Int J Ophthalmol, Vol. 12, No. 12, Dec.18, 2019 www.ijo.cn
Tel: 8629-82245172 8629-82210956 Email: ijopress@163.com

· Investigation ·

A novel three-dimensional electric ophthalmotrope for improving the teaching of ocular movements

Lei Xiong[1], Xiao-Yan Ding[2], Ya-Zhi Fan[1], Yao Xing[1], Xiao-Hui Zhang[1], Ting Li[1], Jian-Ming Wang[1], Feng Wang[1]

[1]Department of Ophthalmology, the Second Affiliated Hospital, Xi'an Jiaotong University, Xi'an 710004, Shaanxi Province, China
[2]Department of Ophthalmology, Xi'an No. 3 Hospital, Xi'an 710082, Shaanxi Province, China
Correspondence to: Jian-Ming Wang and Feng Wang. The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an 710004, Shannxi Province, China. xjtuwjm@163.com; wfoculist@126.com
Received: 2019-10-21 Accepted: 2019-11-25

Abstract
● AIM: To develop a novel three-dimensional (3D) electric ophthalmotrope to improve the ophthalmology teaching effectiveness and evaluate the teaching value.

● METHODS: A 3D electric ophthalmotrope was designed by simulating the movement of the ocular and the extraocular muscles according to Sherrington's law. The model with joint bearing was to ensure the flexibility and centripetal rotation of the simulated ball and stepper motor as the driving device. A programmable processor was used to control the motion amplitude of the stepper motor. The size of hole was set at the back of the simulated shell to limit the amount of eye movement. Afterwards, using a 5-point Likert scale, 7 experts evaluated the 3D electric ophthalmotrope's simulation ability and precision, compared with the traditional anatomical model. In addition, the teaching effectiveness of the 3D electric ophthalmotrope was evaluated at in-class quiz and final exam in a randomized controlled trial.

● RESULTS: The 3D electric ophthalmotrope could be operated easily to demonstrate the eye movements with motion of different ocular muscles. The experts agreed that the 3D electric ophthalmotrope was different from the traditional model and was easier for students to understand every extraocular muscles' movement in each evaluation index ($P<0.05$). Moreover, the results of teaching effectiveness showed that the 3D electric ophthalmotrope were significantly greater than the traditional model both at in-class quiz ($P<0.01$) and final exam ($P<0.05$).

● CONCLUSION: This novel 3D electric ophthalmotrope is better than the traditional model, which can be to improve the ophthalmology teaching effectiveness for students to understand the extraocular muscles' movement.

● KEYWORDS: extraocular muscles movement; ocular myopathy; medical education; ophthalmotrope; three-dimensional electric model
DOI:10.18240/ijo.2019.12.12

Citation: Xiong L, Ding XY, Fan YZ, Xing Y, Zhang XH, Li T, Wang JM, Wang F. A novel three-dimensional electric ophthalmotrope for improving the teaching of ocular movements. *Int J Ophthalmol* 2019;12(12):1893-1897

INTRODUCTION

The extraocular musculature is always a difficult topic for students to learn in ophthalmology classes because the interlaced distribution of six extraocular muscles forms the complicated anatomical structure. The function of the six extraocular muscles is very complex[1]. The medial rectus muscle and the lateral rectus muscle are simply inward and outward, but the other four muscles distribute in three dimensions and form a three-dimensional (3D) composite motion. Surprisingly, their movements are sometimes synergic and sometimes mutually antagonistic[2].

At present, anatomy diagrams and anatomy models are usually used for ophthalmology teaching. The anatomy diagrams are two-dimensional and do not give a good representation of the stereo structure. With the development of science and technology, 3D technology has been developed rapidly[3]. There are a lot of clinical discipline used vivid 3D model in medical education, such as anatomy, osteology, otolaryngology and surgery department[4-7]. However, the eye models are static, which only show the structure in orbit without movement[8]. It is still difficult for students to understand the ocular myopathy during ophthalmology teaching using the traditional static model for interpreting physiological movement of extraocular muscles[9]. There is no vivid 3D anatomical model available for teaching the extraocular muscles movements[10]. In the present study, we developed a novel electric ophthalmotrope

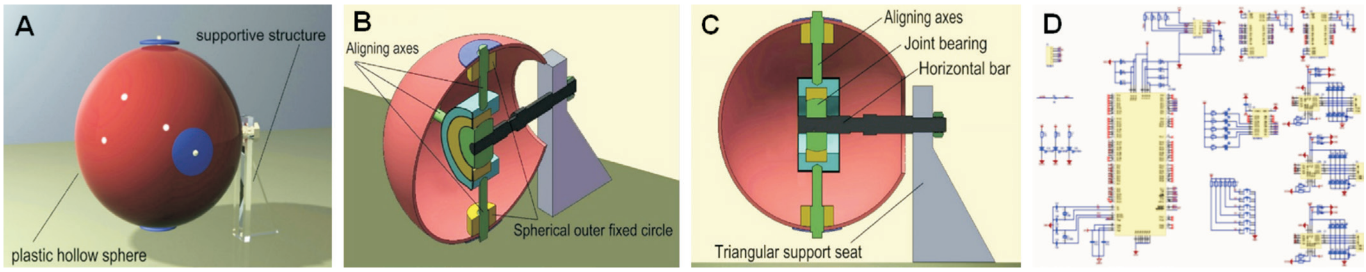

Figure 1 External and internal views of the shell and circuit diagram A: Spherical shell containing a plastic hollow sphere and supportive structure; B: Internal structure including a joint bearing, four aligning axes, horizontal bar and a triangular support seat; C: Planar graph of internal structure view; D: Circuit diagram of electrical control system.

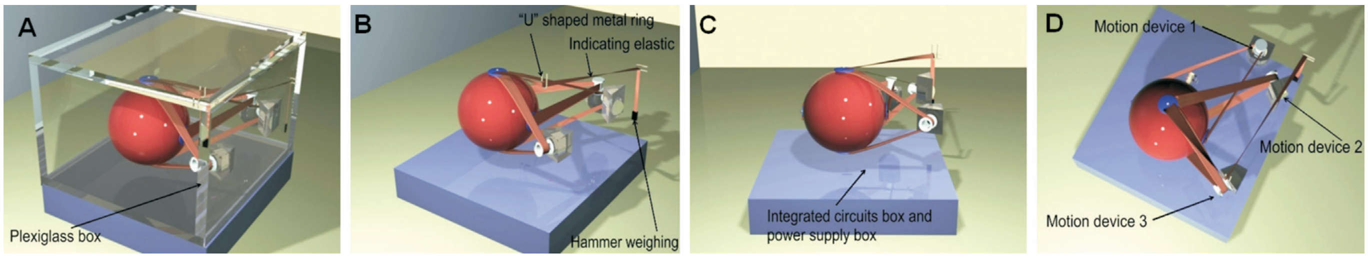

Figure 2 Design drawing of 3D electric ophthalmotrope A: The lateral view with exterior frame; B: Lateral view without the frame, showing that an elastic band starts from above the spherical shell through the "U" shaped metal ring witch simulated tackle, and further extends to the left rear. A lead hammer is used to maintain its extension. C: An integrated circuits box and power supply are located on the bottom of the sphere model; D: The location of the three-motion device.

that could simulate the movement of the extraocular muscles dynamically, and evaluate the teaching effectiveness of the novel model compared with that of traditional instruction with anatomical atlases.

MATERIALS AND METHODS

Ethical Approval The study protocol has been approved by the Ethics Committee on human research of the Second Affiliated Hospital of Xi'an Jiaotong University. This research adhered to the tenets set forth in the Declaration of Helsinki, and written informed consent was provided by all students.

Instrument Design The electric ophthalmotrope designed between March 2014 and September 2015 using joint bearing to ensure the flexibility and centripetal rotation of the simulated eyeball. Stepper motors were used as the driving device to simulate muscle motion (Figure 1). A programmable processor is used to control the motion amplitude of the stepper motor. In addition, the size of hole was set at the back of the simulated shell to limit the amount of eyeball movement (Figure 2). The design of different parts is described below.

3D Electric Ophthalmotrope's Inner Structure A 12-cm diameter plastic hollow sphere representing the ocular surface was shown in color pigments (Figure 1A-1C). The rotation limit of the model was restricted to 30° with globe axis by combining a horizontal bar in the center of the sphere with a 6-mm diameter circular hole opened at back of the sphere, which limits the movement when the range of eye motion reaches to greater than 30 degrees.

3D Electric Ophthalmotrope's Supporting Structure A joint bearing located in the center of the sphere of the eye model constitutes a concave spherical connection similar to the human joint that allows free rotation of two interconnected parts (Figure 1B, 1C). The bore within the sphere was fixed on the horizontal bar which was fixed on a triangular support seat. A plastic ring was fixed on the outside of the sphere, four aligning axes for the up, down, left, and right directions were attached to the surface of the model with screws. Therefore, the joint bearing is located at the center of the spherical shell by adjusting the length of the aligning axis.

3D Electric Ophthalmotrope's Movement Controls Outside the sphere of the eye model, we used elastic bands to represent the extraocular muscles. So, we used three elastic bands to represent the six extraocular muscles, in order to demonstrate the principle of pairwise conjugate of extraocular muscles. The positions of simulated extraocular muscles connected to the three motors as shown in Figure 2. Motor No.1 (motion device 1) is responsible for abduction and adduction, and Motor No.2 (motion device 2) elevates and depresses. Motor No. 3 (motion device 3) is located at left front of the model, and its direction is same as the direction of the inferior oblique, simulating movement of the inferior oblique muscle by driving elastic band No.3.

Furthermore, an indicating elastic band is used to show the trend of the superior oblique muscle. This indicates that elastic band starts from above the spherical shell, goes through

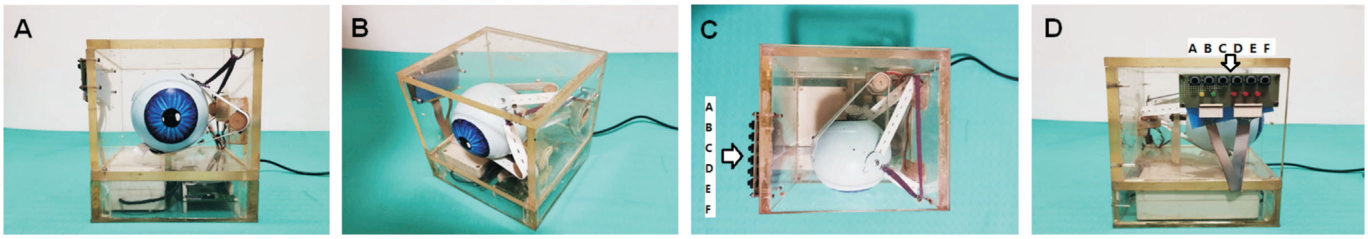

Figure 3 Photo of 3D electric ophthalmotrope A: Positive view; B: The lateral view; C: The above view; D: Control buttons.

the "U" shaped metal ring of the simulated tackle (Figure 2B), which is located at the upper left of the PMMA box, and further extends in the left rear direction. A lead hammer (Figure 2B) weighing 0.1 kg is used to maintain its extension.

Experts' Evaluation of the 3D Electric Ophthalmotrope Seven professors were invited to evaluate our model. Two professors came from the Department of Anatomy at Xi'an Jiaotong University, others from the Ophthalmology Department, the Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China. All experts were requested to fill out two questionnaires. The first is to evaluate 3D electric ophthalmotrope's simulation ability and precision, and the second is to evaluate the 3D electric ophthalmotrope as a teaching tools in the process of teaching effectiveness compared with the traditional model in four aspects: anatomical features, imitativeness, maneuverability and overall satisfaction. All questions were answered using 5-point Likert scale (1=strongly disagree; 2=disagree; 3=neither agree nor disagree; 4=agree; and 5=strongly agree)[9]. The expert's evaluation score is expressed in the form of median.

Teaching Effectiveness Evaluation of the 3D Electric Ophthalmotrope A total of 166 medical students, who were registered for taking ophthalmology course, from Medical Collage of Xi'an Jiaotong University, were recruited to attend in the students' evaluation progress in 2018. They were randomized divided into 2 groups: group 1 (n=83) for 3D electric ophthalmotrope model, group 2 (n=83) for traditional model. Randomization sequence was created using Stata 9.0 (StataCorp., College Station, TX, USA) statistical software. Same teachers were assigned to teach the group 1 students with the 3D electric ophthalmotrope model and eye anatomy image, while the group 2 students with the traditional anatomical eyeball model and the eye anatomy image to compare the teaching effectiveness.

Teachers briefly introduced eye extraocular myopathy for 15min, and students studied the specimens by themselves respectively with the two different models for 20min, then completed the in-class quizzes[10] within 10min. A prospective randomized controlled trial using specially designed questionnaire examinations with 12 questions was conducted to evaluate the teaching effectiveness of 3D electric ophthalmotrope on movement of extraocular muscles compared to the traditional model. The questionnaires were about exercise physiology of extraocular muscles, including identification of the direction of movement of each extraocular muscle, and the theoretical knowledge and concepts involved in the extraocular muscles. In addition, in the final exam, 4 questions were designed related to extraocular myopathy, and the scores of each group of students were recorded and analyzed. The score data from the questionnaires were recorded and analyzed to compare the differences of each group as described previously.

Data Analysis Continuous variables were expressed as median. Wilcoxon tests were used to evaluate the simulation fidelity of the models in the experts' evaluations and the teaching effect of the 3D electric ophthalmotrope. $P<0.05$ were considered as statistically significant. Statistical analysis was performed with SPSS 19.0 software (USA).

RESULTS

The 3D Electric Ophthalmotrope Model The 3D electric ophthalmotrope model was constructed with the right eye as the prototype and was enlarged to a ratio of 1:5. The volume of the model is 25×25×25 cm^3 and the weight is 3.5 kg. It consists of a concentric rotating sphere, a support device for the sphere, a movement device, a control circuit, and a power supply (210 V and 50 Hz) and a PMMA box is the exterior frame. This device had been granted with Chinese invention patent at September 5th 2012 and patent number is "ZL 201110134201.7" (Figure 3).

The 3D electric ophthalmotrope's model is composed of three parts: the control circuit, the control panel, and the indicator. The control circuit consists of integrated circuits controlled by a Philips LPC2368 microprocessor chipset (NXP Semiconductors NV, Eindhoven, and the Netherlands; Figure 3D). The control panel is composed of six buttons: A, B, C, D, E, and F (Figure 3A, 3C). A and B control motor No. 1: Button A simulates the movement of the medial rectus muscle, and Button B simulates the movement of the lateral rectus muscle. C and D control motor No.2: Button C simulates the movement of the superior rectus muscle, and Button D simulates the movement of the inferior rectus muscle. E and F control motor No.3: Button E simulates the movement of the superior oblique muscle, and Button F simulates the movement of the inferior oblique muscle. The power supply (210V AC to the 12 V AC) is located on the model to control circuit and motor.

Experts' Evaluation of the 3D Electric Ophthalmotrope The expert's evaluation score for the imitation effect of each extraocular muscle was expressed in the form of media (Figure 4). All the experts strongly agreed that the 3D electric ophthalmotrope could imitate the movement of the internal rectus, external rectus, superior rectus and inferior rectus. Most experts agreed that the 3D electric ophthalmotrope could imitate the movement of the superior and inferior oblique muscles. All the experts agreed that the 3D electric ophthalmotrope model was better than the traditional anatomical model for ophthalmology teaching. The expert's evaluation score is expressed in the form of median. Wilcoxon tests showed significant differences between the traditional anatomical model of eyeball and 3D electric ophthalmotrope in each index ($P<0.05$; Figure 5).

Teaching Effectiveness Evaluation of the 3D Electric Ophthalmotrope The teaching effectiveness showed that the 3D electric ophthalmotrope has the advantage in ophthalmology teaching. The scores of the students with the 3D electric ophthalmotrope model were greater than those with the traditional anatomical model in the in-class quiz and final quiz ($P<0.05$; Figure 6).

DISCUSSION

To our knowledge, this 3D electric ophthalmotrope is the first instrument which simulates the superior oblique muscle and inferior oblique muscle's movement by electric model. Since understanding the extraocular muscles movement is difficult and frustrating for medical students, this model provides us an efficient and effective tool for medical student to explain extraocular myopathy. It simulates the extraocular muscle motion based on the theory of conjugate muscle movements. It also simulates eye motion under each extraocular muscle and the accompany movements of the rest of the extraocular muscles. Moreover, it simulates the movements of the superior oblique muscles using ligament instructions. This model is compact and easy to move, which makes in-class application of this 3D electric ophthalmotrope possible.

As early as 1857, Christian Theodor invented the world's first ophthalmotrope[11]. Since then, several eye models have been reported to demonstrate different eye positions with varying degrees of accuracy[12]. The Mims ophthalmotrope focused on the description of extraocular muscle movements and energy requirements for the movements of different extraocular muscles[13]. All of these ophthalmotrope are mainly focused the anatomical structure, but they couldn't imitate the movement of ocular muscle automatically and the entire system was clumsy[14]. Reeh *et al*'s[15] ophthalmotrope is the close to the present model, using motors to induce the movement of the extraocular muscles. However, his model could only simulate the movements of the superior rectus, inferior rectus, medial rectus, and lateral rectus muscles, but could not make the movements of the superior oblique and the inferior oblique muscles.

Our 3D electric ophthalmotrope could substantially enhance the teaching of extraocular muscle function. The students commented that this model was intuitive and vivid and

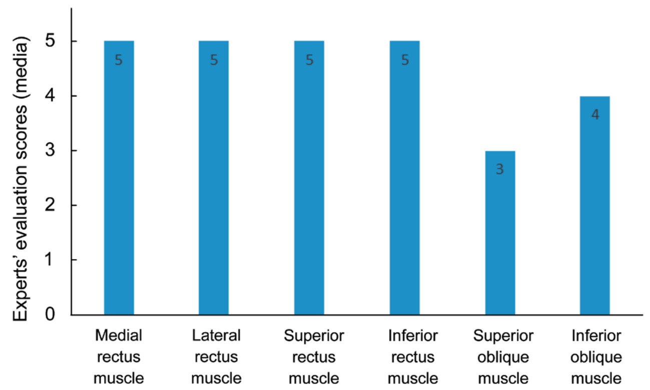

Figure 4 Experts' evaluation score (media) of the movement of every extraocular muscle.

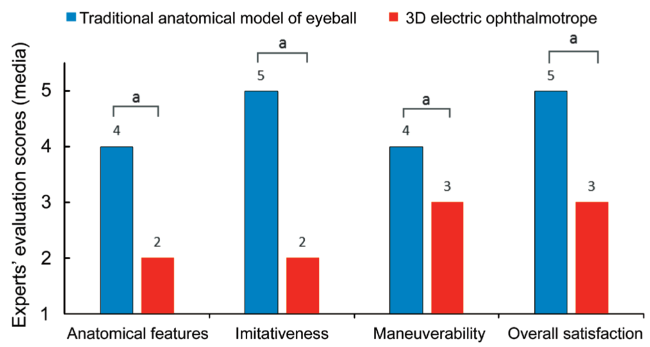

Figure 5 Experts' evaluation score (media) 3D motor-driven ophthalmotrope were significant better than traditional anatomical model of eyeball with Wilcoxon tests. $^aP<0.05$.

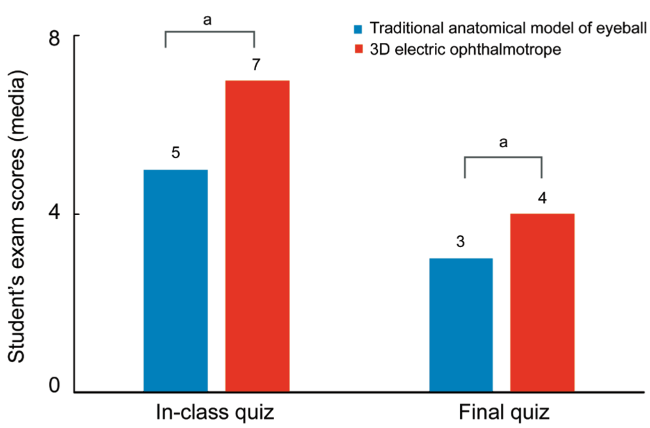

Figure 6 Medical student examination scores (media) 3D motor-driven ophthalmotrope group performed better than traditional anatomical model of eyeball group by Wilcoxon tests both in the in-class tests and final examinations respectively. $^aP<0.05$.

largely boosted their interest in learning and their memory of theoretical knowledge. Moreover, the model helps them transform the theory to clinical problems quite well[16-18].

The specific model also has some limitations. For example, promotion and application need higher cost and longer time, and students' study is limited by space and time. It may be greater for better teaching effectiveness and wider dissemination, if computer software can be combined with virtual simulation technology to make movement of the extraocular muscle[19-20].

In summary, the 3D electric ophthalmotrope promotes the teaching effectiveness of extraocular movement, which could be operated easily by students in practice, with unique authenticity and good sense of experience. In the future work, re-validation is required with a large number of student samples and focus on the promotion of this model in ophthalmology teaching and its application in various forms.

ACKNOWLEDGEMENTS

Foundations: Supported by the National Natural Science Foundation of China (No.30901655); Shaanxi Provincial Key Research and Development Program (No.2018SF-230).

Conflicts of Interest: Xiong L, None; **Ding XY,** None; **Fan YZ,** None, **Xing Y,** None; **Zhang XH,** None; **Li T,** None; **Wang JM,** None; **Wang F,** None.

REFERENCES

1 Iwanaga J, Refsland J, Iovino L, Holley G, Laws T, Oskouian RJ, Tubbs RS. A new teaching model for demonstrating the movement of the extraocular muscles. *Clin Anat* 2017;30(6):733-735.

2 Wong AM. Listing's law: clinical significance and implications for neural control. *Surv Ophthalmol* 2004; 49(6):563-575.

3 Erolin C. Interactive 3D digital models for anatomy and medical education. *Adv Exp Med Biol* 2019;1138:1-16.

4 Chen S, Pan ZX, Wu YY, Gu ZQ, Li M, Liang Z, Zhu HJ, Yao Y, Shui WY, Shen Z, Zhao J, Pan H. The role of three-dimensional printed models of skull in anatomy education: a randomized controlled trail. *Sci Rep* 2017;7(1):575.

5 Mogali SR, Yeong WY, Tan HKJ, Tan GJS, Abrahams PH, Zary N, Low-Beer N, Ferenczi MA. Evaluation by medical students of the educational value of multi-material and multi-colored three-dimensional printed models of the upper limb for anatomical education. *Anat Sci Educ* 2018;11(1):54-64.

6 Hochman JB, Rhodes C, Wong D, Kraut J, Pisa J, Unger B. Comparison of cadaveric and isomorphic three-dimensional printed models in temporal bone education. *Laryngoscope* 2015;125(10):2353-2357.

7 Kong XX, Nie LY, Zhang HJ, Wang ZL, Ye Q, Tang L, Li JY, Huang WH. Do three-dimensional visualization and three-dimensional printing improve hepatic segment anatomy teaching? A randomized controlled study. *J Surg Educ* 2016;73(2):264-269.

8 Wood AJ, Dayal MR. Using a model to understand the symptoms of ophthalmoplegia. *J Undergrad Neurosci Educ* 2018;16(2):R33-R38.

9 Zhang N, He XH. Understanding the extraocular muscles and oculomotor, trochlear, and abducens nerves through a simulation in physical examination training: an innovative approach. *J Chiropr Educ* 2010;24(2):153-158.

10 Spivey BE. Education in ophthalmology over the past 60 years. *Surv Ophthalmol* 2017;62(2):241-247.

11 Simonsz HJ. Christian Theodor Georg Ruete: the first strabismologist, coauthor of listing's law, maker of the first ophthalmotrope and inventor of indirect fundoscopy. *Strabismus* 2004;12(1):53-57.

12 Askovitz SI. A device for the demonstration and analysis of ocular rotations. *Am J Ophthalmol* 1957;43(5):765-766.

13 Mims JL Jr, Martin FN, Clark WB. An ophthalmotrope constructed on a new principle. *Am J Ophthalmol* 1951;34(3):437-441.

14 Pruehsner WR, Enderle JD. The DaVinci Group: a second modern Ophthalmotrope. *Biomed Sci Instrum* 2006;42:440-445.

15 Reeh MJ, Stimmel EW, Heagan FV. A motor-driven ophthalmotrope. *Am J Ophthalmol* 1947;30(1):58-59.

16 Chen ZH, Fu H, Lo WL, Chi ZR, Xu BG. Eye-tracking-aided digital system for strabismus diagnosis. *Healthc Technol Lett* 2018;5(1):1-6.

17 Lee JY, Lim HW, Yoon J, Oh JE, Park KA, Oh SY. Comparison of the efficiency of various muscle transposition procedures using a novel three-dimensional model. *PLoS One* 2018;13(9):e0204078.

18 Rüssmann W. Computer-assisted determination of indications and follow-up in strabismus surgery. *Klin Monbl Augenheilkd* 1996;208(1):27-32.

19 Schreiber KM, Schor CM. A virtual ophthalmotrope illustrating oculomotor coordinate systems and retinal projection geometry. *J Vis* 2007;7(10):4. 1-14.

20 Allen LK, Bhattacharyya S, Wilson TD. Development of an interactive anatomical three-dimensional eye model. *Anat Sci Educ* 2015;8(3):275-282.