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Postoperative vault prediction for phakic implantable collamer lens surgery: LASSO formulas

Leandro Rocamora, MSc, José I. Orlando, PhD, Christoph Lwowski, MD, Thomas Kohnen, MD, PhD, Erik Mertens, MD, Karel Van Keer, MD, PhD

Purpose: To develop and evaluate reliable formulas for predicting postoperative vault more accurately after implantable collamer lens (ICL) surgery in a White patient population with varying degrees of ametropia.

Setting: Private clinical practice.

Design: Retrospective analysis on dataset split into a separate training and test set.

Methods: 115 eyes of 59 patients were used to train regression models predicting postoperative vault based on anterior segment optical coherence tomography (OCT) parameters (Least Absolute Shrinkage and Selection Operator [LASSO]-OCT formula), ocular biometry data (LASSO-Biometry formula), or data from both devices (LASSO-Full formula). The performance of these models was evaluated against the manufacturer's nomogram (Online Calculation and Ordering System [OCOS]) and Nakamura 1 (NK1) and 2 (NK2) formulas on a matched separate test set of 37 eyes of 19 patients.

Results: The mean preoperative spherical equivalent was −5.32 ± 3.37 (range: +3.75 to −17.375 diopters). The mean absolute errors of the estimated vs achieved postoperative vault for the LASSO-Biometry, LASSO-OCT, and LASSO-Full formulas were 144.1 ± 107.9 μm, 145.6 ± 100.6 μm, and 132.0 ± 86.6 μm, respectively. These results were significantly lower compared with the OCOS, NK1, and NK2 formulas ($P <$ .006). Postoperative vault could be estimated within 500 μm in 97.3% (LASSO-Biometry) to 100% of cases (LASSO-OCT and LASSO-Full).

Conclusions: The LASSO suite provided a set of powerful, reproducible yet convenient ICL sizing formulas with state-of-the-art performance in White patients, including those with low to moderate degrees of myopia. The calculator can be accessed at http://icl.emmetropia.be.

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Implantable collamer lens (ICL) surgery offers a compelling surgical alternative for patients who are not eligible for, or prefer to avoid, corneal refractive laser surgery. Several studies have demonstrated the excellent safety and efficacy profile of ICL surgery.[1–5] To minimize the risks of ICL surgery, maximal effort should be made to avoid the need for reinterventions.

Inadequate postoperative vault is the leading cause for ICL exchange/explantation.[6–9] Vault refers to the sagittal distance between the posterior surface of the ICL and the anterior capsule of the crystalline lens. Within the range of 250 to 750 μm, the risks for developing anterior subcapsular cataract (due to insufficient vaulting), as well as for secondary glaucoma due to iris pigment dispersion and endothelial cell loss (due to excessive vaulting), are very low.[2,3,10–13] Postoperative vault is determined by the ocular anatomy and the dimensions of the implanted ICL. The anatomy of the eye influences the vault in 2 major ways: first, sagittal dimensions (anterior chamber depth [ACD] and crystalline lens rise) determine the anteroposterior distance between the resting position of the ICL in the ciliary sulcus and the anterior lens capsule. Second, the coronal dimension of the eye (sulcus-to-sulcus diameter) determines the degree by which the ICL is compressed in the ciliary sulcus.[14–16] The STAAR V4c ICL (STAAR Surgical AG) is designed in such a way that lateral compression of the ICL will lead to an anterior bowing of the lens.[15] For a given sulcus-to-sulcus diameter, increasing the ICL size will therefore increase the vault.

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From the Yatiris Group, PLADEMA Institute, Universidad Nacional del Centro de la Provincia de Buenos Aires (UNICEN), Tandil, Buenos Aires, Argentina (Rocamora, Orlando); Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Tandil, Buenos Aires, Argentina (Orlando); Department of Ophthalmology, Goethe-University, Frankfurt Am Main, Germany (Lwowski, Kohnen); Medipolis, Antwerp, Belgium (Mertens); Department of Ophthalmology, University Hospitals UZ Leuven, Leuven, Belgium (Van Keer); Biomedical Sciences Group, Department of Neurosciences, Research Group Ophthalmology, KU Leuven, Leuven, Belgium (Van Keer).

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Corresponding author: Karel Van Keer, MD, PhD, Herestraat 49, 3000 Leuven, Belgium. Email: karel.vankeer@uzleuven.be.

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Choosing the optimal ICL size remains challenging. The STAAR V4c ICL comes in 4 sizes (diameter of 12.1 mm, 12.6 mm, 13.2 mm, or 13.7 mm). Based on preoperative data, the surgeon should choose the diameter with the highest probability of resulting in an adequate vault. The manufacturer's official Online Calculation and Ordering System (OCOS) formula selects the preferred ICL size based on the corneal diameter (white to white) and ACD. While achieving excellent average results, this formula is notable for its outliers.[15,17] Moreover, the formula reports only the preferred ICL size but does not estimate the achieved vault for the selected ICL. In an effort to improve the predictability of ICL sizing, several formulas have been developed, with their own strengths and weaknesses with regard to precision, accuracy, external validity, and ease of use.[14,18–24] Of particular importance, the majority of these new ICL sizing formulas have been trained on Asian datasets with a high proportion of strongly myopic eyes.[19–21,23,24] Racial differences in ocular anatomy may limit the performance of these formulas in patients of other ethnicities.[25,26]

The aim of this study was to develop and share a convenient suite of ICL sizing formulas optimally suited for a less myopic population of White descent.

METHODS

Patients

This study was conducted using retrospective data of patients undergoing same-day bilateral ICL surgery at the Medipolis Eye Center, Antwerp, Belgium. In total, 78 patients, aged 18 to 52 years, were retrieved, of whom both eyes were included. Only eyes in which all preoperative and postoperative measurements were available were retained for further analysis, leaving a total of 152 eyes of 78 patients. Each patient was randomly assigned to a training set (80%) or a test set (20%), ensuring a similar distribution of postoperative vault values in both sets. Eyes corresponding to the same patient were assigned to the same set, resulting in a training set of N = 115 eyes (59 patients) and a test set of N = 37 eyes (19 patients). The training set was used for learning the vault prediction formulas and to calibrate their hyperparameters, whereas the test set was kept strictly separate and used only for evaluating the final models and the existing formulas.

Measurements

All patients underwent extensive ophthalmological preoperative and postoperative examinations. Intraocular pressure, autorefraction, visual acuity, and subjective refraction were assessed by a trained optometrist. An experienced technician performed endothelial cell count, optical biometry (IOLMaster 700, Carl Zeiss Meditec AG), and corneal topography + anterior segment optical coherence tomography (AS-OCT/MS-39, Costruzione Strumenti Oftalmici) under standardized mesopic conditions. A list of the relevant parameters that were used in the models, as well as their mean and SD in the training set, can be found in Supplemental Table 1 (http://links.lww.com/JRS/A723). Anamnesis, slitlamp biomicroscopy, and fundoscopy were performed by the operating surgeon (E.M.). The decision on the ICL size was made at the discretion of the surgeon and was guided by the OCOS and Nakamura 1 and 2 formulas (Supplemental Figure 2, http://links.lww.com/JRS/A719).[19,20] Postoperative vault was measured at 12 ± 4 weeks after surgery using the provided caliper tool of the OCT software. All OCT images were acquired under stable, mesopic light conditions to minimize the influence of pupil dilation or accommodation on the vault measurement.[27]

Surgical Procedure

All surgeries were performed by the same experienced surgeon (E.M.) under topical (preservative-free oxybuprocaine HCl 0.4%) + intracameral (preservative-free lidocaine 1%) anesthesia. Left eyes were operated first and right eyes second. A 1.0 mm side port was made at 5 o'clock (right eye) or 10 o'clock (left eye), followed by intracameral injection of lidocaine and methylcellulose (OcuCoat, Bausch & Lomb, Inc.). A temporal 2.6 mm clear corneal incision was made, followed by the implantation of the ICL. After unfolding, the lens was positioned in the ciliary sulcus. Nontoric ICLs were aligned along the horizontal meridian, and toric ICLs were rotated to the required axis. After verification of lens centration and alignment, the ophthalmic viscosurgical device material was rinsed with saline, incisions were sealed, intracameral preservative-free antibiotics (0.1 mL cefuroxime [10 mg/mL]) were injected, and 1 drop of dorzolamide 20% and timolol 5% was administered topically. In the recovery room, patients were given a tablet of acetazolamide 250 mg.

Model Development

Models were developed to predict postoperative vault based on patient demographics (age, refraction, and implanted ICL) and AS-OCT parameters (Least Absolute Shrinkage and Selection Operator [LASSO]-OCT formula), optical biometry parameters (LASSO-Biometry formula), or a combination of both (LASSO-Full formula). Rather than resorting to a classical multivariate linear regression approach, the LASSO technique was used.[28] This technique is an alternative linear regression model widely applied in the field of machine learning for predictive tasks with a high number of independent variables. It holds a major advantage over traditional multivariate linear regression in its ability to automatically discard irrelevant parameters that do not significantly contribute to the accuracy of the model. For a more in-depth description of this technique, as well as for a better understanding of the following paragraph, we refer to the reference article in the specialized literature.[28]

To control the effect of the L1 penalty in the optimization objective, α values in the set $\{10^{-4}, 10^{-3}, 10^{-2}, 10^{-1}, 1, 10, 10^2, 10^3, 10^4\}$ were explored by evaluating their resulting mean absolute error (MAE) on a 5-fold cross-validation scheme on the training set. The optimal α configuration was then applied to retrain the model on the entire training set. To reduce the effect of differences in feature scalings, data samples were standardized by subtracting each feature's individual mean and dividing the result by its corresponding SD before training and prediction, as estimated from the training set. The corresponding mean and SD values are reported in Supplemental Table 1 (http://links.lww.com/JRS/A723) for reproducibility purposes. All data preprocessing and model adjustments were performed using Python 3 (v. 3.9.9), Scikit-learn3 (v. 1.0.1), and SciPy4 (v. 1.7.1) modules.[29,30]

Evaluation Metrics and Statistical Analysis

The resulting models were evaluated on the separated test set to avoid biases in the results. The performance of the constructed models was also benchmarked against the OCOS and Nakamura et al.'s formula 1 (NK1) and 2 (NK2).[19,20] Because these alternative models are predictors for the ideal diameter of the ICL to implant, they were adapted to perform postoperative vault prediction using the equation proposed by Nakamura et al.[19]:

Predicted vault = 0.5 + 1.1 (implanted ICL size − optimal ICL size calculated from each formula).

Differences between the predicted vault value obtained by each formula and the corresponding ground truth postoperative vault were evaluated on a per-eye basis on the test set, using MAE, root

Table 1. Patient demographics and characteristics			
Parameter	**Training set Mean ± SD (range)**	**Test set Mean ± SD (range)**	***P* value**
Patients (eyes), n	59 (115)	19 (37)	
Age (y)	32.09 ± 7.00 (18.00, 52.00)	31.46 ± 7.53 (21.00, 43.00)	.813
Manifest refractive sphere (D)	−4.86 ± 3.37 (−17.00, 4.75)	−4.76 ± 2.65 (−14.00, 0.25)	.463
Manifest refractive cylinder (D)	−0.92 ± 1.01 (−5.50, 0.00)	−1.01 ± 1.19 (−6.00, 0.00)	.377
AL (mm)	25.50 ± 1.55 (21.08, 31.63)	25.55 ± 1.06 (24.19, 29.05)	.473
ACD (mm)	3.70 ± 0.23 (3.24, 4.36)	3.71 ± 0.24 (3.27, 4.28)	.470
Scleral spur to scleral spur (mm)	12.40 ± 0.47 (11.62, 13.58)	12.39 ± 0.27 (11.91, 12.99)	.384
Crystalline lens rise (mm)	−0.24 ± 0.16 (−0.69, 0.25)	−0.21 ± 0.14 (−0.55, 0.04)	.226
Implanted ICL power (D)	−5.93 ± 3.52 (−16.50, 4.75)	−5.93 ± 2.63 (−13.5, −0.75)	.445
Toric ICL (%)	43	38	.549
Postoperative achieved vault (μm)	479.51 ± 224.15 (80.00, 1376.00)	491.78 ± 253.47 (46.00, 1127.00)	.476

ACD = anterior chamber depth; AL = axial length

P value corresponds to the results of a Wilcoxon signed-rank test comparing the statistical differences in the distribution of each characteristic in training and test sets

mean square error, and the coefficient of determination R^2 values as obtained using Scikit-learn.[29] Nonparametric paired Wilcoxon signed-rank tests with the level of significance of 0.05 were used to statistically compare the distributions of vault predictions obtained by each formula with respect to the ground truth (2-tailed) and to evaluate differences in the error distribution (1-tailed), using SciPy.[30]

RESULTS

Model Design and Coefficients

Table 1 summarizes the main characteristics of the patient cohort after splitting the database into training and test sets. No statistical significant differences between training and test measurements were observed (Wilcoxon signed-rank test, $P > .05$). Supplemental Figure 1 (http://links.lww.com/JRS/A718) illustrates the distribution of spherical equivalent values in the training set.

A comparison in the distribution of ICL diameters recommended by the OCOS formula and the actual implanted ICL diameter as chosen by the surgeon is depicted in Supplemental Figure 2 (http://links.lww.com/JRS/A719). The postoperative vault achieved in the entire dataset was 482.5 ± 230.1 μm (range 46 to 1376 μm). A correlation analysis between pairs of measurements was performed using only the training set to avoid data leakage in model design. Supplemental Figure 3 (http://links.lww.com/JRS/A720) presents a heatmap with the R values corresponding to each pair of features, with those associated with the postoperative vault highlighted in blue (first column/row).

Figure 1 depicts the coefficients of each of the 3 different LASSO models. Notice that the learning algorithm automatically assigned an associated weight of zero to several features. This indicates that their contribution to minimize the objective error in the training set is minimal and that these features can thus be ignored in the model. On the other hand, parameters that are important to the model are

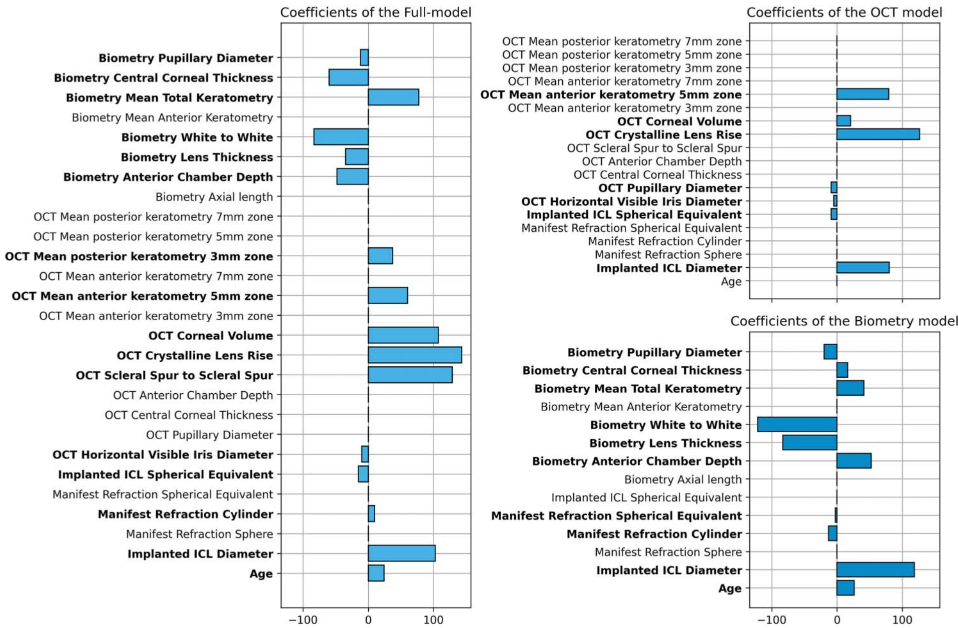

Figure 1. Model regression coefficients: Coefficients learned by the Full model (*left*), OCT model (*right*, *top*), and Biometry model (*right*, *bottom*).

Table 2. Postoperative vault prediction error

Parameter	Vault Mean ± SD	MAE ± SD	Maximal absolute error	RMSE	2-Tailed *P* value[a]	1-Tailed *P* value[b]
Measured postop vault	491.8 ± 250.0	—	—	—	—	—
OCOS	538.6 ± 369.0	285.4 ± 217.5	841.0	358.8	.414	.0011*
NK1	544.6 ± 255.8	269.5 ± 173.5	707.6	320.5	.330	.0003*
NK2	491.5 ± 241.4	239.7 ± 242.8	550.6	286.9	.922	.0017*
LASSO-Biometry	479.3 ± 126.2	144.1 ± 107.9	524.8	180.0	.729	.381
LASSO-OCT	506.8 ± 121.6	145.6 ± 100.6	437.8	177.0	.449	.376
LASSO-Full	494.3 ± 134.7	132.0 ± 86.6	347.6	157.9	.673	—

LASSO = Least Absolute Shrinkage and Selection Operator; MAE = mean absolute error; NK1 = Nakamura 1; NK2 = Nakamura 2; OCOS = Online Calculation and Ordering System; RMSE = root mean square error
From left to right: Mean and SD postoperative vault values as measured in the test set and predicted by OCOS, NK1, and NK2 formulas and our 3 proposed models. MAE and SD, maximal absolute error, and RMSE as reported by each formula.
*Statistically significant
[a]*P* value comparing the formula-estimated vault with the measured value
[b]*P* value comparing the formula's MAE with MAE of the LASSO-Full formula

attributed a positive or negative coefficient, the magnitude of which relates to the relative importance of the parameter.

Model Evaluation

Performance statistics of the different models are listed in Table 2, together with ground truth measurements and results from OCOS, NK1, and NK2 formulas. All models predicted vault values whose distribution is not statistically different from the achieved vault measurements (2-tailed paired Wilcoxon signed-rank test, $P > .05$). However, there exist significant differences in their error rates. The distributions of MAEs obtained by each formula are depicted as box plots in Figure 2. The LASSO formulas report the lowest errors, both in terms of MAE, maximal absolute error, and root mean square error. From the 3 LASSO models, the LASSO-Full formula was the most accurate, with the lowest MAE in terms of magnitude and SD.

Figure 3 depicts a cumulative bar chart showing the percentage of eyes in the test set with absolute errors (AEs) smaller than 50 μm, 100 μm, 200 μm, and 500 μm, for each of the proposed and baseline formulas. The LASSO-Full model obtained AEs below 100 μm for 40% of the test eyes, 70% under 200 μm, and 100% under 500 μm. By contrast, NK1, NK2, and OCOS formulas obtained consistently higher error rates, with the majority of the test eyes reporting errors exceeding 200 μm. Evaluating the cases with suboptimal postoperative vault in the test set (6 eyes <250 μm, 6 eyes >750 μm), the LASSO formulas would have resulted in a 50% (LASSO-Biometry, 3 eyes <250 μm, 3 eyes >750 μm) to 75% (LASSO-OCT and LASSO-Full, both 5 eyes <250 μm and 4 eyes >750 μm) reduction of excessive low or excessive high vault.

One-tailed Wilcoxon signed-rank tests were performed comparing the MAEs reported by the LASSO-Full model and each of the baseline formulas (Table 2). This analysis shows that the LASSO-Full model reported consistently lower errors than the OCOS, NK1, and NK2 formulas ($P < .05$). There was no statistically significant difference between the LASSO-Full and the LASSO-OCT or LASSO-Biometry models ($P > .05$).

Figure 4 presents a Bland-Altman plot demonstrating the differences in the vault prediction in the test set between the LASSO-Full and the NK2 formulas. Vault predictions by

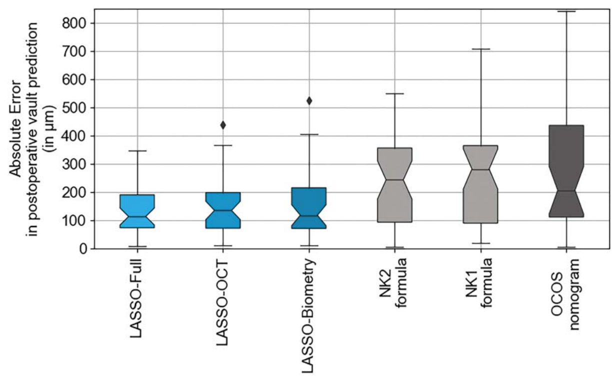

Figure 2. Distribution of absolute errors in the postoperative vault prediction. LASSO = Least Absolute Shrinkage and Selection Operator; NK1 = Nakamura 1; NK2 = Nakamura 2; OCOS = Online Calculation and Ordering System

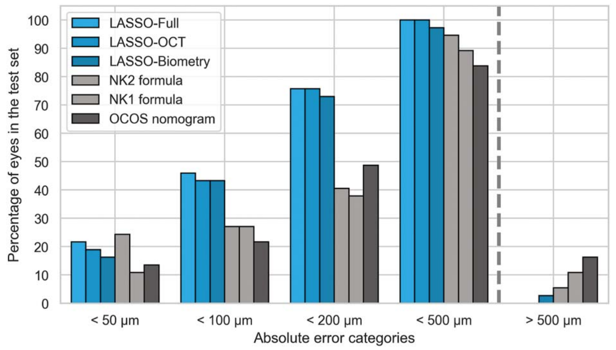

Figure 3. Cumulative predictive accuracy. *Left*: Cumulative bar chart with the percentages of eyes in the test set with absolute errors smaller than 50 μm, 100 μm, 200 μm, and 500 μm, for each of the LASSO models and the baseline formulas. *Right*: Percentage of eyes in the test set with absolute errors higher than 500 μm. LASSO = Least Absolute Shrinkage and Selection Operator; NK1 = Nakamura 1; NK2 = Nakamura 2; OCOS = Online Calculation and Ordering System

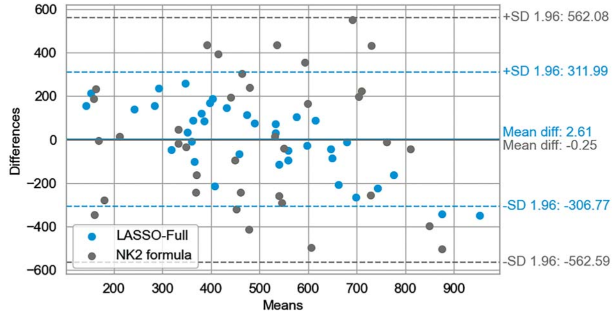

Figure 4. Bland-Altman plot comparing LASSO-Full and NK2. Agreement between the measured postoperative vault values in the test set and the predictions from the LASSO-Full model and NK2 formula. LASSO = Least Absolute Shrinkage and Selection Operator; NK2 = Nakamura 2

the LASSO-Full model report a mean signed difference with the achieved vault of 2.61 and are narrowly spread around zero. The NK2 formula has an even smaller mean signed difference of only −0.25 but is characterized by much more spreaded results. Supplemental Figure 4 (http://links.lww.com/JRS/A721) depicts these data in a different perspective, showing the scatterplot and regression lines between achieved and predicted vault for the LASSO-Full model (R^2 = 0.68) and NK2 formula (R^2 = 0.11).

DISCUSSION

In this article, we describe the development and performance of the LASSO formulas, a convenient suite of ICL sizing formulas that can assist refractive surgeons in further improving the safety of ICL surgery. The elective nature of refractive surgery demands the most stringent safety standards. Over the years, studies have shown that in the hands of an experienced surgeon, ICL implantation has an excellent efficacy and safety profile with a very low risk for sight-threatening complications.[1–5] Postoperative vault is considered one of the most important risk factors for complications after ICL surgery. Accordingly, inadequate vault is reported as the major reason for ICL exchange/explantation.[6–9] Improving the process of ICL sizing is therefore of key importance to further improve the safety profile of ICL surgery.[2,4] The LASSO suite contributes to this evolution in 3 major areas: accuracy and precision, external validity, and convenience.

The LASSO models are characterized by a high accuracy and precision compared with the standard and state-of-the-art models. With the favorable postoperative vault range between 250 μm and 750 μm, the recommended target vault for the STAAR V4c ICL is 500 μm.[2] To improve the predictability of ICL sizing, not only should the *average* estimated vault be close to the average achieved postoperative vault (overall accuracy), the *individual* estimates should also be as close as possible to the individual achieved postoperative vaults (precision).[31] The latter is important to reduce the risk of achieving a vault outside the favorable range. When evaluating the performance of an ICL formula, one should therefore not only compare the *average* estimated vs achieved vault but also, more importantly, assess the prediction error of the *individual* cases. The most relevant metrics in this regard are the MAE (the MAE between the estimated and achieved vault in an individual case) and its SD, together with the maximal absolute error (the largest absolute difference between the estimated and achieved vault in the dataset). As can be observed in Table 2, on average, all the formulas that were used in this manuscript were able to estimate the postoperative vault fairly well, with no significant differences between the estimated and achieved vault for any of the models. The OCOS formula, however, is characterized by a high MAE (284.5 ± 217.5 μm) and high maximal absolute error. This illustrates a known shortcoming of the OCOS formulas and explains why this formula is prone to outliers that fall outside the favorable range.[15,17] In agreement with previous studies, the NK1 and especially the NK2 formulas show improved MAE ± SD and maximal absolute errors in our test dataset.[19,20] The LASSO models further improve the precision, as evident from the significantly smaller MAE, SDs, and maximal absolute errors. Where the maximal absolute error of the OCOS formula in our test set was 841.0 μm, this error was only 347.6 μm in the LASSO-Full model. Figure 3 illustrates how these findings translate into clinical practice: following the OCOS formula would have resulted in an error of more than 500 μm in 10.8% of cases, whereas the LASSO-Full, LASSO-OCT, and LASSO-Biometry formulas predicted, respectively, 100%, 100%, and 97.3% of cases within 500 μm. For the LASSO-Full model, over 90% of cases could be estimated within 200 μm. These results put the performance of the LASSO-Full model on a par with the recently published state-of-the-art formulas by Kang et al. and Kamiya et al.[23,24]

In contrast to most other recent formulas, the LASSO models were trained on a European dataset, comprising a considerable amount of patients with low and moderate myopia. Supplemental Table 2 (http://links.lww.com/JRS/A723) lists an overview of previously published publicly available formulas. The majority of them were trained on an Asian, more myopic population. Racial differences in the anatomy of the anterior segment are known to have an impact on ICL sizing.[25,26] This translates to a very different distribution of implanted ICL sizes between Asian and European studies (Supplemental Figure 5, http://links.lww.com/JRS/A722). In the study from Kamiya et al. and Kang et al., the 13.7 mm diameter ICL was only implanted in, respectively, 2 (0.1%) of 1745 eyes and 1 (0.04%) of 2756 eyes. The second largest 13.2 mm ICL accounts to less than 10% in both studies, with most patients receiving a 12.6 mm or 12.1 mm ICL.[23,24] Our study is in line with other recently published European studies and shows an opposite pattern with few 12.1 mm implantations but a much higher percentage of the larger 13.2 mm and 13.7 mm lenses.[22,32] These differences between Asian and White eyes may limit the external validity of the Asian models when used in White patients. Having almost no 13.7 mm ICLs in their training dataset, the models trained on an Asian population cannot be expected to be as accurate for the larger ICL sizes as they are for the 12.1 mm and 12.6 mm lenses. Moreover, the training set used for the LASSO models is also considerably less myopic compared with most other studies (Supplemental Table 2, http://links.lww.com/JRS/A723). As ICL surgery is becoming more and more popular in patients with mild and moderate myopia, it is important that new formulas follow this trend.[33] The level of myopia has a significant influence on several anterior chamber parameters of relevance in ICL sizing including crystalline lens rise, ACD, and WTW.[34,35] The training set used in this study included patients across the ametropic spectrum (manifest refractive sphere ranging from −17.00 to +4.75 diopters [D]), with a particular large percentage of eyes with low (>−3 D) and moderate (>−6 D) myopia (Supplemental Figure 1, http://links.lww.com/JRS/A718). This sets the LASSO models apart from previously published formulas and makes them particularly suited for White patients with low to moderate myopia.

The LASSO suite is convenient and can be easily implemented into clinical practice. First, the models rely largely on automatically captured measurements. In comparison with ultrasound imaging, the ocular biometry and AS-OCT imaging techniques used in this study are less operator dependent.[36] Second, by providing 3 different formulas, the LASSO suite allows the user to tailor the formula to the available equipment. The LASSO-Biometry model offers a compelling option for surgeons without access to an AS-OCT device to improve the accuracy of their ICL calculations over the OCOS formula. Third, the models are provided as linear regression formulas that can be easily implemented by the end user in a spreadsheet calculator without the need for programming skills or special software.

The study should be read in the context of its limitations. Although the training set is of respectable size, the performance of the models could likely be improved by increasing the dataset, especially for the extreme ICL sizes of 12.1 mm and 13.7 mm, of which only few cases were included in this study. Second, the monocentric, retrospective nature of this study may overestimate the performance of the models when used in a different setting. Given the constraints of the study setting, we took measures to minimize its impact by strictly separating the training and test sets at the patient level, thus avoiding data leakage between both eyes of the same patient. Future studies should examine whether the high level of performance achieved in our test set can be matched on external datasets.

In conclusion, the LASSO suite is a set of powerful ICL sizing formulas that were trained on a White population including a large portion of low to moderate myopia. The LASSO-Biometry, the LASSO-OCT, and the LASSO-Full models report excellent accuracy and precision over a wide range of refractive errors and show especially improved results in the low myopic range. The formulas can be accessed at http://icl.emmetropia.be. Based on the available equipment, refractive surgeons can easily implement one of the formulas in their clinical practice. By refining the postoperative vault prediction, the LASSO suite may ultimately help to further improve the safety profile of ICL surgery.

WHAT WAS KNOWN

- ICL provides a safe and effective alternative to corneal refractive surgery.
- Inadequate postoperative vault is the major reason for ICL explantation.
- Most recently published ICL sizing formulas are trained on Asian datasets with predominantly highly myopic patients.

WHAT THIS PAPER ADDS

- The LASSO models offer excellent performance for predicting postoperative vault in White patients, also in those with low to moderate myopia.

REFERENCES

1. Choi JH, Lim DH, Nam SW, Yang CM, Chung ES, Chung TY. Ten-year clinical outcomes after implantation of a posterior chamber phakic intraocular lens for myopia. J Cataract Refract Surg 2019;45:1555–1561
2. Packer M. Meta-analysis and review: effectiveness, safety, and central port design of the intraocular collamer lens. Clin Ophthalmol 2016;10:1059–1077
3. Alfonso JF, Fernández-Vega-Cueto L, Alfonso-Bartolozzi B, Montés-Micó R, Fernández-Vega L. Five-year follow-up of correction of myopia: posterior chamber phakic intraocular lens with a central port design. J Refract Surg 2019;35:169–176
4. Montés-Micó R, Ruiz-Mesa R, Rodríguez-Prats JL, Tañá-Rivero P. Posterior-chamber phakic implantable collamer lenses with a central port: a review. Acta Ophthalmol 2021;99:e288–e301
5. Repplinger B, Kohnen T. Intraocular pressure after implantation of an ICL with aquaport: development of intraocular pressure after implantation of an ICL (model V4c) with aquaport without iridotomy [in German]. Ophthalmologe 2018;115:29–33
6. Zeng QY, Xie XL, Chen Q. Prevention and management of collagen copolymer phakic intraocular lens exchange: causes and surgical techniques. J Cataract Refract Surg 2015;41:576–584
7. AlSabaani NA, Behrens A, Jastanieah S, Al Malki S, Al Jindan M, Al Motowa S. Causes of phakic implantable collamer lens explantation/exchange at King Khaled Eye Specialist Hospital. Middle East Afr J Ophthalmol 2016;23:293
8. Kaur M, Titiyal JS, Falera R, Sinha R, Sharma N. Indications for explant of implantable collamer lens. Eye (Lond) 2018;32:838–840
9. Alhamzah A, Almudhaiyan T, Alfardan F, Aldebasi T, Almudhaiyan T. Indications for exchange or explantation of phakic implantable collamer lens with central port in patients with and without keratoconus. Int J Ophthalmol 2021;14:1714–1720
10. Yu Y, Zhang C, Zhu Y. Femtosecond laser assisted cataract surgery in a cataract patient with a “0 vaulted” ICL: a case report. BMC Ophthalmol 2020;20:179
11. Strungaru MH, González Rodríguez J, Weisbrod DJ, Tayfour F, Buys YM. Acute angle closure following implantable collamer lens for myopia. J Glaucoma 2020;29:e74–e76
12. Chen X, Wang X, Xu Y, Cheng M, Han T, Wang X, Zhou X. Long-term comparison of vault and complications of implantable collamer lens with and without a central hole for high myopia correction: 5 years. Curr Eye Res 2021;47:540–546
13. Córdoba A, Graue-Hernández EO, Gómez-Bastar A, Navas A. Long-term follow-up of persistent low vault after implantable collamer lens exchange. J Cataract Refract Surg 2019;45:519–522
14. Kojima T, Yokoyama S, Ito M, Horai R, Hara S, Nakamura T, Ichikawa K. Optimization of an implantable collamer lens sizing method using high-frequency ultrasound biomicroscopy. Am J Ophthalmol 2012;153:632–637.e1
15. Nam SW, Lim DH, Hyun J, Chung ES, Chung TY. Buffering zone of implantable collamer lens sizing in V4c. BMC Ophthalmol 2017;17:260–266
16. Gargallo-Martinez B, Garcia-Medina JJ, Rubio-Velazquez E, Fernandes P, Villa-Collar C, Gonzalez-Meijome JM, Gutierrez-Ortega R. Vault changes after cyclopentolate instillation in eyes with posterior chamber phakic intraocular lens. Sci Rep 2020;10:9646–9649

17. Lee DH, Choi SH, Chung ES, Chung TY. Correlation between preoperative biometry and posterior chamber phakic Visian Implantable Collamer Lens vaulting. Ophthalmology 2012;119:272–277
18. Dougherty PJ, Rivera RP, Schneider D, Lane SS, Brown D, Vukich J. Improving accuracy of phakic intraocular lens sizing using high-frequency ultrasound biomicroscopy. J Cataract Refract Surg 2011;37:13–18
19. Nakamura T, Isogai N, Kojima T, Yoshida Y, Sugiyama Y. Implantable collamer lens sizing method based on swept-source anterior segment optical coherence tomography. Am J Ophthalmol 2018;187:99–107
20. Nakamura T, Isogai N, Kojima T, Yoshida Y, Sugiyama Y. Optimization of implantable collamer lens sizing based on swept-source anterior segment optical coherence tomography. J Cataract Refract Surg 2020;46:742–748
21. Igarashi A, Shimizu K, Kato S, Kamiya K. Predictability of the vault after posterior chamber phakic intraocular lens implantation using anterior segment optical coherence tomography. J Cataract Refract Surg 2019;45:1099–1104
22. Trancón AS, Manito SC, Sierra OT, Baptista AM, Serra PM. Determining vault size in implantable collamer lenses: preoperative anatomy and lens parameters. J Cataract Refract Surg 2020;46:728–736
23. Kamiya K, Ryu IH, Yoo TK, Kim JS, Lee IS, Kim JK, Ando W, Shoji N, Yamauchi T, Tabuchi H. Prediction of phakic intraocular lens vault using machine learning of anterior segment optical coherence tomography metrics. Am J Ophthalmol 2021;226:90–99
24. Kang EM, Ryu IH, Lee G, Kim JK, Lee IS, Jeon GH, Song H, Kamiya K, Yoo TK. Development of a web-based ensemble machine learning application to select the optimal size of posterior chamber phakic intraocular lens. Transl Vis Sci Technol 2021;10:5
25. Qin B, Tang M, Li Y, Zhang X, Chu R, Huang D. Anterior segment dimensions in Asian and Caucasian eyes measured by optical coherence tomography. Ophthalmic Surg Lasers Imaging Retina 2012;43:135–142
26. Chang JS, Meau AY. Visian collamer phakic intraocular lens in high myopic Asian eyes. J Refract Surg 2007;23:17–25
27. Xiong Y, Mao Y, Li J, Wan X, Li M, Zhang J, Wang J, Sun X. Vault changes and pupillary responses to light in myopic and toric implantable collamer lens. BMC Ophthalmol 2021;21:366
28. Tibshirani R. Regression shrinkage and selection via the Lasso. J R Stat Soc Ser B 1996;58:267–288
29. Pedregosa F, Varoquaux G, Gramfort A, Michel V, Thirion B, Grisel O, Blondel M, Prettenhofer P, Weiss R, Dubourg V. Scikit-learn: machine learning in Python. J Machine Learn Res 2011;12:2825–2830
30. Virtanen P, Gommers R, Oliphant TE, Haberland M, Reddy T, Cournapeau D, Burovski E, Peterson P, Weckesser W, Bright J, van der Walt SJ, Brett M, Wilson J, Millman KJ, Mayorov N, Nelson ARJ, Jones E, Kern R, Larson E, Carey CJ, Polat I, Feng Y, Moore EW, VanderPlas J, Laxalde D, Perktold J, Cimrman R, Henriksen I, Quintero EA, Harris CR, Archibald AM, Ribeiro AH, Pedregosa F, van Mulbregt P, Vijaykumar A, Bardelli AP, Rothberg A, Hilboll A, Kloeckner A, Scopatz A, Lee A, Rokem A, Woods CN, Fulton C, Masson C, Haggstrom C, Fitzgerald C, Nicholson DA, Hagen DR, Pasechnik DV, Olivetti E, Martin E, Wieser E, Silva F, Lenders F, Wilhelm F, Young G, Price GA, Ingold GL, Allen GE, Lee GR, Audren H, Probst I, Dietrich JP, Silterra J, Webber JT, Slavic J, Nothman J, Buchner J, Kulick J, Schonberger JL, de Miranda Cardoso JV, Reimer J, Harrington J, Rodriguez JLC, Nunez-Iglesias J, Kuczynski J, Tritz K, Thoma M, Newville M, Kummerer M, Bolingbroke M, Tartre M, Pak M, Smith NJ, Nowaczyk N, Shebanov N, Pavlyk O, Brodtkorb PA, Lee P, McGibbon RT, Feldbauer R, Lewis S, Tygier S, Sievert S, Vigna S, Peterson S, More S, Pudlik T, Oshima T, Pingel TJ, Robitaille TP, Spura T, Jones TR, Cera T, Leslie T, Zito T, Krauss T, Upadhyay U, Halchenko YO, Vazquez-Baeza Y. SciPy 1.0: fundamental algorithms for scientific computing in Python. Nat Methods 2020;17:261–272
31. Streiner DL, Norman GR. “Precision” and “accuracy”: two terms that are neither. J Clin Epidemiol 2006;59:327–330
32. Reinstein DZ, Vida RS, Archer TJ. Visual outcomes, footplate position and vault achieved with the Visian implantable collamer lens for myopic astigmatism. Clin Ophthalmol 2021;15:4485–4497
33. Kamiya K, Shimizu K, Igarashi A, Kitazawa Y, Kojima T, Nakamura T, Oka Y, Matsumoto R. Posterior chamber phakic intraocular lens implantation: comparative, multicentre study in 351 eyes with low-to-moderate or high myopia. Br J Ophthalmol 2018;102:177–181
34. Chen Z, Li T, Li M, Xu Y, Zhou X. Effect of tropicamide on crystalline lens rise in low-to-moderate myopic eyes. BMC Ophthalmol 2020;20:327
35. Xu G, Wu G, Du Z, Zhu S, Guo Y, Yu H, Hu Y. Distribution of white-to-white corneal diameter and anterior chamber depth in Chinese myopic patients. Front Med 2021;8:732719
36. Wan T, Yin H, Yang Y, Wu F, Wu Z, Yang Y. Comparative study of anterior segment measurements using 3 different instruments in myopic patients after ICL implantation. BMC Ophthalmol 2019;19:182–188

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First author:

Leandro Rocamora, MSc

Yatiris Group, PLADEMA Institute, Universidad Nacional del Centro de la Provincia de Buenos Aires (UNICEN), Tandil, Buenos Aires, Argentina