# COMPARISON OF VARIOUS SPHERICAL ABERRATION COMPENSATION METHODS IN PSEUDOPHAKIC EYES

*ROZEMA J.*[1,2], *TASSIGNON M.J.*[1,2]


## ABSTRACT

*Purpose:* To provide a numerical comparison of the efficiency of spherical aberration (SA) compensation methods commonly used in commercial aspheric intraocular lenses (IOLs).

*Methods:* Numerical simulations were performed using the wavefront data of 139 right eyes implanted with a spherical Morcher 89A ("Bag-in-the-Lens") IOL. Simulations were done for spherical, constant aspherical and SA-free IOLs, as well as for the customized selection method.

*Results:* Constant aspherical IOLs bought 49.6% of the eyes to a targeted postoperative SA value $\pm 0.05\ \mu$m, while zero-SA IOLs brought 61.2% of the eyes to this range. However with customized selection 95% of the eyes could be brought to this target, resulting in more control over the postoperative spherical aberration. If no aspherical correction was used, only 8.6% of the eyes could reach the set target.

*Conclusion:* These numerical results suggest that IOLs with an asphericity as a function of IOL power, supplemented by a customized selection from a number of fixed SA values according to preoperative corneal SA, may provide sufficient control over the postoperative SA. Given the surgeon centration possibility of the Bag-in-the-Lens IOL used in this study, as well as its centration stability, this is an ideal lens to implement the customized selection method.



## KEY WORDS

Aspherical IOL, corneal spherical aberrations, customized selection


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[1] *Department of Ophthalmology, Antwerp University Hospital, Edegem, Belgium*

[2] *Faculty of Medicine, Antwerp University, Wilrijk, Belgium*



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# INTRODUCTION

It was observed by Artal et al.(1) that in young phakic eyes the crystalline lens has a negative spherical aberration (SA, also indicated by Zernike coefficient $c_4^0$ that compensates for the positive spherical aberration of the cornea. With age this compensation is lost as the lenticular SA increases (2), resulting in an overall increase of total ocular SA. It is also well known that after cataract surgery using a classic spherical intraocular lens (IOL) a certain amount of postoperative positive SA is induced (3, 4). These two observations have led to the development of aspherical IOLs.

While it is generally accepted that positive SA may be harmful to visual performance (5), the extent to which they should be compensated remains a matter of debate. One side of the debate argues that the optimal postoperative SA value would be either zero or slightly negative, because in that case, the point spread function and modulation transfer function at full sphero-cylindrical correction are optimal (6). Moreover it was found that in phakic eyes the contrast sensitivity at 15 cycles per degree is optimized if the SA is fully corrected (7). However other authors point out that this leads to a significantly reduced distance corrected near vision (8).

Parallel to this debate two different types of aspherical IOLs were developed. The first type, called the "constant aspherical IOLs", tries to compensate the postoperative SA by inducing one constant negative SA value for all patients (9). This single negative SA value was obtained by calculating the average postoperative SA of a population implanted with a spherical version of the same IOL. Many outcome studies have been published for this type of lenses and their results have been compared with those of spherical IOLs (see Rękas (10), Kohnen (11) or Montes-Mico (12) for literature reviews on these topics). This category of aspherical IOLs contains lenses such as e.g. the Alcon AcrySof IQ, AMO Tecnis Z9002/ ZA9003 and Acri.Tec Acri.Lyc A.

Another SA compensation philosophy is to preserve some postoperative SA by eliminating only the SA induced by the IOL. By this way the influence of the corneal SA is left intact, resulting in a slightly positive postoperative SA value for the entire eye. Henceforth these aspherical lenses will be referred to as "SA-free IOLs" (e.g. the Bausch & Lomb SoftPort AOV, Acry.Tec Acry.Lyc LC and Rayner C-flex).

For both constant aspherical and SA-free IOLs the achieved postoperative total SA depends on the pupil size (10, 13, 14) and the corneal SA, both of which may vary widely between individuals (15, 16). Postoperative IOL centration and tilt also have an influence (13, 17, 18) as it may reduce the effectiveness of the induced SA correction. This effect was found to be more pronounced in constant SA IOLs than in SA-free IOLs (19).

As the cornea is an important source of inter-individual variability, a number of theoretical studies have investigated the potential benefit of a customized IOL-induced correction of either the corneal SA (20) or all corneal wavefront aberrations. (21-23) Given a near-perfect alignment customized-SA IOLs could in theory provide a diffraction limited image quality (19). However these lenses are not yet commercially available.

In the absence of customized-SA IOLs, several attempts have been made to approximate an ideal postoperative SA value by special selection of either the patient or the IOL. In a study by Beiko (24) a number of eyes were selected with very specific preoperative corneal SA values that could be corrected by the SA correction of the constant aspherical IOL intended to be implanted. Packer et al. (25, 26) on the other hand measured the preoperative corneal SA and selected one out of three constant aspherical IOLs to match the patient's SA. This "customized selection" of constant aspherical IOLs resulted in better outcomes than when no such selection was performed. Similar results were reported by Nochez et al. (27).

The aim of this work is to simulate which of the above methods could most effectively compensate for the postoperative SA measured in a population implanted with a spherical Morcher 89A "Bag in the Lens" IOL. This lens has been shown to eliminate the risk of posterior capsule opacification (PCO) and is not subjected to the effects of capsular changes over time (28), resulting in a good stability for postoperative shifts (29) or rotations. (30) As this lens presents the option of surgeon controlled centration (31), it can be implanted along the Line of Sight using the first and fourth Purkinje reflections of the coaxial lights of the operating microscope. This lens would therefore in theory be ideal for customized corrections of either the corneal SA or the all corneal wavefront aberrations.

# METHODS

## Patients

This retrospective study includes 139 right eyes of 139 patients aged *65.6 ± 16.7* years (range 8 up till 88 years) that were implanted with the spherical Morcher 89A IOL. The average power of the implanted IOLs was *20.2 ± 4.8D* (range *-3D* up till *+31D*).
As part of their follow-up a wavefront measurement was taken of these patients 6 months after implantation by means of a iTrace aberrometer (Tracey Technologies, Houston TX). Measurements were taken over a 5 mm pupil and are reported in a series of 44 Zernike coefficients.

## Formulas

In the following a number of formulas will be derived that describe the effect of the various types of IOLs on the SA. The postoperatively measured SA will henceforth be indicated by $C_{meas}$ (corresponding to coefficient $c_4^0$ of the Zernike expansion) and the desired postoperative SA value is given by $C_{target}$.
In case of perfect alignment between the cornea and the IOL, one can see that:

$$C_{meas} = C_{cornea} + C_{IOL} \tag{1}$$

with $C_{cornea}$ the corneal SA and $C_{IOL}$ the SA induced by the IOL. The corneal SA $C_{cornea}$ can be split up in a constant part $C_{corn,avg}$ (i.e. the average corneal SA in the general population) and a variable part $\Delta C_C$ (the individual deviation from this average), so that:

$$C_{cornea} = C_{corn,avg} + \Delta C_C \tag{2}$$

Typical values for $C_{corn,avg}$ are in the range [0.19 $\mu$m, 0.30 $\mu$m] and for $\Delta C_C$ in the range [0.04 $\mu$m, 0.10 $\mu$m] (see e.g. Sicam et al. (32) for an overview of what has been published in this field).

Following Seidel's aberration theory (33) the SA of an spherical IOL can be written as a fourth power of the IOL power $P$:

$$C_{IOL} = a_{IOL}P^4 \tag{3}$$

in which the $a_{IOL}$ is the intrinsic SA of a spherical IOL, defined by parameters such as lens shape and the refractive index of the IOL biomaterial.
In aspherical IOLs a correction term $C_{corr}$ must be added, so (3) becomes:

$$C_{IOL} = a_{IOL}P^4 - C_{corr}$$
$$\text{with } C_{corr} = (a \cdot P^4 + B) \tag{4}$$

As mentioned in the introduction, there are two types of aspherical IOLs: the zero-SA IOLs and the constant SA IOLs. The SA correction term $C_{corr}$ must therefore have an IOL power dependent part $a \cdot P^4$ to simulate zero-SA lenses and a constant part $b$ to simulate constant SA IOLs. Combining formulas (1) – (4) one finds an equation that calculates the measured SA of a pseudophakic eye implanted with an aspherical IOL using the different contributing components:

$$C_{meas} = (C_{corn,avg} + \Delta C_C) +$$
$$(a_{IOL}P^4 - (a \cdot P^4 + b)) \tag{5}$$

Table I shows the values of the $a$ and $b$ parameters used in spherical, constant aspherical, SA-free and fully customized SA IOLs. The $a$ and $b$ parameters in each of these lens types were chosen so that the postoperatively measured SA $C_{meas}$ would approximate a certain target value $C_{target}$ (usually chosen to be 0). So in case of a near-perfect IOL alignment and tilt it can be said that: $C_{meas} = C_{target}$.
However since the corneal SA is unique for each eye, achieving this would entail a full customization of the $a$ and $b$ parameters in each IOL. As it may be logistically and commercially chal-

Table I: *Parameter values in formula (3) used in various types of aspherical IOLs*

| IOL type | a | b | Total remaining SA* |
|---|---|---|---|
| Spherical | $0$ | $0$ | $C_{meas}$ |
| Constant aspherical | $0$ | $C_{corn,avg} - C_{target}$ | $\Delta C_C + a_{IOL} \cdot P^4 + C_{target}$ |
| SA-free IOL | $a_{IOL}$ | $C_{target}$ | $\Delta C_C + C_{target}$ |
| Customized SA | $a_{IOL}$ | $C_{cornea} - C_{target}$ | $C_{target}$ |
| Customized selection | $a_{IOL}$ | $C_{corn,avg} + m \cdot C_{step} - C_{target}$ | $(\Delta C_C - m \cdot C_{step}) + C_{target}$ |

* $C_{target}$ usually chosen 0.

lenging for manufacturers to produce IOLs with a fully customized SA, we also included a variation of Packer's customized selection method in this work. But instead of constant aspherical IOLs, as Packer did, we considered SA-free IOLs (i.e. $a = a_{IOL}$) and chose for $b$ the value:

$$b = C_{corn,avg} + m \cdot C_{step} - C_{target}$$

$$(m = -2, -1, 0, +1, +2) \qquad (6)$$

with $m$ chosen so that $|m \cdot C_{step} - \Delta C_C|$ is minimized. This allows for a semi-customized SA correction in discrete steps.

# RESULTS

## Total spherical aberration vs. age

The total SA 6 months after implantation of the IOL was found to have no correlation with age (Figure 1; $r^2 = 0.0168$). The average postoperative SA was $0.196 \pm 0.080\ \mu m$ (range: [$-0.006\ \mu m$, $0.449\ \mu m$]).

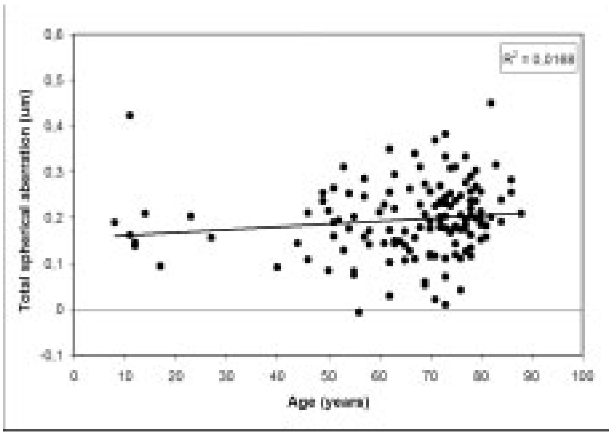


*Fig. 1:* Total Zernike spherical aberration coefficient $C_{meas}$ for 139 eyes 6 months or longer after implantation of a Morcher 89A IOL plotted as a function of age. (44 Zernike polynomials calculated over a 5 mm pupil).

## Total spherical aberration vs. IOL power P

Using formulas (5) - (6) and the parameters given in Table I, it is possible to simulate the amounts of postoperative SA induced by each type of SA correction in case of near-perfect IOL alignment (Figure 2). This allows to compare the efficiency of each correction type to bring the postoperative SA near a targeted SA value of $C_{target} = 0.05\ \mu m$ (The choice for this target value will be justified in the discussion). The percentages of eyes that fall within various ranges around this targeted value are given in Table II.

Comparing these percentages for the constant aspherical and SA-free IOLs, no significant differences were found ($X^2$-test, p 0.05). Comparing the percentages of either the constant aspherical of SA-free IOL with those of either the spherical IOLs or customized selection, highly significant differences are seen ($X^2$-test, p << 0.01).

# DISCUSSION

## Selection of $C_{target}$

In the ongoing discussion about which amount of postoperative SA is desirable after implantation of an IOL, several suggestions have been made based on various arguments (Table III). Zero or slightly negative postoperative SA give an optimal contrast sensitivity, PSF and MTF (20), resulting in a better distance visual acuity. However slightly positive postoperative SA values on the other hand were found to give a better depth of field

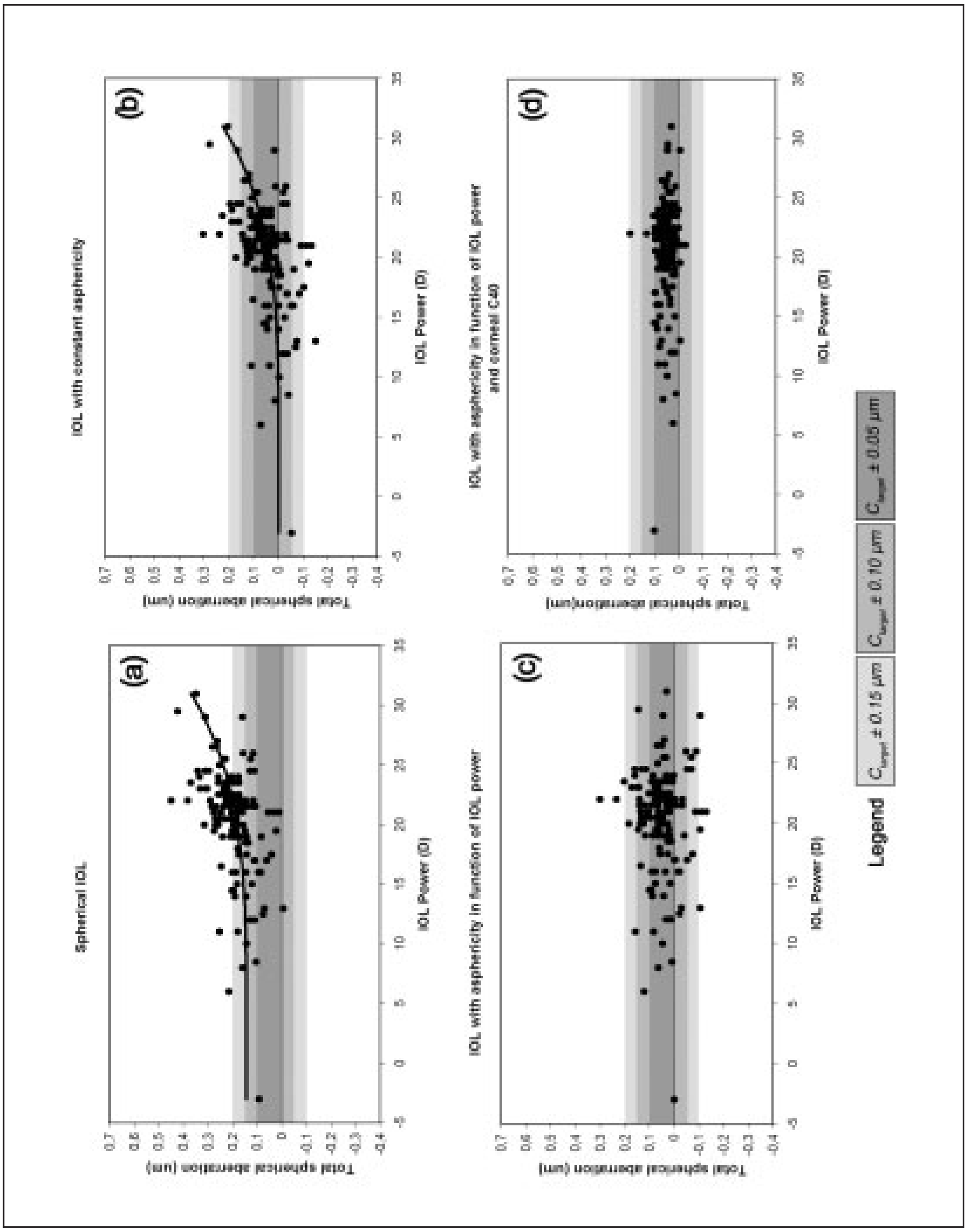


*Fig. 2:* Total Zernike spherical aberration coefficient $C_{meas}$ for (a) a spherical IOL; (b) the same data in case of correction by means of a constant aspherical IOL (c) the same data in case of correction by means of a SA-free IOL (d) the same data in case of correction by means of customized selection. The grey zones correspond with the postoperative ranges defined in Table II. (139 eyes, 44 Zernike polynomials calculated over a 5 mm pupil).

Table II: *Simulated postoperative SA values results using $C_{target} = 0.05\ \mu m$*

| | Spherical IOL | Constant Aspherical IOL | SA-free IOL | Customized selection* |
|---|---|---|---|---|
| **Parameter values** | | | | |
| ***a*** **(m$^5$)** | 0 | 0 | $0.245 \cdot 10^{-12}$ | $0.245 \cdot 10^{-12}$ |
| ***b*** **($\mu$m)** | 0 | 0.143 | 0 | $0.143 + m \cdot 0.1$ |
| **Average total SA ($\mu$m)** | 0.196±0.080 | 0.050±0.080 | 0.050± 0.070 | 0.049±0.032 |
| **Postoperative total SA range** | | | | |
| $C_{target} \pm 0.05\ \mu m$ | 8.6% | 49.6% | 61.2% | 94.2% |
| $C_{target} \pm 0.10\ \mu m$ | 27.3% | 80.6% | 85.6% | 99.3% |
| $C_{target} \pm 0.15\ \mu m$ | 53.2% | 92.8% | 94.2% | 100.0% |
| Outside the range | | | | |
| $C_{target} \pm 0.15\ \mu m$ | 46.8% | 7.2% | 5.8% | 0.0% |

* Customized selectionin three steps (i.e. $m = -1, 0, +1$); $C_{step} = 0.100\ \mu m$

in a clinical comparison between constant SA and spherical IOLs (34, 35). While this would slightly reduce the distance visual acuity in a pseudophakic eye, it improves the uncorrected visual acuity at near and intermediate distances . These results were confirmed in a laboratory setting by Piers (36). However, this author suggested that the definition commonly used for depth of focus may not be adequate if functional vision is concerned.

We attempted to find a balance between both effects by choosing $C_{target} = 0.05\ \mu m$ in our calculations, which is the average value of what is suggested in the literature. Note that, with the exception of the results of the spherical IOLs, the results given in Table II do not depend on the $C_{target}$ value that was chosen.

## Comparing the SA compensation methods

We found that the total postoperative SA in eyes implanted with a spherical IOL did not increase as a function of age, which suggests that a negative SA correction induced by an aspherical IOL might work adequately in a long term. However this needs to be studied in further detail in a longitudinal study setup.

Figure 2a clearly shows that in spherical IOLs the SA increases as a function of the IOL power. Correcting this with a single SA value, as is done in the constant aspherical IOLs, will reduce the average value of SA, but not correct this $P$-dependent trend (Figure 2b). This way only a certain range of IOL powers can be brought in the vicinity of $C_{target}$, while the higher and lower dioptric powers will deviate significantly from this value (by about $0.2\ \mu m$). This could raise the question whether subtracting a fixed SA value provides sufficient control over the postoperative total SA of pseudophakic patients.

In SA-free IOLs on the other hand no increase as a function of $P$ was found anymore, leaving only the corneal SA as influencing factor (Figure 2c). However, as there is a large variation $\Delta C_C$ in corneal SA, deviations up till $0.2\ \mu m$ from $C_{target}$ are still possible. Moreover, no significant differences were found between the distributions of postoperative SA in the SA-free and the constant aspherical IOLs for the different ranges around $C_{target}$ (Table II).

By fine-tuning the SA of the IOL to the patient's preoperative corneal SA using customized selection (formulas (5) – (6)), the variation in total postoperative SA due to the individual $\Delta C_C$ can be reduced considerably. Figure 2d and Table II show that with three steps of $0.10\ \mu m$ it is possible to bring 94.2% of the eyes to a postoperative SA that is within a narrow band $C_{target} \pm 0.05\ \mu m$, while none of the eyes would have a value outside $C_{target} \pm 0.15\ \mu m$. These results can be improved by either using more and smaller steps $C_{step}$ or by using IOLs with fully customized SA.

In practice it would be relatively simple for IOL manufacturers to implement the concept of customized selection. This would require a cer-

Table III: *target postoperative SA suggested in the literature*

| *Author*[1] | *Pupil diameter* | *Optimal SA* | *Argument* | *Type of study* |
|---|---|---|---|---|
| Denoyer[2] | 4.7 mm | $> 0.00\ \mu m$ | Better near vision | Postop comparison of zero-SA and constant aspherical IOLs |
| | 5.1 mm | $0.00\ \mu m$ | Better night-driving vision and mesopic contrast sensitivity | Postop comparison of zero-SA and constant aspherical IOLs |
| Li* | 6.0 mm | $0.10\ \mu m$ | Better visual acuity in presence of other aberrations | Adaptive optics simulator applied to phakic eyes |
| Marcos (34) | 4.5 mm | $> 0.00\ \mu m$ | Better depth of field | Postop comparison of spherical and aspherical IOLs |
| Piers (7) | 4.8 mm | $0.00\ \mu m$ | Optimal contrast sensitivity at 15 cpd | Adaptive optics simulator applied to phakic eyes |
| Rocha (8) | 5.0 mm | $> 0.00\ \mu m$ | Better distance corrected near vision | Postop comparison of spherical and aspherical IOLs |
| Wang (20) | 4.0 mm | $0.00\ \mu m$ | Optimal MTF, PSF and encircled energy | Simulated implantation of aspherical and wavefront customized IOLs |
| | 6.0 mm | $-0.05\ \mu m$ | | |
| Wang (6) | 6.0 mm | Customized | Optimal polychromatic PSF | Simulated implantation of aspherical IOLs with varying degree of asphericity |

[1] In alphabetical order; first author only
[2] Denoyer A, Denoyer L, Halfon J, Majzoub S, Pisella PJ. Comparative study of aspheric intraocular lenses with negative spherical aberration or no aberration. J Cataract Refract Surg. 2009; 35(3): 496-503.
* Li J, Xiong Y, Wang N, Li S, Dai Y, Xue L, Zhao H, Jiang W, Zhang Y. Effects of spherical aberration on visual acuity at different contrasts. J Cataract Refract Surg. 2009 Aug; 35(8): 1389-1395.

tain dioptric range of zero-SA IOLs, with the addition of three different levels of $b = C_{target} + m \cdot C_{step}$ ($m = -1, 0, +1$; $C_{step} = 0.10\ \mu m$). Such a logistic approach is already in use for toric IOLs.

Prior to the IOL implantation the surgeon should measure the corneal SA $C_{cornea}$. Although that after cataract surgery the corneal aberration pattern may change slightly from the preoperative pattern, it was reported that the corneal SA values remain unaltered (37). It is therefore safe to consider the preoperative corneal SA value as an approximation of the postoperative value.

From this measurement the right *a* and *b* values can be calculated that will achieve a previously determined value $C_{target}$. This could e.g. be done using a calculation program based on formula (4) provided by the IOL manufacturer. Next the IOL with the appropriate aspherical correction can be implanted in a standard cataract procedure.
The results in this work suggest that IOL asphericity as a function of IOL power, supplemented by a customized selection according to preoperative corneal SA, may provide a good control over the postoperative SA. However this may be limited by the unpredictability of the postoperative centration and tilt found in many IOL designs.

## REFERENCES


(1) Artal P, Benito A, Tabernero J – The human eye is an example of robust optical design. J Vis 2006; 6: 1-7.
(2) Artal P, Berrio E, Guirao A, Piers PA – Contribution of the cornea and internal surfaces to the change of ocular aberrations with age. J Opt Soc Am A 2002; 19: 137-143
(3) Uchio E, Ohno S, Kusakawa T – Spherical aberration and glare disability with intraocular lenses of different optical design. J Cataract Refract Surg 1995 Nov; 21(6): 690-696.
(4) Werner W, Roth EH – Image properties of spherical as aspheric intraocular lenses. Klin Monatsbl Augenheilkd 1999; 214(4): 246-250.
(5) Applegate RA, Sarver EJ, Khemsara V – Are all aberrations equal? J Refract Surg 2002 Sep-Oct; 18(5):S556-S562.

(6) Wang L, Koch DD – Custom optimization of intraocular lens asphericity. J Cataract Refract Surg 2007; 33: 1713-1720
(7) Piers PA, Manzanera S, Prieto PM, Gorceix N, Artal P – Use of adaptive optics to determine the optimal ocular spherical aberration. J Cataract Refract Surg. 2007; 33: 1721-1726
(8) Rocha KM, Soriano ES, Chamon W, Chalita MR, Nosé W – Spherical aberration and depth of focus in eyes implanted with aspheric and spherical intraocular lenses: a prospective randomized study. Ophthalmology 2007; 114: 2050-2054
(9) Holladay JT, Piers PA, Koranyi G, van der Mooren M, Norrby NE – A New Intraocular Lens Design to Reduce Spherical Aberration of Pseudophakic Eyes. J Refrac Surg 2002, 18: 683-691
(10) Rękas M, Krix-Jachym K, Zelichowska B, Ferrer-Blasco T, Montés-Micó R – Optical quality in eyes with aspheric intraocular lenses and in younger and older adult phakic eyes: Comparative study. J Cataract Refract Surg 2009; 35: 297-230
(11) Kohnen T, Klaproth OK – Asphärische Intraokularlinsen. Der Ophthalmologe 2008; 105: 234-240
(12) Montes-Mico R, Ferrer-Blasco T, Cervino A – Analysis of the possible benefits of aspheric intraocular lenses: Review of the literature. J Cataract Refract Surg 2009;35: 172-181
(13) Dietze HH, Cox MJ – Limitations of correcting spherical aberration with aspheric intraocular lenses. J Ref Surg 2005; 21: S541-S546
(14) Yamaguchi T, Negishi K, Ono T, et al. – Feasibility of spherical aberration correction with aspheric intraocular lenses in cataract surgery based on individual pupil diameter. J Cataract Refract Surg 2009; 35(10): 1725-1733.
(15) Artal P, Guirao A – Contributions of the cornea and the lens to the aberrations of the human eye. Opt Lett 1998; 23: 1713-1715
(16) Guirao A, Redondo M, Artal P – Optical aberrations of the human cornea as a function of age. J. Opt. Soc. Am. 2000; 17: 1697-1702
(17) Rosales P, Marcos S – Customized computer models of eyes with intraocular lenses. Opt Express 2007; 15: 2204-2218
(18) Baumeister M, Bühren J, Kohnen T – Tilt and decentration of spherical and aspheric intraocular lenses: effect on higher-order aberrations. J Cataract Refract Surg 2009; 35(6): 1006-1012.
(19) Eppig T, Scholz K, Loffler A, Messner A, Langenbucher A – Effect of decentration and tilt on the image quality of aspheric intraocular lens designs in a model eye. J Cataract Refract Surg 2009; 35: 1091-1100
(20) Wang L, Koch DD – Custom optimization of intraocular lens asphericity. J Cataract Refract Surg 2007; 33: 1713-1720
(21) Wang L, Koch DD – Effect of decentration of wavefront-corrected intraocular lenses on the higher-order aberrations of the eye. Arch Ophthalmol 2005; 123: 1226-1230
(22) Piers PA, Weeber HA, Artal P, Norrby S – Theoretical comparison of aberration-correcting customized and aspheric intraocular lenses. J Refract Surg 2007; 23: 374-385
(23) Barbero S, Marcos S – Analytical tools for customized design of monofocal intraocular lenses. Opt Express 2007; 15: 8576-8591
(24) Beiko GHH – Personalized correction of spherical aberration in cataract. J Cataract Refract Surg 2007; 33: 1455-1460
(25) Packer M, Fine IH, Hoffman RS – Aspheric intraocular lens selection: the evolution of refractive cataract surgery. Curr Opin Ophthalmol 2008; 19: 1-4
(26) Packer M, Fine IH, Hoffman RS – Aspheric Intraocular Lens Selection Based on Corneal Wavefront. J Ref Surg 2009; 25: 12-20
(27) Nochez Y, Favard A, Majzoub S, Pisella PJ – Measurement of corneal aberrations for customization of intraocular lens asphericity: impact on quality of vision after micro-incision cataract surgery. Br J Ophthalmol 2009 Oct 14. [Epub ahead of print]
(28) De Groot V, Leysen I, Neuhann T, Gobin L, Tassignon MJ – One-year follow-up of the bag-in-the-lens intraocular lens implantation in 60 eyes. J Cataract Refract Surg 2006; 32: 1632-1637
(29) Verbruggen KHM, Rozema JJ, Gobin L, Coeckelbergh T, De Groot V, Tassignon MJ – Intraocular lens centration and visual outcomes after bag-in-the-lens implantation. J Cataract Refract Surg 2007; 33: 1267-1272
(30) Rozema JJ, Gobin L, Verbruggen K, Tassignon MJ – Changes in rotation after implantation of a bag-in-the-lens intraocular lens. J Cataract Refract Surg 2009; 35: 1385-1388
(31) Tassignon, MJ; Rozema, JJ; Gobin, L – Ring-shaped caliper for better anterior capsulorhexis sizing and centration. J Cataract Refract Surg 2006; 32: 1253-1255
(32) Sicam VA, Dubbelman M, van der Heijde RG – Spherical aberration of the anterior and posterior surfaces of the human cornea. J Opt Soc Am A Opt Image Sci Vis 2006 Mar; 23(3): 544-549.
(33) Born M, Wolf E – Chapter 5: Geometrical theory of aberrations. In: Principles of Optics, sixth

edition. Cambridge UK, Cambridge University Press 1980; 203-232
(34) Marcos S, Barbero S, Jiménez-Alfaro I – Optical quality and depth-of-field of eyes implanted with spherical and aspheric intraocular lenses. J Refract Surg 2005; 21: 223-235
(35) Johansson B, Sundelin S, Wikberg-Matsson A, Unsbo P, Behndig A – Visual and optical performance of the akreos adapt advanced optics and tecnis Z9000 intraocular lenses - Swedish multicenter study. J Cataract Ref Surg 2007; 33: 1565-1572
(36) Piers PA, Fernandez EJ, Manzanera S, Norrby S, Artal P. – Adaptive optics simulation of intraocular lenses with modified spherical aberration. Invest Ophthalmol Vis Sci 2004; 45: 4601-10
(37) Marcos S, Rosales P, Llorente L, Jiménez-Alfaro I – Change in corneal aberrations after cataract surgery with 2 types of aspherical intraocular lenses. J Cataract Refract Surg 2007 Feb; 33(2): 217-226

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*Adress for correspondance:*
*J. ROZEMA*
*Department of Ophthalmology,*
*Antwerp University Hospital,*
*Wilrijkstraat 10,*
*2650 Edegem, BELGIUM*
*Tel: + 32 3 821 48 15*
*Fax: + 32 3 825 19 26*
*Email: Jos.Rozema@uza.be*