 patients in each category). For residual hyperopia, the change was statistically significant only for the +1.00 D level, with the corresponding OR of 1.6 (CI, 1.0-2.5, P = .0393).

In patients with multifocal IOLs, the effect of the residual sphere on satisfaction was statistically significant for every quarter-diopter step of the residual myopic or hyperopic sphere (Table 3). Figure 3 shows the relationship between residual sphere and patient satisfaction in patients with multifocal IOLs. Increasing ametropia gradually decreased the percentage of patients being satisfied with vision, but the decrease in percentages was more noticeable for increasing myopia than for increasing hyperopia. On average, every additional quarter diopter of myopia decreased the percentage of satisfied patients by 3.4%, while every additional quarter diopter of residual hyperopia decreased the percentage of satisfied patients by 2.2%. Such a decrease in the percentage of satisfied patient translates to an average of 26.8% increase in patients not satisfied with the vision for every additional quarter diopter of myopia and an average 19.3% increase in not satisfied patients with every additional quarter diopter of residual hyperopia.

DISCUSSION

Modern cataract surgery has become a refractive procedure, and patients often have high expectations for superior visual outcomes. The effect of residual refractive error on VA and patient's quality of vision is quite complex, depending on the components and type of refractive error. Most of the IOL studies in the literature explore the negative effect of residual astigmatism.[7–12] The fact that increasing ametropia will affect VA is quite apparent. Still, no previous study investigated what amount of hyperopia or myopia already has a significant effect on visual outcomes and satisfaction in pseudophakic patients.

The findings of this study indicate that a residual refractive sphere as low as −0.25 D or +0.50 D increases the odds of not achieving ≥20/20 distance VA. Examining the mean logMAR VA values stratified by the residual sphere, both monofocal and multifocal IOLs demonstrated a very similar trend in the decrease of distance VA with increasing refractive error (Figure 1). Some studies in the literature suggest that certain multifocal IOLs have a better tolerance to residual refractive errors, whereas others claim quite the opposite.[13–18] Thus, one would assume that different IOL designs might have a different tolerance to residual refractive error. Interestingly, in this study, we have seen a very similar trend in distance vision across a wide range of multifocal IOLs, including diffractive, extended depth of focus, and refractive segmented bifocal IOLs.

It is very likely that the effects observed in our analysis would be slightly attenuated at the distance VA levels worse than 20/20. However, for this study, we believe that investigating the ≥20/20 VA level was appropriate because that is the acuity many premium IOL candidates anticipate, and most of the patients in this study had the potential to achieve 20/20 VA (postoperative mean CDVA of our cohort was −0.04 ± 0.08 logMAR, or $20/20^{+2}$, Supplemental Table 2, available at http://links.lww.com/JRS/B101). Furthermore, the change in the percentages of eyes achieving ≥20/20 UDVA followed a very similar trend as the change in the mean logMAR UDVA, which affirms the relationship between the residual sphere and UDVA.

Near VA showed a very different trend in patients with monofocal and multifocal IOLs. Although there was a considerable improvement in near VA with increasing myopia in patients with monofocal IOLs, as expected, the change in eyes with multifocal IOLs was very subtle. In other words, comparing the change in monocular UNVA between eyes with 0.0 D residual sphere and those with −1.0 D residual sphere, the mean monocular UNVA improved by almost 3 Snellen lines (0.26 logMAR) in monofocal IOL eyes, whereas eyes with a multifocal IOL only showed approximately 1 letter (0.03 logMAR) improvement (Figure 2). This outcome strongly suggests that postoperative myopia should not be targeted in patients with multifocal IOLs. We observed a slight variation among different multifocal lenses. IOLs with lower near addition demonstrated slightly higher improvement in UNVA with increasing myopia, whereas IOLs with high near addition showed no improvement or even slight worsening of UNVA with increasing myopia. However, even in patients with low near-addition IOLs, the improvement in UNVA with increasing myopia was only small and not as substantial as with monofocal lenses. On the other hand, near VA seemed to be less affected by increasing hyperopia in patients with high near-addition lenses.

Several studies have demonstrated that the overall performance of certain IOLs (mainly extended depth-of-focus lenses) could be improved by targeting mini-monovision in the nondominant eye.[19,20] However, others have found that residual myopia does not improve near acuity. Lee et al. found that eyes with a refractive multifocal IOL had significantly better UNVA when targeted for emmetropia (within ±0.50 D) than eyes with postoperative myopia between −0.50 D and −1.50 D.[17] In another prospective study, correction of residual refractive error improved UDVA in patients with apodized diffractive IOLs, but near VA was maintained whether the residual refractive error was corrected or not.[18] In one of our previous studies, we found that targeting bilateral emmetropia rather than mini-monovision resulted in higher satisfaction rates in patients with a diffractive extended depth-of-focus IOL.[21] A more complex analysis would be necessary to elucidate whether and what amount of residual myopia in 1 eye affect the overall binocular performance of certain multifocal IOLs. This could be a subject for further study.

Residual sphere had a significant effect on postoperative patient satisfaction, most pronounced with multifocal IOLs. For multifocal IOLs, the chance of being satisfied decreases by approximately 3.4% (myopia) and 2.2% (hyperopia) for each 0.25 D of increasing ametropia. Residual sphere correspondingly translates into more patients being dissatisfied. With a residual sphere of −0.25 D, the modest decrease in satisfaction would represent more than a 25% increase in patients not satisfied with the procedure.

Oftentimes, these are the patients who are the most difficult to manage and can consume time and effort to address.

There are many factors that can affect postoperative patient satisfaction (e.g., visual side effects from multifocal lenses, postoperative complications, and presence of dry eye), but achieving emmetropia should be viewed as a significant factor in patient happiness.[21–23] The relationship between the residual sphere and the satisfaction in this study was assessed only based on the outcome of the dominant eye. The combination of refractive error in the dominant and nondominant eye might further elucidate the relationship, especially in patients targeted for monovision.

There are several limitations that need to be acknowledged. The retrospective design of this study might seem to be a drawback; however, the size of the data set and its statistical power help mitigate this limitation. As highlighted previously, postoperative refractions were collected by a number of practitioners in different testing rooms, which could affect the repeatability and reproducibility of manifest refractions.[5] However, the testing room parameters (testing distance, testing charts, equipment, and room illumination) are standardized across all our clinics, with all practitioners following standardized protocols for testing. Despite this, variations in subjective refraction measurements might still occur, but it is unlikely that they would affect overall trends in outcomes in a large data set. Some might perceive the large variations in preoperative data (patient demographics, variety of included IOLs and lens powers, multicenter, and multisurgeon approach) as a limitation of the study; however, we believe that it added strength to the analysis because we could explore the effect of residual sphere independent of all these factors.

Despite these limitations, the contributions and implications of the study are noteworthy. The study demonstrates that VA can significantly vary even within the ± 0.50 D or ± 1.00 D range of residual refraction, a commonly used threshold to rate the refractive success of cataract surgery. Hence, every effort should be made to achieve the intended target refraction. Because IOLs usually come in 0.5 D increments, typically, a decision has to be made to select a power that straddles the desired postoperative sphere of 0.00 D. Surgeons often opt for IOL power that targets a slight amount of myopia out of concern for the supposed deleterious visual outcome of being slightly hyperopic vs the slight improvement in near vision by being slightly myopic. However, this study demonstrated that intentionally aiming for myopia, especially myopia of 0.25 D or more, might not be beneficial to patients with multifocal IOLs. We recommend that patients desiring distance vision and those receiving multifocal IOLs should receive the IOL that is targeted closest to emmetropia, even if it means targeting slight hyperopia.

Nevertheless, the accuracy and predictability of postoperative refraction will often be limited by a number of factors, including limitations in preoperative measurements and IOL calculations, intraoperative and postoperative factors that affect the stability of IOL in the capsular bag, as well as IOL manufacturing precision.[16,24] Our VA outcomes are based on monocular VA. It would be worth exploring binocular performance with different combinations of sphere in dominant and nondominant eyes. This would be particularly useful in monofocal IOL candidates, who might benefit from induced monovision. However, this is out of the scope of this study and could be a subject of a follow-up study.

WHAT WAS KNOWN

- Residual ametropia undesirably affects postoperative outcomes of pseudophakic patients, but it is now well understood what amount of residual sphere has a significant effect on outcomes and how different IOL types respond to residual ametropia.
- There are contradictory opinions among surgeons about the best target refraction in eyes with multifocal IOLs. Some believe that targeting slight myopia might enhance the overall performance of multifocal IOLs.

WHAT THIS PAPER ADDS

- This study demonstrated how each additional 0.25 D of residual ametropia affected VA and satisfaction of patients with monofocal and multifocal IOLs
- Patients with multifocal IOLs did not benefit from residual myopia, and postoperative emmetropia might be the best target in multifocal IOL candidates.

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