TO THE EDITOR

Nowadays is well stated that after keratorefractive surgery, without a special correction, the intraocular lens (IOL) power is usually inaccurate. The article by Kenneth J. Hoffer1 which appeared in the first January-March 2010 issue of the Journal of Emmetropia is an excellent review of recently published studies that analyze and try to solve the problems to calculate IOL power in eyes with prior refractive surgery. In his review, Hoffer report our method2 as a mere correction factor to the keratometric index of refraction. This is not true. The reason why the IOL power after corneal refractive surgery could be inaccurate is multifactorial. The possible sources of error are: change of corneal asphericity, change of ratio between anterior and posterior corneal surfaces, and K-based estimation of effective lens position. For this reason, we proposed a formula based on a multiple approach2-4.

Our formula originates from a theoretical one that we empirically adjusted in two parameters: 1) the corneal power and 2) the prediction of effective lens position:

\[ P = \frac{1366(4R_{adj} - L)}{(L - ACD_{post})(4R_{adj} - ACD_{post})} \quad (1) \]

where

\[ R_{adj} = f(R, KRS, \Delta D) \quad (2) \]

and

\[ ACD_{post} = f(ACD_{pre}, CT, L, ACD_{const}) \quad (3) \]

The theoretical base formula is the modified Binkhorst II one5. The corneal radius \((R_{adj})\) to be inserted in the formula is a fictitious curvature radius, expressed in mm, whose value is a function of the actual corneal curvature \((R)\), of the kind of keratorefractive surgery \((KRS)\) and of the surgically induced refractive change \((\Delta D)\). For convenience, all following formulas have been developed in order to consider \(\Delta D\) on the spectacle plane. The value \(ACD_{post}\) of our formula represents the prediction of the effective implant position (ELP), more precisely the distance between the princi-

ple planes of the cornea and of the IOL. In a different way from other third-generation formulas that often use keratometry as one of the predictors to estimate the ELP of the IOL, and in a similar way to Haigis’ formula6, we have chosen a method independent of K. The variable \(ACD_{post}\) is a function of the anterior chamber depth previous to cataract surgery \((ACD_{pre})\), of the lens thickness \((CT)\), of the axial length \((L)\) and of the ACD constant \((ACD_{const})\). Our formula follows two different procedures according to the kind of refractive surgery performed on the eye for which we must calculate IOL: in the case of incisional surgery, keratometers perform an incorrect measurement of the corneal curvature; instead, in the case of laser ablative surgery, the prime cause of error is the conversion from curvature radius to dioptric power of the cornea7.

\[(a)\] If the eye for which we must calculate the IOL power has undergone incisional refractive surgery or any other kind of surgery that does not modify the ratio between anterior and posterior corneal surface, we consider as radius \((R)\) the average curvature, weighted according to SCE, of the corneal area that covers the entrance pupil. Then we calculate the real corneal power with the paraxial equation (4) \(P = (n - 1) / R\) adopting a keratometric refractive index \((n)\) of 1.3319. In our opinion, after radial keratotomy (RK) we should use conventional keratometric readings only when reliable topographic measurements are not available, because after RK the measurement of the corneal radius with a keratometer is affected by errors, due to great variations of corneal eccentricity and the possibility that the keratometric targets are reflected out of the optical zone, in an irregular and very curved area8,9. After RK, when we use keratometric readings, we can improve their precision following this procedure: we consider the average of the conventional keratometric readings \((R)\), then we calculate the real corneal power according to the paraxial equation (4) utilizing an adjusted keratometric refractive index \((n_{adj})\) that is a function of the surgical induced refractive change \((\Delta D)\) according to the following empirical linear regression formula:

\[ n_{adj} = 1.3319 + 0.00096x\Delta D \quad (5) \]

At this point, the fictitious curvature ray \((R_{adj})\) is calculated by solving (4) inversely with \(n = 1.3319\):

\[ R_{adj} = \frac{0.3319xR}{n_{adj} - 1} = \frac{0.3319xR}{0.00096x\Delta D + 0.3319} \quad (6) \]

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(b) When the eye for which we must calculate IOL power has previously undergone laser ablative refractive surgery or any other kind of surgery that modifies the ratio between anterior and posterior corneal surfaces, we calculate the real corneal power with the paraxial equation (4) utilizing a relative keratometric refractive index ($n_{rel}$).

$$n_{rel} = 1.3319 + 0.00113x\Delta D$$  \hspace{1cm} (7)

Following myopic LASIK, Jarade et al\textsuperscript{10} proposed a similar regression formula to correct the overestimation of automated K-readings:

$$n_{rel} = 1.3375 + 0.0014x\Delta D$$  \hspace{1cm} (7)

In our opinion, as explained above, the more adequate curvature radius ($R$) is the average curvature, weighted according to SCE, of the corneal area that covers the entrance pupil. In the case of PRK, LASEK or LASIK, for mild or moderate myopia with an ablation zone size $\geq 5.5$ mm, there are minimal discrepancies between Sim-K and average central power\textsuperscript{9,11}, so we can consider $R$ equal to the average of the keratometric readings. Then the fictitious radius of curvature ($R_{adj}$) is calculated by solving the paraxial equation inversely with $n = 1.3319$:

$$R_{adj} = \frac{0.3319xR}{n_{rel} - 1} = \frac{0.3319xR}{0.00113x\Delta D + 0.3319}$$  \hspace{1cm} (8)

In this formula an error in the estimate of SIRC produces an error in the refractive outcome lower than the one produced by the clinical history method, because this datum is not directly used to calculate the corneal power but is used to obtain a relative keratometric index. In this way the error in refractive outcome will be only a fraction of the error in the estimate of SIRC.

The above described methods are not usable when the patient clinical history is completely unknown (i.e. no data about the SIRC), or in cases of lamellar keratoplasty operated corneas (LK) or phototherapeutic keratectomy corneas (PTK). To solve these particular cases, we suggest the following method: we can obtain the curvature of the posterior surface of the cornea utilizing the Camellin Formula\textsuperscript{12} to calculate the radius of the curvature of the posterior corneal surface on the basis of the measurement of the radius of curvature of the anterior corneal surface, of the central pachymetry and of a series of pachymetries performed in a 3 mm circular zone.

Once we know the radius of the anterior ($R_{ant}$) and posterior ($R_{post}$) curvature in mm, we can calculate the relative powers:

$$P_{ant} = \frac{1376 - 1000}{R_{ant}}$$  \hspace{1cm} (9)

By adding the anterior corneal power to the posterior one, we obtain the real corneal power, by which, after solving (1) inversely, it is possible to obtain the new keratometric refractive index ($n_{rel}$) that shall be used, as described above, to calculate $R_{adj}$:

$$R_{adj} = \frac{0.3319xR}{n_{rel} - 1}$$  \hspace{1cm} (11)

An advantage of this method is that, having a multiple approach, it can be applied to any type of keratorefractive surgery. But for the same reason, it is not so easy to apply, and required calculations are rather tedious, unless a dedicated computer program is used\textsuperscript{3,4}.

After keratorefractive surgery, a lot of work has been done to optimize the prediction of IOL power with different methods. A direct comparison between the different proposed methods is difficult to do, because of: the different ways for measuring corneal curvature (keratometric data, topographic data, K flat, central K, etc.); the different ways for measuring biometric data (ultrasound or optical interferometry); the different IOL power calculation formulas to which apply statistical adjustments; and the different ranges of ametropias from which these statistical adjustments have been derived and to which they could be applied (for example, for hyperopic surgery we cannot use an index derived from a myopic sample). As stressed by Koch\textsuperscript{13}, as is always the case when there are several solutions to a problem, none is perfect. Fortunately, new methods continue to improve accuracy and, in some cases, reduce the complexity of these calculations. The issue of IOL calculation after refractive surgery is becoming an ever-increasing one, as more refractive patients are presenting for cataract surgery. Up to now, intraocular lens power calculation after corneal refractive surgery has remained challenging\textsuperscript{13,14}. Surgeons are significantly challenged by the expectations of patients associated with any form of refractive surgery; the challenge becomes even greater when former refractive surgery patients require cataract surgery. The paradox is that, as a group, postrefractive surgery patients may have unrealistic goals for the exactness of the optical results after cataract surgery, although their outcomes have been less predictable than in routine eyes\textsuperscript{15}. We believe that in our first series of cases, we have obtained encouraging results\textsuperscript{2,16}. With follow up of a greater number of cases, we will be able to perform further statistical empirical adjustments relative to the different types of refractive surgery in order to better improve the accuracy of calculations. The number of cataract surgeries after corneal refractive surgery is
anticipated to increase. As more and more refractive patients will present for cataract surgery, more and more cases will be analyzed. In the future, it would be useful if a central data bank could be established for all eyes that had keratorefractive surgery so that details and records of previous laser treatment would be available. In this way, we shall be able to perform further statistical empirical adjustments, in order to better correct patients who, by their original decision to have vision correction surgery, have demonstrated that they have above-average refractive demands.

REFERENCES