Influence of Biometric Data on Planning Strabismus Surgery

Einfluss von biometrischen Daten auf die Planung der Augenmuskeloperation

Authors

Nino Hirnschall[1,2], Katharina Malek[1], Thomas Kaltofen[3], Siegfried Priglinger[4], Siegmund Priglinger[4], Annette Harrer[1], Oliver Findl[1], Gerhard Partik[1]

Affiliations

1 Ophthalmology, Vienna Institute for Research in Ocular Surgery (VIROS), Hanusch-Krankenhaus, Wien, Österreich
2 Department of Ophthalmology and Optometry, Kepler University Hospital GmbH, Johannes Kepler University Linz, Österreich
3 Research Institute für Symbolic Computation – Software GmbH, Hagenberg, Österreich
4 Institut Integriert Studieren, Johannes Kepler University Linz, Österreich

Key words

strabismus, biometry, strabismus surgery, extent of strabismus

Schlüsselwörter

Strabismus, Biometrie, Augenmuskeloperation, Schielwinkel

received	12.5.2021
accepted	15.11.2021
published online	23.3.2022

Bibliography

Klin Monatsbl Augenheilkd 2022; 239: 1483–1488
DOI 10.1055/a-1699-2679
ISSN 0023-2165

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

Correspondence

Dr. Gerhard Partik
Ophthalmology, Vienna Institute for Research
in Ocular Surgery
Heinrich-Collin-Straße 30, 1140 Wien, Österreich
Phone: + 43 1 91 02 18 46 11, Fax: + 43 1 91 02 18 46 19
sakkade@me.com

ABSTRACT

Purpose To evaluate the influence of optical biometry data (axial eye length, anterior chamber depth) on planning strabismus surgery using a simulation software and partial least squares regression.

Methods This retrospective study included patients who had undergone strabismus surgery in one eye involving only the horizontal eye muscles. Furthermore, optical biometry had been performed and the extent of strabismus had been measured pre- and postoperatively. In the next step the strabismus surgery was simulated (See++, RISC, Austria) with and without axial eye length data. In the last step, anatomical data of the eye were used and their influence on the postoperative extent of strabismus was evaluated using partial least squares regression and boot strapping.

Results Of 97 patients, 92 were included in the analysis. In all cases the extent of strabismus was reduced by at least 25% and in 60% of the cases the reduction was at least 75%. Taking the axial eye length into account improved the simulation slightly (change of surgical planning: 0.30 mm, standard deviation 1.65 mm).

Discussion The simulation model used showed that including the axial eye length is useful for strabismus surgery planning. However, the anterior chamber depth/axial eye length was found to have a significantly greater impact.

ZUSAMMENFASSUNG

Hintergrund Evaluierung des Einflusses von biometrischen Daten (Augenlänge, Vorderkammertiefe) auf die Planung der Augenmuskeloperation mithilfe einer Simulationssoftware und „Partial-least-Squares-Regression".

Material und Methoden In diese retrospektive Studie wurden Patienten/-innen eingeschlossen, bei denen auf einem Auge eine Augenmuskeloperation an einem oder beiden horizontalen Augenmuskeln stattgefunden hatte. Zusätzlich wurde eine optische Biometrie durchgeführt und der Schielwinkel in der Ferne vor und nach der Augenmuskeloperation gemessen. Im nächsten Schritt wurde die Operation mittels Simulationsprogramm (See++, RISC, Österreich) mit und ohne axiale Augenlänge simuliert und mit der tatsächlichen OP-Strecke verglichen. Im letzten Schritt wurde dann der Einfluss verschiedener anatomischer Parameter des operierten Auges auf den postoperativen Schielwinkel untersucht. Dafür wurde zuerst eine Partial-least-Squares-Regression (variable importance of projection, VIP) und danach ein Boot-Strapping-Verfahren verwendet.

Ergebnisse Insgesamt wurden 97 Patienten/-innen in die Studie eingeschlossen, und 92 Datensätze konnten analysiert werden. In allen Fällen wurde der Schielwinkel um mindestens 25 % reduziert und in 60 % konnte eine Reduktion von mindestens 75 % erreicht werden. Die Berücksichtigung der Augenlänge verbesserte die Simulation geringfügig (0,3 mm Änderung der Operationsstrecke, Standardabweichung: 1,65 mm). Ein relevanter Einfluss konnte für die Faktoren präoperativer Schielwinkel (VIP: 1,8), gefolgt von Vorderkammertiefe (VIP: 1,0) und Alter (VIP: 0,9) gezeigt werden. Signifikant höher war er, verglichen zu einzelnen Parametern, bei der Ratio Vorderkammertiefe/Augenlänge.

Schlussfolgerung Das verwendete Simulationsmodell konnte zeigen, dass die Verwendung der axialen Augenlänge zu einer geringen Verbesserung der Planung der Augenmuskeloperation führt. Einen größeren Einfluss hatte allerdings die Berücksichtigung der Ratio Vorderkammertiefe/Augenlänge.

Background

In principle, when strabismus surgery is performed on the horizontal eye muscles, whether on one muscle only or on both in combination, the preoperative angle of deviation is corrected (“eye muscle modification”) so as to achieve a result as close as possible to the orthoposition. This cancels out the combined torsional moments of the agonist and antagonist muscles (e.g., the medial rectus and the lateral rectus muscles). The eye movements are then concomitant within the given range of rolling motion [1, 2]. The See++ eye modelling software that we used (Seekid software: RISC Software GmbH, Hagenberg, Austria) is a biomechanical eye model designed to facilitate a basic understanding of the biological structures of the eye and to enable a mechanical analysis and understanding of eye movements [3].

One variable that is used in all of the calculation models, e.g., “Orbit” and “See++”, is the preoperative angle of deviation. In most cases it is assumed that there is a fixed relationship between the preoperative angle of deviation and the required incision length (dose-response relationship) [4, 5].

Many experienced surgeons use their empirical knowledge to supplement this linear prediction model. This aspect of personal experience, for example assessing the elasticity of the tissue (e.g., in the case of repeated operations), eye length [6–8], and other factors can be simulated, variably modified, and tested in the Seekid biomechanical eye model.

The goal of our study was to simulate the measured preoperative angle of deviation (pathology) and biometric data of the eye, and then to simulate the strabismus operation (including all recessions, plications and resections [in mm]) and compare the simulation with the actual clinical results.

Methods

In this retrospective study we included patients who had undergone strabismus surgery in one eye, on one or both horizontal eye muscles. Inclusion criteria were the presence of preoperative optical biometry data (IOLMaster500, Carl Zeiss Meditec AG, Germany) and preoperative and postoperative (8 weeks) angle of deviation measured at distance. Patients who had undergone surgery in both eyes or on muscles other than the horizontal eye muscles, or who had already had a previous eye operation, were excluded. Because of the retrospective nature of this study, surgical planning was carried out according to the “surgeon’s choice” principle. For this purpose, as a starting point we applied the following fixed dose-response relationship: a recession of 1 mm reduces the angle of deviation by 2°, a plication of 1 mm reduces the angle of deviation by 3°. However, the surgeon was free to adjust the incision size according to personal experience and the known eye length.

All simulations were carried out retrospectively. The angle of deviation was measured both before and after the operation, using either an alternate or unilateral prism cover test depending on whether the strabismus was manifest or latent.

All data were imported into an Excel file (Microsoft for Mac, Version 16.43, Microsoft, USA+Xlstat-plug-in), in anonymized form, and the optical biometry data were added as a batch export/import. In the next step, all of the data were imported into the Seekid program.

For evaluation purposes we always used the total incision length, so as to also be able to depict the effect when two eye muscles where operated on. In all cases we first simulated the pathology, and then the strabismus operation as follows:

1. Simulation of the optimum incision length as determined by Seekid, without knowing the postoperative angle of deviation (T. K.):
   a) without taking the eye length (or corresponding muscle radius) into account. Here we used 11.994 mm as a standard value for the axial bulb radius;
   b) taking the eye length into account.
2. Simulating the actual incision length:
   a) “surgeon’s choice” – set dose-response relationship with empirical values (G. P.).
3. Using partial least squares regression to optimize the prediction.

Seekid (See++ software)

This software, developed in Linz (RISC Software GmbH, Hagenberg, Austria), enables computer-supported planning of the strabismus operation through digital adaptation of conventional ophthalmotropes manufactured by Ruete, Donder or Wundt. The software displays a biomechanical 3D model of the eye which can be influenced through simulation of surgical incisions; this model has already been evaluated [9]. By entering the axial eye diameter in Seekid [2], it is also possible to adjust the muscle radius (the medial rectus muscle has a radius approx. 1.093 mm larger relative to the eye length, and the lateral rectus muscle more or less corresponds to the axial eye length).

▶ **Table 1** Descriptive data for the patient cohort.

	Mean (standard deviation)	Minimum–Maximum
Eye length (mm)	23.40 (1.49)	20.65–29.34
Anterior chamber depth (mm)	3.41 (0.44)	2.07–4.48
Corneal radii (mm)	7.72 (0.30)	7.00–8.57
White-to-white (mm)	12.14 (0.44)	10.85–13.48

Statistics

For the descriptive analysis we reported the mean value and standard deviation. The predictive models are based on partial least squares regression, because this form of regression is better able to avoid problems that arise with overfitting and interactions between variables, and also allows nonlinear conclusions. The regression was then validated using bootstrapping methods. Both of these procedures are described elsewhere in detail [10, 11]. The predictive power of the regression model is reported as the "variable importance for projection" (VIP). A value with a mean deviation of over 0.8 indicates a high level of predictive power.

Results

Preoperative angle of deviation

Out of 97 patients initially included, 5 had to be excluded because the preoperative angle of deviation was too large; simulation in Seekid only allows a maximum angle of 30 degrees. The following data relate to the remaining 92 patients. The mean age was 30.2 years (ranging from 6 to 78); 41 patients were female (44.6%) and 51 male (55.4%). Of these, 38 patients had their right eye operated, and 54 patients had their left eye operated. The mean eye length of the operated eyes was 23.40 mm (SD: 1.50), ▶ **Table 1**.

The preoperative angle of deviation was convergent in 41 cases (44.6%), and divergent in 51 cases (55.4). In this study we did not distinguish between primary strabismus and decompensated heterophoria.

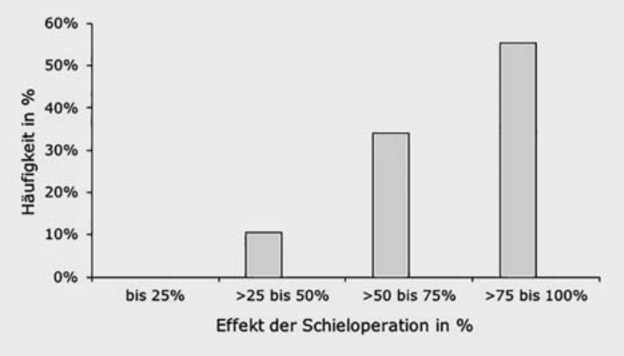
All operations were performed by the same experienced strabismus surgeon (G. P.). ▶ **Table 2** shows the frequency of the operations performed. In most cases, a combined operation was performed involving recession and plication (n = 78, 84.8%).

Postoperative angle of deviation and predictive models

The mean reduction in angle of deviation was 21.0 prism diopters, with a standard deviation of 8.5 prism diopters. This corresponds to a reduction of 76.0% (standard deviation: 17.4%). There were no cases of reduction less than 25%, and a reduction of at least 75% was achieved in nearly 60% of cases (▶ **Fig. 1**). In one case there was an overcorrection of over 10 prism diopters, and in three cases there was an overcorrection of less than 10 prism diopters. There was no significant difference between convergent and divergent angles of squint in relation to the success of the operation (p = 0.31).

▶ **Table 2** Number of recessions, plications, and combined operations, and the muscles involved.

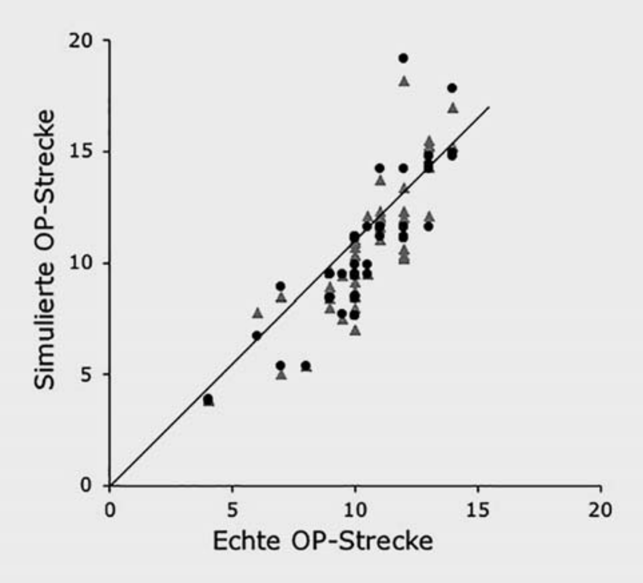
	Recession	Plication	Combined operation
Lateral rectus muscle	1	2	78
Medial rectus muscle	8	3	



▶ **Fig. 1** Angle of deviation reduction due to strabismus surgery in %.

There was only a slight correlation between postoperative angle of deviation and eye length ($r^2 = 0.002$). While the correlation between the postoperative angle of deviation and anterior chamber depth was five times higher than this, it was still small ($r^2 = 0.010$).

The different models did not show any significant differences with regard to incision length. The total mean deviation between the actual incision length and the simulated incision length without taking eye length into account was 0.30 mm (SD: 1.65). This mean deviation was reduced by more than half (0.14 mm, SD: 1.71) when eye length was taken into account in the model (▶ **Fig. 2**). A similar mean deviation was observed when comparing the two simulated incision lengths (with and without eye length data) (0.16 mm, SD: 0.56). The influence of eye length on planning was 1.6 times greater for convergent strabismus than for divergent strabismus.



▶ **Fig. 2** Comparison between actual incision length (x-axis) and simulated incision length (y-axis) in mm. Circle = eye length not taken into account, triangle = eye length taken into account.

Regression model

In an initial model, we included the following explanatory variables: preoperative angle of deviation measured at distance (°), eye length (EL, mm) incl. ACD, anterior chamber depth (ACD, mm), white-to-white distance (mm) and mean corneal radius (mm). The following factors were found to have a relevant influence: preoperative angle of deviation (variable importance of projection, VIP: 1.8), followed by ACD (VIP: 1.0) and age (VIP: 0.9) (▶ **Fig. 3**). The bootstrapping model showed significance for all three factors. Although eye length did not show significant influence (VIP: 0.6), it was included in the subsequent model. The resulting model showed a good ability to predict the postoperative angle of deviation, although again eye length did not prove to be a significant factor:

$$AS_{postOP} = -7.0 + 0.4 * AS_{preOP} - 2.4 * ACD + 0.6 * age + 0.5 * EL$$

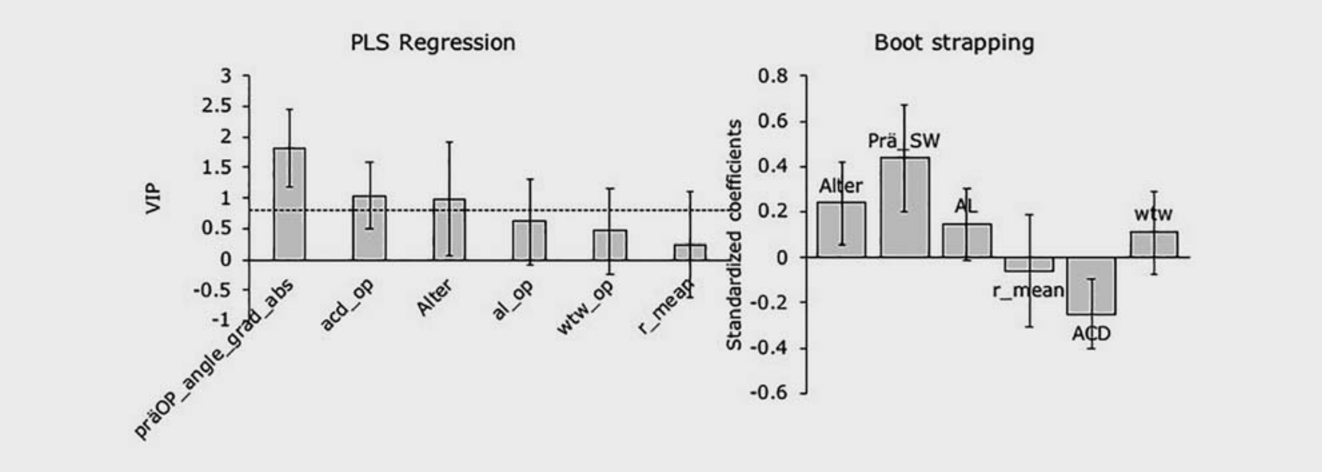
The analysis showed a synergistic effect between eye length and anterior chamber depth. By simulating various effects, we were able to show that the ACD/EL ratio was associated with significantly better ability to predict the postoperative angle of deviation than ACD or EL alone (▶ **Fig. 4 a** and **4 b**).

$$AS_{postOP} = 7.9 + 0.05 * age + 0.33 * AS_{preOP} - 70.6 * ACD/EL$$

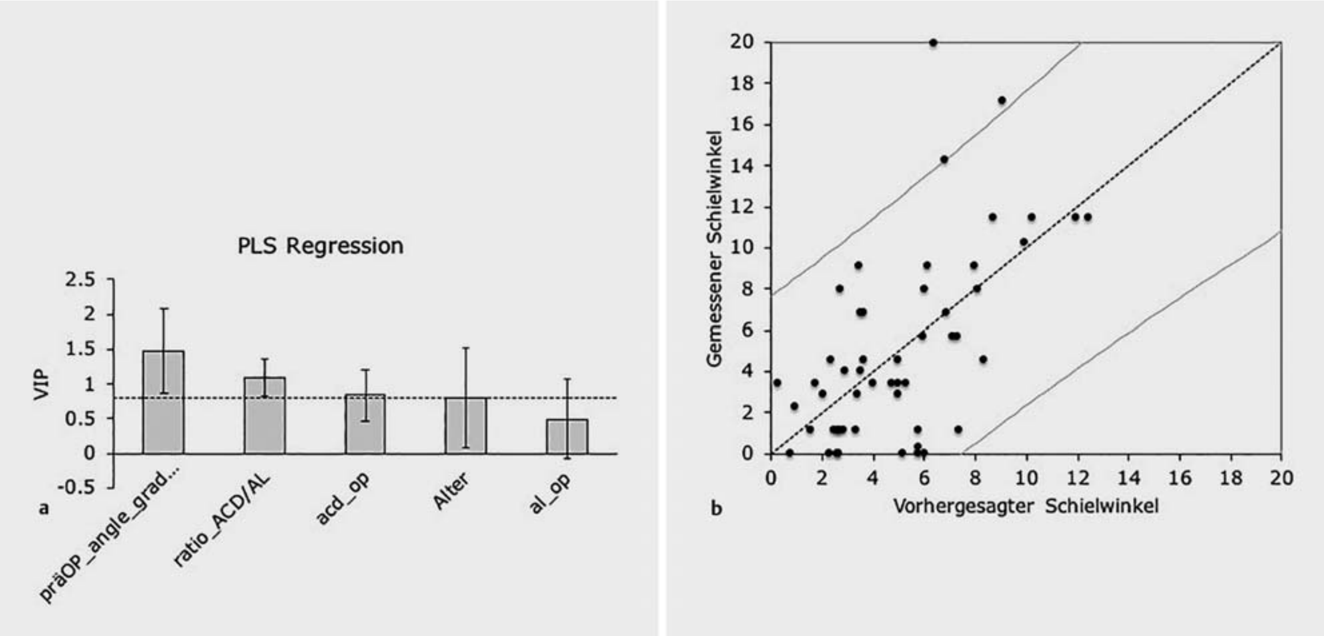
Discussion

This study shows that taking biometric data into account when planning a strabismus operation can significantly improve the ability to predict the postoperative angle of deviation. Moreover, it appears that while eye length is relevant, it is not the best parameter to use for this kind of optimization; it seems that the anterior chamber depth/eye length ratio is better suited for this purpose. What makes the anterior chamber depth/eye length ratio a relevant factor is a question we are unable to answer in this article. One possibility is that this ratio enables a better description of the bulb diameter (or its difference measured nasally or temporally).

The significance of taking eye length into account has already been investigated in other studies [6, 7]. In a randomized study, Bisse et al. [7] showed that this correction is beneficial in particular to farsighted patients with a refraction of at least + 2.0 D. In this study, patients with a convergent angle of deviation benefited more from taking eye length into account than did patients with a



▶ **Fig. 3** Partial least squares regression model (PLSR, left) and bootstrapping (right) used to predict the postoperative angle of deviation. Under the PLSR model, a VIP of at least 0.8 is classed as relevant. The factor that had the largest influence was the preoperative angle of deviation, followed by anterior chamber depth. acd_op = preoperative anterior chamber depth in mm; el_op = preoperative eye length in mm; preOP_angle_grad_abs = preoperative angle of deviation measured at distance in degrees; r_mean = mean corneal radius in mm; wtw_op = preoperative white-to-white distance in mm.



▶ **Fig. 4** **a** Partial least squares regression model used to predict the postoperative angle of deviation, including the anterior chamber depth/eye length ratio (ACD/EL). The factor with the greatest influence was the preoperative angle of deviation, followed by the anterior chamber depth/eye length ratio. This model shows that the ratio has a greater effect than anterior chamber depth on its own. acd_op = preoperative anterior chamber depth in mm; al_op = preoperative eye length in mm; preOP_angle_grad… = preoperative angle of deviation measured at distance; ratio_ACD/EL = anterior chamber depth/eye length ratio in mm. **b** Correlation between actual postoperative angle of deviation (y-axis) and the angle of deviation simulated using the partial least squares regression model, taking into account the anterior chamber depth/eye length ratio (x-axis). The curved lines represent the 95% confidence interval.

divergent angle of deviation. Similar results were obtained by Kushner et al. [12]. This study showed an inverse correlation between eye length and calculation of the postoperative angle of deviation, although the correlation was smaller for divergent strabismus than for convergent strabismus. This has also been confirmed in a study by Broniarczyk-Loba et al. [13]. This study found a strong correlation between eye length and postoperative angle of deviation for convergent strabismus, but not for divergent strabismus. Gräf et al. [8] also found a strong correlation for convergent strabismus but not for divergent strabismus, and made the recommendation that bulb length should at least be taken into account if the total incision length is 10.0 mm or more.

Kushner et al. [14] did not find eye length to have any relevant influence on the (calculated) postoperative angle of deviation, although this finding contradicts one of their own earlier studies. Although this study confirms a correlation between eye length and the effect of the operation (the shorter the eye, the greater the effect), the authors were not able to create a model in which taking the eye length into account enabled an actual improvement to be made in the calculation of the incision length.

In general, for strabismus operations, the bulb diameter (in the frontal plane) is more relevant than the axial eye length. Accordingly, the software we used in this study (See++) allowed us to enter the bulb diameter (resulting from a linear function of the eye length). Kim et al. succeeded in showing that it is not possible to derive the bulb diameter from eye length alone, and proposed the following calculation: BD = EL * π/4 − corneal diameter/2 [15].

However, this calculation model also has limitations, as there appears to be only a small correlation between corneal diameter and bulb diameter [16].

Abstract

To our knowledge, this is the first study to show that other biometric data apart from eye length are relevant for calculating the incision length. The See++ eye model [2] allows biometric data to be entered, and then used variably in simulations. Based on these inputs, by entering the axial bulb radius, it was possible to co-adjust the corresponding muscle radii, pulley parameters, etc. Perhaps in the future Seekid could be expanded to include the anterior chamber depth/eye length ratio as a factor, as is enabled by the software's "operation generator". In addition, we were able to show that a nonlinear regression model is useful for predicting the optimum incision length, and that digital ophthalmotrope software is necessary for this purpose. However, the relevant components must always be selected by an experienced strabismus surgeon. This study clearly shows that only empirical optimization applied by an experienced surgeon leads to results of similar quality. A limitation of this study was the exclusion of very large angles of squint. It appears that experienced strabismus surgeons have a good ability to take the effect of eye length into account when determining the full extent of the incision [5, 8], obtaining results of a similar quality to those produced by calculation software.

Conflict of Interest

Mr. Kaltofen, Professor Priglinger and Dr. Priglinger were/are currently involved in developing the See++ simulation program. Professor Findl and PD Hirnschall have no conflicts of interest relevant to this study, although they are also involved in other projects. Dr. Harrer, Dr. Partik, and Ms. Malek, BSc have no financial interests to declare.

References

[1] Kaufmann H, Steffen H. Strabismus. 4. Aufl. Stuttgart, New York: Thieme; 2012

[2] Priglinger S, Buchberger M. Augenmotilitätsstörungen: Computerunterstützte Diagnose und Therapie. Heidelberg: Springer; 2004: 6–10

[3] Milburn PD. You Still Can't Tell One If You See One. Proceedings of the First Australasian Biomechanics Conference. Sydney, Australia, 1996: 116–117

[4] Fricke J, Neugebauer A. [Basic principles of eye muscle surgery]. Klin Monbl Augenheilkd 2008; 225: R87–R97

[5] Steffen H. [Eye muscle surgery]. Ophthalmologe 2015; 112: 281–291

[6] Krzizok T, Graf M, Kaufmann H. [Effect of bulbus length of reduction of squint angle after suture fixation]. Ophthalmologe 1994; 91: 68–76

[7] Beisse F, Koch M, Uhlmann L et al. Consideration of eyeball length and prismatic side-effects of spectacle lenses in strabismus surgery–a randomised, double-blind interventional study. Graefes Arch Clin Exp Ophthalmol 2020; 258: 1319–1326

[8] Gräf M, Krzizok T, Kaufmann H. [Effect of axial bulbus length and preoperative squint angle on the effect of horizontal combined squint operations]. Ophthalmologe 1994; 91: 62–67

[9] Mayr H. Virtual eye muscle surgery based upon biomechanical models. Stud Health Technol Inform 2001; 81: 305–311

[10] Hirnschall N, Amir-Asgari S, Maedel S et al. Predicting the postoperative intraocular lens position using continuous intraoperative optical coherence tomography measurements. Invest Ophthalmol Vis Sci 2013; 54: 5196–5203

[11] Hirnschall N, Norrby S, Weber M et al. Using continuous intraoperative optical coherence tomography measurements of the aphakic eye for intraocular lens power calculation. Br J Ophthalmol 2015; 99: 7–10

[12] Kushner BJ, Qui CO, Lucchese NJ et al. Axial length estimation in strabismic patients. J Pediatr Ophthalmol Strabismus 1996; 33: 257–261

[13] Broniarczyk-Loba A, Suprunowicz I, Nowakowska O. [Squint angle, eyeball length and surgical results in horizontal strabismus]. Klin Oczna 1994; 96: 206–209

[14] Kushner BJ, Fisher MR, Lucchese NJ et al. Factors influencing response to strabismus surgery. Arch Ophthalmol 1993; 111: 75–79

[15] Kim S, Suh Y, Cho YA. Simple formula for determining the location of the equator. Clin Exp Ophthalmol 2005; 33: 126–128

[16] Erb-Eigner K, Hirnschall N, Hackl C et al. Predicting Lens Diameter: Ocular Biometry With High-Resolution MRI. Invest Ophthalmol Vis Sci 2015; 56: 6847–6854