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Index of contrast sensitivity (ICS) in pseudophakic eyes with different intraocular lens designs

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ABSTRACT.

Purpose: **To evaluate the index of contrast sensitivity (ICS) in eyes after cataract surgery with various intraocular lens designs and to compare with the area under log contrast sensitivity curve (AULCSF).**

Methods: **The study comprised 395 eyes of 198 patients in the age of 73.1 ± 7.86 years receiving 11 different aspheric IOL designs (aberration-free and correcting) and a spherical (IOL) as control group. Follow-up examination after bilateral cataract surgery was completed within 71 ± 21.4 days after second IOL implantation. Patients underwent complete examination and biometry before surgery. The follow-up examination included visual acuity, pupil diameter, residual spherical aberration and mesopic as well as photopic contrast sensitivity (CS) measured with the Optec 6500 Functional Vision Analyzer. From the contrast sensitivity, we calculated the ICS according to Haughom and Strand.**

Results: **The median mesopic ICS was −144, −131 and −85, and the median photopic ICS was −289, −285 and −212 for the spherical, aberration-free and aberration-correcting IOL group, respectively. While we could not detect a significant difference between the aberration groups in some spatial frequencies, the ICS showed a significant difference between the aberration-correcting and the aberration-free or the spherical group, respectively. No significant difference was found between the aberration-free and the spherical group.**

Conclusions: **The ICS is a useful index for evaluation of overall CS and comparison of different patient groups. With aberration-correcting IOLs, ICS was statistically better than with aberration-free or spherical IOLs, whereas the latter two showed no significant difference.**

Key words: area under log contrast sensitivity curve – contrast sensitivity – aspheric intraocular lenses – index of contrast sensitivity

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Introduction

Sine wave contrast sensitivity (CS) is one reliable measure for visual performance after ophthalmic surgery, for example, after implantation of an intraocular lens (IOL). It has been used to quantify visual performance after implantation of multifocal lenses, which are well known to decrease CS due to the underlying optical principle. On the other hand, the potential visual gain with aspheric intraocular lenses has been investigated by the use of CS measures. Normative data on the contrast sensitivity function (CSF) of a healthy population has been provided for different populations and age groups (Hohberger et al. 2007; Haughom & Strand 2013; Sia et al. 2013). However, the overall CS is difficult to compare due to different test methods or devices (F.A.C.T., Pelli-Robson, Ginsburg, Optec 6500, FrACT, etc.) (Ginsburg 1984; Elliott & Whitaker 1992; Bach 1996; Mäntyjärvi & Laitinen 2001; Bühren et al. 2006; Hohberger et al. 2007; Durst et al. 2013; Pelli & Bex 2013; Richman et al. 2013). In addition, CS is usually represented by five values at different spatial frequencies, and a single-index criterion to facilitate comparison was available in the area under the log CSF curve (AULCSF). However, the AULCSF is calculated by integrating the area under a 3rd order polynomial fitted to the log CSF data. In addition, there is no strict definition which range of spatial frequencies should be used for integration. Some use the range from 3 to 24 cycles/degree (cpd), but many tests only supply data from 1.5 to 18 cpd (Applegate et al. 1998). Furthermore, different tests lack comparability due to different stimuli or lighting conditions (Richman et al. 2013). Recently, Haughom & Strand (2013) defined such a single-index measure for a young population which they called index of contrast sensitivity (ICS). The ICS is calculated for both mesopic (mICS) and photopic (pICS) contrast sensitivity and is a simple linear weighting function taking into account that the eye's sensitivity peaks at 6 cpd:

$$\mathrm{ICS} = \mathrm{dCSF}(1.5) + 2 \cdot \mathrm{dCSF}(3) + 3 \cdot \mathrm{dCSF}(6) + 2 \cdot \mathrm{dCSF}(12) + \mathrm{dCSF}(18), \quad (1)$$

where dCSF(f) refers to the deviation of the measured CS value and the median value at spatial frequency f:

$$\mathrm{dCSF}_i(f) = \mathrm{CSF}_i(f) - \mathrm{Median}(\mathrm{CSF}(f)), \quad (2)$$

Aspheric intraocular lenses have been widely used in clinical practice to enhance visual acuity and CS after cataract surgery in order to fulfil the patients' wish of restoring juvenile contrast vision. The two concepts currently available on the market include aberration-free lenses, which correct for the lens' intrinsic spherical aberration (SA), and aberration-correcting lenses, which provide partial or full correction of the corneal SA. Most aberration-correcting IOL designs are optimized upon model eyes which reflect average biometrical and optical data of the human eye, providing a best fit correction for a large group of potential patient eyes. Several schematic model eyes such as the Liou-Brennan Model Eye (LBME) are accepted as basis for aberration-correcting designs; however some IOL designs are based on proprietary model eyes and customized IOLs are derived using model eyes based on individual patient data (Langenbucher et al. 2011, 2014; Zhu et al. 2011). As these models do not fully reflect the variety of cataract patients' eyes, a remarkable number of eyes exist where corneal asphericity, and therefore spherical aberration, is considerably different to the aberration correction provided by the IOL design. Little data is known about the effect of overcorrecting corneal spherical aberration by an aspheric IOL.

The present study aims to provide data on the CS of a pseudophakic population which had received various intraocular lens concepts from various manufacturers. We compare the data to a control group with a spherical IOL and a young normal population.

Patients and Methods

Between January 2008 and September 2009 a total of 395 eyes of 198 patients were included in this randomized, prospective study. Patients underwent complete ophthalmic examination including biometry (IOLMaster; Carl Zeiss Meditec, Jena, Germany), visual acuity and objective refraction before being scheduled for bilateral sequential cataract surgery. Preoperative demographic and biometric data is given in Table 1. Inclusion criteria were: age of 18 years and older, uneventful cataract surgery, a potential visual acuity of 0.15 logMAR or better and a preoperative refractive astigmatism ≤ 2 D. Exclusion criteria were: systemic diseases which may affect surgical outcome, corneal diseases, expected postoperative astigmatism > 2 D, uncontrolled glaucoma, ocular trauma, capsular bag or zonula defects potentially affecting lens centration and retinal disorders affecting visual acuity or surgical intervention during this study.

Twelve intraocular lens designs were used in this study, defining the 12 IOL groups, among them five aberration-free (AF) IOLs, six aberration-correcting (AC) types and one spherical IOL as control (SC) group (Table 2). The IOL

Table 1. Preoperative demographic and biometric data of the study population. The data is given as mean ± standard deviation and [median]. The differences between the different intraocular lens groups were not statistically significant.

Number of patients (eyes)	198 (395)
Age [years]	73.1 ± 7.86 [74]
Males/females	47%/53%
Spherical equivalent K reading (n_K = 1.332) [D]	43.18 ± 1.46 [43.09]
Corneal astigmatism [D]	0.88 ± 0.54 [0.76]
Axial length [mm]	23.26 ± 0.90 [23.27]
Anterior chamber depth [mm]	3.04 ± 0.39 [3.03]
Spherical equivalent refraction [D]	0.76 ± 1.91 [0.75]
Refractive cylinder [D]	0.64 ± 0.56 [0.5]
Visual acuity [logMAR]	0.43 range: 0.0–2.0

Table 2. List of the intraocular lens types investigated in the current study along with number of eyes with completed follow-up examinations.

Aberration group	IOL type	Manufacturer	Number of eyes (completed)
Spherical IOL (control, SC)	AcrySof SA60AT	Alcon Laboratories Inc., Fort Worth, TX, USA	66 (63)
Aberration-free (AF)	Acri.Smart 46LC	Acri.Tec GmbH, Henningsdorf, Germany	32 (28)
	Akreos Adapt AO	Bausch & Lomb, Rochester, NY, USA	32 (30)
	C-flex/Superflex aspheric	Rayner Intraocular Lenses Ltd., Hove, East Sussex, UK	29 (27)
	Domicryl SHD	Domilens GmbH, Hamburg, Germany	29 (27)
	EasAcryl 100	Technomed GmbH, Baesweiler, Germany	31 (28)
Aberration-correcting (AC)	Acri.Smart 36A	Acri.Tec GmbH, Henningsdorf, Germany	29 (29)
	AcrySof IQ SN60WF	Alcon Laboratories Inc., Forth Worth, TX, USA	30 (27)
	PY-60AD	Hoya Corporation, Tokyo, Japan	30 (23)
	Quatrix Aspheric	Corneal Laboratories, La Rochelle, France	24 (21)
	Tecnis ZA9003	Advanced Medical Optics Inc., Santa Ana, CA, USA	33 (33)
	XL Stabi ZO	Carl Zeiss Meditec AG, Jena, Germany	30 (29)

were chosen randomly taking into account that a patient may receive lenses based on two different IOL concepts.

The study protocol was approved by the institutional ethics committee and informed written consent was obtained from every patient before inclusion.

Patients were included into the study on the day of primary cataract surgery; surgery of the fellow eye was planned at the 2 weeks follow-up of the initially treated eye. Patients were planned for follow-up examination at least 45 days after second cataract surgery.

IOL calculation was performed using the IOLMaster (Carl Zeiss Meditec AG), and IOL power calculation was performed using the Haigis formula (2014). Target refraction was chosen to be close to −0.5 D unless an explicit patients' request, the average target refraction was −0.49 ± 0.32 [−0.47] D.

Postoperative examination included visual acuity, refraction, spherical aberration (Zernike coefficient $Z_{4,0}$ measured by Ocular Wavefront Analyzer; Schwind eye-tech solutions GmbH & Co. KG, Kleinostheim, Germany) with natural and dilated pupil (6 mm diameter) as well as mesopic and photopic contrast sensitivity (Optec 6500 Functional Vision Analyzer; Stereo Optical Inc., Chicago, IL, USA). Postoperative pupil diameter was measured with a Colvard pupillometer (OASIS Medical Inc., San Dimas, CA, USA). Comparisons of CS were performed using the ICS in two different ways: one was calculated by subtracting the median CS score of the normal population provided by Haughom and Strand giving an impression how the individually measured CS matches that of a young population. As they provided data for binocular CS which is generally accepted to be approximately √2 higher than monocular CS (Campbell & Green 1965; Home 1978; Legge 1984; Simpson et al. 2009), we divided the median CS values by a factor of √2 for a more realistic comparison. The second ICS was calculated using the median CS score of the control group providing the comparison with the spherical IOL. To improve readability and comparability with the results of other publications we present the logarithm (base 10) of the CS values (logCSF). In addition to the ICS and for comparison reasons, we calculated the AULCSF as the area under the logCS curve. This was done by fitting a 3rd order polynomial to the logCSF data points and integrating the area under the curve between 1.5 and 18 cpd.

Statistical analysis was performed using IBM SPSS 19 (IBM SPSS Corp., Chicago, IL, USA). Descriptive data are presented as mean ± standard deviation (SD) and [median]. Differences between groups were tested using the Mann–Whitney *U*-test. p Values less than 0.05 were considered statistically significant.

Results

The ratio of right eyes was 50.1%; thus, we had one patient which had only one eye included in the study. Among the 198 patients, 179 (357 eyes) completed the follow-up ranging from 48 to 211 days after second cataract surgery (71 ± 21.4 [63] days). Second cataract surgery was performed 46.6 ± 26.5 [45] days after first IOL implantation. Contrast sensitivity could not be acquired by another four patients (eight eyes); thus, the remaining data is based on a total of 175 patients (353 eyes). Mean postoperative visual acuity was 0.055 [0.0458] logMAR, mean deviation from target refraction 0.22 ± 0.73 [0.26] D. Mean natural pupil diameter was 3.65 ± 0.79 [4.00] mm. Problems with night vision or dysphotopsia were not observed.

The data of the CSF for the different IOL groups is shown in Table 3 (mesopic) and Table 4 (photopic) along with the corresponding mICS/pICS and area under mesopic contrast sensitivity function/area under photopic contrast sensitivity function (mAULCSF/pAULCSF) values. There was no statistically significant difference in the CSF or mICS/pICS values between the spherical and the aberration-free group ($p > 0.688$, Table 5). However, we found statistically significant differences between the aberration-correcting group compared with the spherical ($p < 0.022$) or the aberration-free group ($p < 0.038$, Table 5).

Figure 1 shows the mean CS for mesopic and photopic lighting conditions along with the 95% confidence interval. The distribution of the mICS and pICS among the three aberration type groups is given in Fig. 2. The mICS and pICS did not correlate with the pupil diameter except the pICS of the control group which showed a weak correlation ($r = 0.305$, < 0.017). In this group, we also found a significant correlation of both mICS and pICS scores with residual spherical aberration (mesopic: $r > 0.25$; $p < 0.049$ and photopic: $r > 0.30$; $p < 0.019$) regard-

Table 3. Median contrast sensitivity function (CSF) values under mesopic lighting conditions for all lenses and aberration groups along with the corresponding mAULCSF and mICS referred to normal population and control group.

	Median mesopic logCSF					mICS versus		
IOL type	1.5	3	6	12	18	Haughom and Strand	SA60AT	mAULCSF
AcrySof SA60AT	1.56	1.60	1.52	0.90	–	−144	–	1.41
Acri.Smart 46LC	1.70	1.76	1.59	0.98	–	−92	71	1.48
Akreos Adapt AO	1.56	1.69	1.52	0.90	–	−141	21.5	1.42
C-flex/Superflex aspheric	1.56	1.60	1.36	–	–	−195	−32	1.30*
Domicryl SHD	1.56	1.60	1.45	–	–	−169	−6	1.21*
EasAcryl 100	1.70	1.76	1.52	0.90	–	−125	38	1.38
AF group	1.63	1.76	1.52	0.60	–	−131	32	1.38
Acri.Smart 36A	1.70	1.76	1.65	1.18	–	−52	111	1.58
AcrySof IQ SN60WF	1.70	1.76	1.65	1.04	–	−69	94	1.56
PY-60AD	1.70	1.76	1.52	–	–	−115	48	1.36†
Quatrix Aspheric	1.56	1.76	1.52	0.60	–	−116	46.5	1.42†
Tecnis ZA9003	1.70	1.76	1.65	1.18	–	−76	87	1.59
XL Stabi ZO	1.70	1.76	1.65	1.18	–	−83	79.5	1.55
AC group	1.70	1.76	1.65	1.04	–	−85	47	1.54

mICS = mesopic index of contrast sensitivity, mAULCSF = area under mesopic contrast sensitivity function.
* Significant difference to Acri.Smart 46LC, $p < 0.013$.
† Significant difference to other lenses in AC group, but no difference to SA60AT.

Table 4. Median contrast sensitivity function (CSF) values at photopic lighting conditions for all lenses and aberration groups along with the corresponding pAULCSF and pICS referred to normal population and control group.

	Median photopic logCSF					pICS versus		
IOL type	1.5	3	6	12	18	Haughom and Strand	SA60AT	pAULCSF
AcrySof SA60AT	1.56	1.76	1.81	1.34	1.08	−289	–	1.72
Acri.Smart 46LC	1.70	1.90	1.81	1.48	1.08	−258	31	1.78
Akreos Adapt AO	1.56	1.76	1.81	1.34	1.08	−276	13	1.75
C-flex/Superflex aspheric	1.70	1.76	1.65	1.34	0.60	−341	−52	1.63
Domicryl SHD	1.56	1.76	1.65	1.41	0.70	−337	−48.5	1.67
EasAcryl 100	1.70	1.76	1.81	1.48	0.90	−284	5	1.74
AF group	1.70	1.76	1.81	1.34	1.00	−284	4	1.74
Acri.Smart 36A	1.70	1.90	1.81	1.48	1.08	−181	108	1.78
AcrySof IQ SN60WF	1.70	1.90	1.81	1.48	1.08	−227	62	1.78
PY-60AD	1.70	1.76	1.81	1.34	0.90	−213	76	1.82
Quatrix Aspheric	1.56	1.76	1.81	1.34	1.00	−266	23	1.74
Tecnis ZA9003	1.56	1.76	1.81	1.48	1.08	−178	111	1.83
XL Stabi ZO	1.70	1.90	1.89	1.48	1.08	−172	116	1.85
AC group	1.70	1.76	1.81	1.48	1.08	−212	76.5	1.81

pICS = photopic index of contrast sensitivity, pAULCSF = area under photopic contrast sensitivity function.

Table 5. Statistical significance levels (Mann–Whitney *U*-test) of the comparison between the aberration groups in respect to CSF, ICS and AULCSF (*statistically significant).

	Statistical significance of differences in mesopic CSF						
IOL type	1.5	3	6	12	18	mICS	mAULCSF
Control versus AF	0.442	0.427	0.989	0.955	0.162	0.763	0.975
Control versus AC	0.136	0.002*	0.001*	0.026*	0.091	0.001*	0.002*
AF versus AC	0.397	0.008*	0.002*	0.013*	0.692	0.003*	0.003*
	Statistical significance of differences in photopic CSF						
IOL type	1.5	3	6	12	18	pICS	pAULCSF
Control versus AF	0.541	0.337	0.734	0.648	0.731	0.688	0.980
Control versus AC	0.172	0.017*	0.025*	0.254	0.209	0.022*	0.032*
AF versus AC	0.358	0.107	0.029*	0.076	0.041*	0.038*	0.019*

mICS/pICS = mesopic/photopic index of contrast sensitivity, mAULCSF/pAULCSF = area under mesopic/photopic contrast sensitivity function.

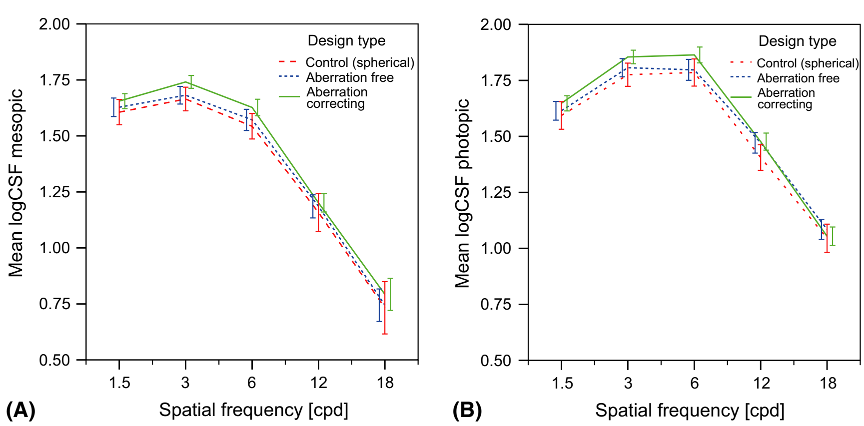

Fig. 1. Mean contrast sensitivity curves for mesopic (A) and photopic (B) vision in log units for spatial frequencies between 1.5 and 18 cycles per degree (cpd) according to the stimulus rows (A–F) in the Optec Vision Tester. The error bars show the 95% confidence intervals.

less of pupil size, whereas the aberration-free and aberration-correcting group showed no correlation.

Discussion

Contrast sensitivity is an important measure of visual performance after ophthalmological intervention. It has been widely used to quantify visual performance in visually impaired patients or with implants that pursue to improve contrast vision such as aberration-correcting lenses or those that are used to treat presbyopia such as multifocal lenses or the KAMRA inlay (Mester et al. 2003; Nio et al. 2003; Packer et al. 2004; Chen et al. 2006; Rocha et al. 2006; Caporossi et al. 2007; Pepose et al. 2009; Wahba et al. 2011; Waring 2011; Alió et al. 2012; Gong et al. 2012; Giannakopoulou et al. 2013; Schuster et al. 2013; Schweitzer et al. 2013; Seyeddain et al. 2013; Thomas et al. 2013; Yamauchi et al. 2013; Ye et al. 2013; Crnej et al. 2014; Schrecker et al. 2014). Contrast sensitivity is mostly presented with the contrast sensitivity function (CSF) chart, which corresponds to the test stimuli on the F.A.C.T. chart implemented in the Optec 6500 Functional Vision Analyzer (Ginsburg 1984; Richman et al. 2013). Comparison of different measurements is possible by direct comparison of the CSF values. CS of a single eye therefore requires comparison of ten values (five spatial frequencies for each, mesopic and photopic vision). This makes statistical comparison between patients rather difficult. Just recently, Haughom & Strand (2013) published data on CS of a normal population and they proposed a new index to represent CS by a single numerical value for each lighting condition. Their *index of contrast sensitivity* (ICS) was developed to account also for the different relevance of spatial frequency, as the human eye shows higher sensitivity for 6 cpd than for other spatial frequencies. The normal ICS range was −385 to 606 for mesopic vision (mICS) and −679 to 294 for photopic vision (pICS), with a median of 0 for both indices. Therefore, any other patient group can easily be compared to that data by their ICS median and range. To our knowledge this is the first study to provide CSF and mICS/

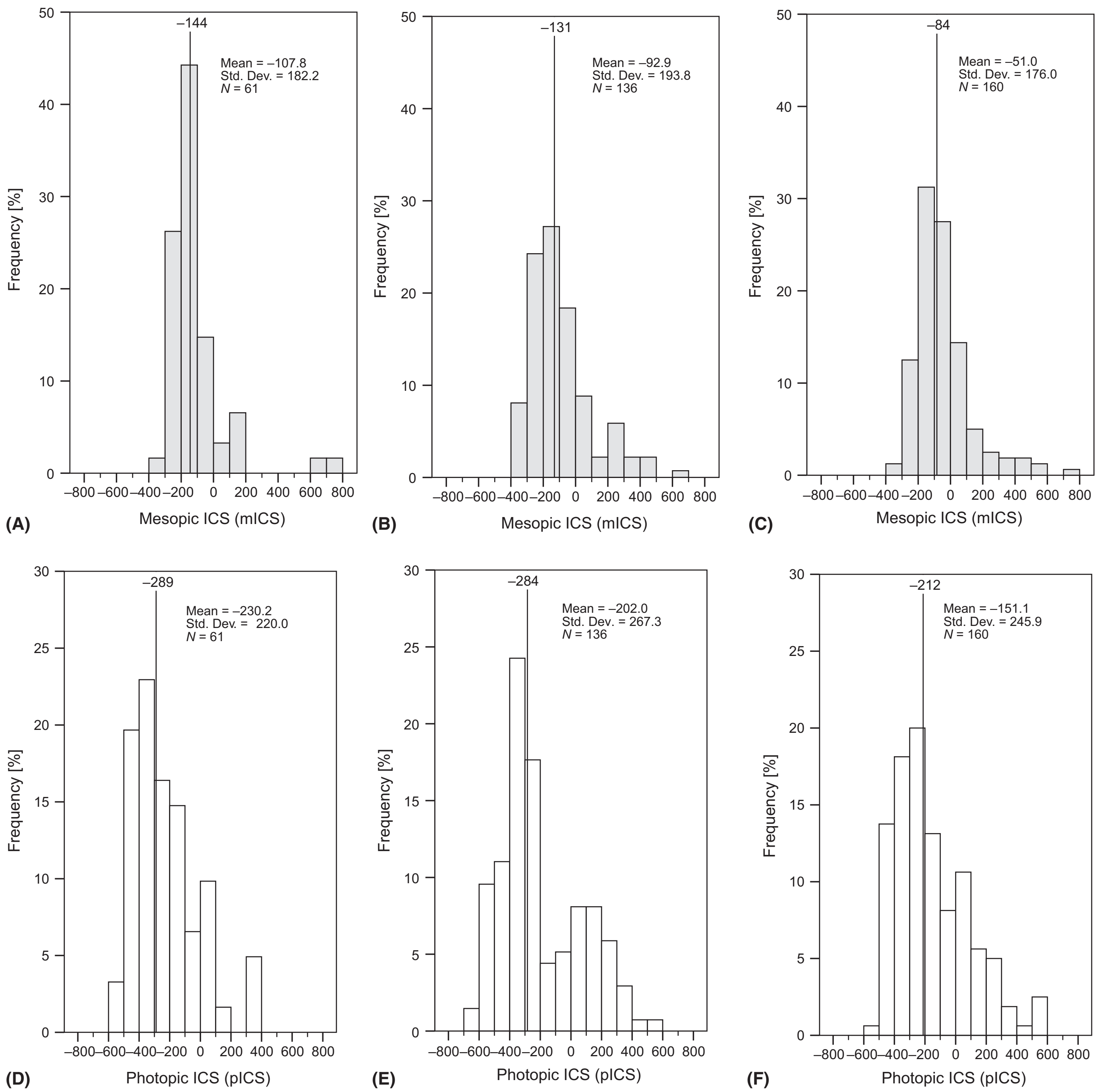

Fig. 2. Distribution of the mesopic and photopic ICS (mICS, pICS) scores among the aberration groups for mesopic and photopic vision (histograms). The vertical lines show the median of the distribution. Values are spread around zero, showing that pseudophakic contrast sensitivity is close to contrast sensitivy of the normal population. Subfigures A/D show the mesopic/photopic ICS distribution with the spherical IOL, B/E with aberration-free IOLs and C/F with aberration-correcting IOLs, respectively.

pICS data with different intraocular lenses comprising different optical concepts. We compared the pseudophakic patients with the normal population data of Haughom & Strand (2013) as well as with the data of our control group which received a spherical intraocular lens. This allows a comparison of the eleven aberration-free or aberration-correcting lenses to the contrast vision of a young adult population and with pseudophakic eyes with a spherical IOL. Hohberger et al. (2007) published data on the monocular contrast sensitivity of a healthy population at different age levels. With the available data, we calculated a mICS of −179 and a pICS of −382 (referenced to the Haughom & Strand normal) for the age-matched group >60 years ($N = 13$). These values show that eyes which had undergone cataract surgery have better median contrast sensitivity (mICS = −115 and pICS = −263) than an age-matched healthy group regardless of intraocular lens design. However, the differences are small which may be explained by the findings of Sia et al. (2013) who found that different types of cataract cause a reduction in the intermediate to high (12–18 cpd) spatial frequencies only. Due to the weighting of the spatial frequencies for ICS calculation, this decline in CS at higher frequencies will result only in minor differences in the ICS. In addition, mesopic vision benefits more from an aspheric IOL than photopic vision, especially due to the correction of spherical aberration at large pupil diameters, which is supported by the findings of Crnej et al. (2014). We found significant differences between the IOL groups. As anticipated, the CS in the aberration-correcting group was significantly ($p < 0.04$) better than in the aberration-free or spherical group. However, we expected that the aberration-free group might perform better than the spherical group, which could not be supported by our data ($p > 0.688$). An explanation for this might be the high variability in corneal aberrations, which remain uncorrected by aberration-free or spherical IOL concepts. Comparing the range of mICS/pICS among the IOL groups with the normal values of Haughom & Strand (2013), we found out that the range of pseudophakic CS is comparable with that of a young healthy normal population. However, the median is slightly inferior (compare Fig. 2a-f), but the median mICS/pICS of eyes with aspheric IOLs is closer to the young normal population compared to a spherical IOL. The CSF values for our patients can be compared with other published values after cataract surgery with implantation of spherical or aspherical IOLs (Mester et al. 2003; Nio et al. 2003; Packer et al. 2004; Chen et al. 2006; Rocha et al. 2006; Caporossi et al. 2007; Pepose et al. 2009; Wahba et al. 2011; Gong et al. 2012; Ye et al. 2013; Crnej et al. 2014). Schuster et al. (2013) reported a high variability among the reported contrast sensitivity results of pseudophakic eyes. This is supported by our ICS data. The results of the different IOLs and aberration designs show a large overlap, and we also observed large standard deviations in our data. This emphasizes that the benefit with aspheric IOL cannot be achieved for all eyes. It moreover depends on effects like corneal asphericity and corneal spherical aberration, pupil size, postoperative IOL position in axial and lateral direction as well as the individual neural contrast perception. Effects of corneal asphericity and IOL position on the theoretical image quality has been investigated before (Pieh et al. 2009; Gillner et al. 2012; Langenbucher et al. 2014).

This leads also to the limitations of the current study: differences between the different aberration concepts might be more significant if the individual correction of spherical aberration and IOL decentration are taken into account. In addition, spherical aberration of the individual eye plays an important role in the performance of an intraocular lens. Our aberration-correcting group included clear material and blue light blocking (yellow) IOLs; however, we did not analyse the effect of the blue light filter as it has been already reported that CS is comparable with clear and yellow tinted IOLs (Leibovitch et al. 2006; Muñoz et al. 2012). We also included lenses with intended full correction of spherical aberration such as the Tecnis as well as lenses with a balanced optical design to account for possible decentration effects [Hoya with Aspheric Balanced Curve™ (ABC) design and Zeiss ZO design (Gillner et al. 2012)]. Mesopic CSF with glare was not tested with our patients, which may show reduced CS in the presence of higher order aberrations (e.g. with a spherical lens). Another limitation is the reference to the data from Haughom & Strand (2013) instead of a real age-matched group. More than 60% of the patients included by Haughom & Strand (2013) were reported to be commercial aviators and their patients had a best corrected binocular visual acuity of 1.2 or better in 95% of the patients. As contrast sensitivity is correlated to visual acuity (Kromer et al. 2013), this may indicate that the normal population of Haughom & Strand (2013) may have a better contrast sensitivity than a normal population representing a higher variability of professions. In addition, they reported binocular contrast sensitivity which is reported to be a factor of $\sqrt{2}$ to 1.6 higher than monocular CS. We therefore corrected their median CS values by a factor of $1/\sqrt{2}$ due to the lack of published data on monocular CS. We believe that this simple model for binocular summation is adequate for our study of calculating estimated monocular CS from binocular CS. In general, binocular summation is proven to be more complex than just considering a weighting factor of $1/\sqrt{2}$ (Meese et al. 2006; Blake & Wilson 2011; Meese & Summers 2012).

To deal with all these limitations of using the reference data (different age, binocular summation problem etc.), we also calculated the ICS referenced to our control group which gives a direct impression on how good aspheric IOL perform in comparison with a widely used spherical IOL.

Another general limitation refers to the general concept of the ICS as it requires reliable median reference data for contrast sensitivity. Therefore, ICS data are relative data and always referenced to respective values of a normal population. Other CS measuring indices such as the area under the CS or log CS curve (AUCSF or AULCSF) have been defined previously which do not require referencing to normal values (Applegate et al. 1998; Marcos 2001; Bühren et al. 2006; Hohberger et al. 2007). However, the coarse sampling in spatial frequency of the F.A.C.T. and the requirement of interpolation algorithms affect the quality of this CS index as well as the lack of a weighting function to account for the retinal sensitivity to different spatial frequencies. Both concepts of AULCSF and ICS have to be calculated separately for mesopic and photopic vision.

Conclusions

The improvement of contrast sensitivity with aspheric intraocular lenses was small but significant compared to that of a spherical IOL, which is in accordance with the literature (Schuster et al. 2013; Crnej et al. 2014). Eyes with aspheric IOLs can achieve a contrast sensitivity close to that of young normal eyes.

We were able to separate various intraocular lens designs in terms of contrast sensitivity using the *index of contrast sensitivity* (ICS). Pseudophakic patients showed better contrast sensitivity than an age-matched phakic control group. The ICS is a useful score to evaluate and compare overall contrast sensitivity in pseudophakic eyes, and we provided normal values for the photopic and mesopic ICS after cataract surgery.

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