



## Convergence ability in patients after cataract phacoemulsification and patients with their own lens

Badanie różnic w zdolności konwergencji gałek ocznych u osób po zabiegu fakoemulsyfikacji oraz u osób z własną soczewką

Marcin Piotr Jaworski<sup>1</sup>, Tomasz Tomczyk<sup>1</sup>, Sylwia Gładysz<sup>1</sup>, Anna Babik<sup>1</sup>, Krzysztof Maria Wilczyński<sup>1</sup>, Tomasz Kirmes<sup>1</sup>, Dorota Pojda-Wilczek<sup>2</sup>

<sup>1</sup>Students' Scientific Society Department of Ophthalmology, School of Medicine in Katowice, Medical University of Silesia in Katowice, Poland

<sup>2</sup>Department of Ophthalmology, School of Medicine in Katowice, Medical University of Silesia in Katowice, Poland

### ABSTRACT

**INTRODUCTION:** The aim of this study was to determine whether convergence varies with age and pseudophakia.

**MATERIAL AND METHODS:** 86 patients, aged 21–85 (average age: 62.7) years were included in the study group: 39 patients with binocular pseudophakia and 41 with their own lens, as well as 68 people with their own lens, at the age of 19–25 (average 22.1) years. Examinations were carried out at distances of 50 and 10 cm, and for distant vision. Interpupillary distance measurements were used to calculate the difference of convergence capabilities. The examination results of phakic and pseudophakic eyes were compared.

**RESULTS:** The mean convergence of the pseudophakic patients was 3.52 mm ( $\pm$  0.42 mm), in the patients with their own lens: 3.46 ( $\pm$  0.74 mm). No statistically significant differences between the groups were found. No statistically significant difference was found in the mean convergence between the two groups of patients aged 19–25 (group 1) and over 65 years (group 2), either. The average value of convergence in group 1 was 3.47 mm (3.84–2.93 mm). However, in the second group the values were 3.46 mm (3.96–2.48 mm). There was no evidence of statistical differences in the average value of convergence in both groups for distances of 50 cm and 10 cm.

**CONCLUSIONS:** Convergence does not depend on age. Presbyopia does not lead to a loss of convergence in phakic or pseudophakic eyes.

#### KEY WORDS

convergence, lens, phacoemulsification, accommodation, pseudophakia

Received: 29.03.2016

Revised: 23.07.2016

Accepted: 11.08.2016

Published online: 31.01.2017

Address for correspondence: Marcin Piotr Jaworski, Students' Scientific Society Department of Ophthalmology, School of Medicine in Katowice, Medical University of Silesia in Katowice, Poland, ul. Ceglana 35, 40-515 Katowice, Poland, e-mail: m.jaworski01@gmail.com

Copyright © Śląski Uniwersytet Medyczny w Katowicach  
www.annales.sum.edu.pl



## STRESZCZENIE

**WSTĘP:** Celem badania było stwierdzenie, czy konwergencja zależy od wieku i pseudofakii.

**MATERIAŁ I METODY:** Do grupy badanej włączono 86 pacjentów w wieku 21–85 lat (średnia: 62,7): 39 pacjentów z obuoczną pseudofakią, 41 z własną soczewką oraz 68 osób z własną soczewką w wieku 19–25 lat (średnia 22,1). Badanie zostało wykonane w odległości 50 i 10 cm oraz dla spojrzenia w dal. Wykorzystując uzyskane pomiary rozstawu źrenic, obliczono różnicę zdolności konwergencji oraz porównano obie grupy badanych.

**WYNIKI:** Średnia wartość konwergencji u pacjentów z pseudofakią wyniosła 3,52 mm ( $\pm 0,42$  mm), a w grupie pacjentów z własną soczewką 3,46 mm ( $\pm 0,74$  mm). Na podstawie przeprowadzanych analiz nie stwierdzono istotnych statystycznie różnic pod względem średniej konwergencji pomiędzy grupami pacjentów w wieku od 19 do 25 lat (grupa 1.) i powyżej 65 lat (grupa 2). Średnia wartość konwergencji w grupie 1. wynosiła 3,47 mm (maksymalna 3,84 mm, minimalna 2,93 mm). Natomiast w grupie 2 – 3,46 mm (maksymalna 3,96 mm, minimalna 2,48 mm). Średnia wartość konwergencji przy patrzeniu na przedmiot znajdujący się w odległości 50 cm i 10 cm różniła się istotnie statystycznie pomiędzy badanymi grupami.

**WNIOSKI:** Dane z uzyskanych analiz statycznych pozwalają stwierdzić, że konwergencja nie zależy od wieku oraz starczowzroczność, nie prowadzi do utraty zdolności konwergencji w oczach fakijnych i pseudofakijnych.

## SŁOWA KLUCZOWE

soczewka oka, fakoemulsyfikacja, konwergencja, akomodacja, pseudofakia

## INTRODUCTION

Eye convergence, which is the ability to direct both eyes at one point, is one of the essential elements in vision. With proper convergence, the created images resulting from stimulating the corresponding retina spot in both eyes can be superposed in the brain and are perceived as a single image [1].

Constant interaction of the internal and external muscles of the eyeball provides precise adjustment of the eye organ position to the desired convergence angle, which varies with the distance of the observed object from the eye. The closer the visual focus point to the observer, the bigger the convergence angle. By analysing these relationships, the human brain infers (calculates) the distance between the eyes and the observed object. The above mentioned phenomenon matters only when observing objects located no more than 3 m from the observer, because for objects located at a greater distance, the ability to perceive depth disappears [2].

The ability of the eyes to converge is an individual variable feature, depending on many factors. In some disease stages, as a result of ongoing degenerative processes or due to applied treatment, accommodation disturbances take place, which combined with the ability of the eyes to converge, allows sharp vision of objects positioned close to the eyes. This phenomenon is often associated with cataract (clouding of the lens), a congenital or degenerative disease of the eye [3]. Currently, the most popular method of removing cataracts is phacoemulsification surgery, where the cloudy lens is crushed by ultrasound, followed by sucking out

the remaining masses. In place of the removed lens, an artificial intraocular lens of a desired optical power is implanted [4].

The state, in which one's own lens is replaced by an artificial one is called pseudophakia [5]. The most commonly implanted artificial monofocal lens has no accommodating property, and its optical power is usually selected in such a way that the patient does not need to use any correction for distance. Therefore, it is necessary to use an additional spectacle correction when looking from a close distance.

The available literature has not yet answered the question whether the lack of accommodation after cataract surgery is associated with convergence disturbances.

The research was planned so as to compare the ability of convergence of people with their own lens and those after phacoemulsification surgery, and to assess the convergence ability in patients who can or cannot accommodate due to presbyopia.

## MATERIAL AND METHODS

The research was conducted at the University Center of Ophthalmology and Oncology, Independent Public Hospital of the Medical University of Silesia in Katowice.

The study group comprised 86 patients, aged from 21 to 85 (mean: 62.7) years, including 39 patients with binocular pseudophakia and 47 with their own lenses and 68 people with their own lenses at the age of 19–25 (mean 22.1) years. The patients with their own lenses were divided according to age – into 19–25 years old (group 1), and over 65 years (group 2), assu-



ming that the patients up to 25 years of age should be able to accommodate, while in those over 65 years of age, accommodation is almost absent.

The research set consisted of a pupillometer and two measuring instruments of the authors' own design, with the text appropriately placed at distances of 10 cm and 50 cm from the examined eyes. Using the prepared test kit, spacing of the pupils was assessed when focusing the patient's sight at three points; far distance (assuming a distance of more than 2 m), reading distance (50 cm) and near distance (10 cm). During the examination, no glasses were worn by the patients. Each measurement was performed three times in order to avoid an accidental measurement error. Then, the values of pupillary distance (PD) were averaged for each respective distance. The figures show the manner the testing was performed (Fig. 1, Fig. 2).

**Table I.** Examination inclusion and exclusion criteria  
**Tabela I.** Kryteria włączenia i wyłączenia pacjentów do badania

**I. Inclusion criteria for examinations:**

1. The presence of binocular implants in a lenticular capsule (examined group)
2. Own lens in both eyes (control group)
3. Age – over 18 years
4. Full cooperation with the patient

**II. Exclusion criteria:**

1. Ophthalmic diseases that may affect visual acuity, such as:
  - A. Retinopathies, for example AMD
  - B. Diseases of the optic nerve and tract
  - C. Retinitis
  - D. Corneal diseases
  - E. Vitreous disorders
  - F. Strabismus
2. General neurological diseases



**Fig. 1.** Pupillometer examination with text placed at distance of 50 cm.  
**Ryc. 1.** Badanie pupilometrem z tekstem w odległości 50 cm.



**Fig. 2.** Pupillometer examination with text placed at distance of 10 cm.  
**Ryc. 2.** Badanie pupilometrem z tekstem w odległości 10 cm.

The collected data were analysed statistically with the StatSoft "STATISTICA" program, version 10. Student's t-tests were used to compare groups, and R Spearman to determine the correlation. The level of significance was set at  $p = 0.05$ .

## RESULTS

In the patients with artificial lenses, the average convergence value was 3.52 mm ( $\pm 0.42$  mm), and in patients with their own lenses 3.46 mm, respectively ( $\pm 0.74$  mm). Analysis of the collected results showed no statistically significant differences between the groups. The maximal convergence in the phakic group was 3.96 mm and the minimal – 2.48 mm. Similar values were obtained when comparing patients wearing glasses and those who do not use any optical aids. The T-test showed no statistically significant differences. The results are shown in Table II.

**Tabela II.** Comparison of convergence between patients with artificial lenses and patients with their own lenses.

**Tabela II.** Porównanie konwergencji u pacjentów po zabiegu fakoemulsyfikacji i pacjentów z własną soczewką

Patients	Number of patients	Average convergence [mm]	Maximal convergence [mm]	Minimal convergence [mm]
Patients with artificial lens	39	3.52	3.94	3.10
Patients with their own lens	47	3.46	3.96	2.48

No significant correlation was found between the age of the patient, and the average convergence ( $r = -0.09$ ;  $p > 0.05$ , Fig. 3).

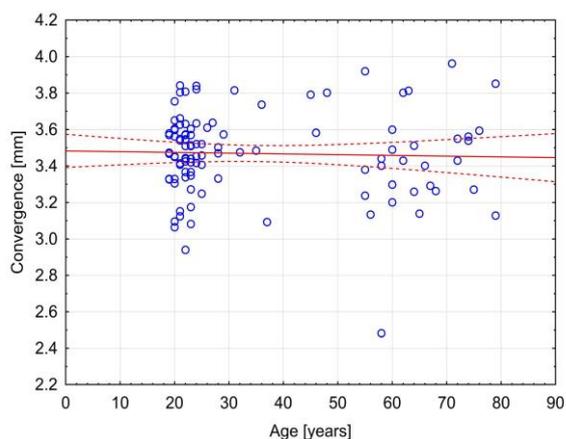


Fig. 3. Correlation between convergence and age in group with their own lenses.

Ryc. 3. Korelacja pomiędzy konwergencją a wiekiem w grupie pacjentów, którzy nie przeszli zabiegu fakoemulsyfikacji.

No statistically significant difference was found in the mean convergence between the two groups of patients, aged 19–25 years (group 1) and over 65 years (group 2). The average value of convergence in group 1 was 3.47 mm and 3.46 mm in group 2. The maximal values for these groups were: 3.84 mm and 3.96 mm, and the minimal 2.93 mm and 2.48 mm, respectively (Tab. III). There were no significant differences between the mean value of the convergence when looking at the object at a distance of 50 cm and 10 cm in both groups, either. In patients aged 19–25, convergence when looking at object placed 10 cm away averaged 4.26 mm, and at 50 cm it was 0.8 mm. In the group over 65, these values were 4.28 mm and 0.9 mm, respectively.

Tabela III. Comparison of convergence between patients aged 19–25 (group 1), and patients over 65 years of age (group 2)

Tabela III. Porównanie konwergencji u pacjentów po zabiegu fakoemulsyfikacji i pacjentów z własną soczewką

Group	Number of patients	Average convergence [mm]	Maximal convergence [mm]	Minimal convergence [mm]
Group 1	68	3.47	3.84	2.93
Group 2	39	3.46	3.96	2.48

## DISCUSSION

Several factors may cause disturbances in accommodation, which include eye diseases, systemic diseases and medications. It is believed that agents used in the treatment of systemic diseases and narcotic substances largely affect accommodation. Morphine and sulfonamides are substances with a stimulating effect. Tetrahydrocannabinol, ethanol and antihistamines can cause insufficient or inefficient accommodation. There

are several diseases of a systemic character, nervous system diseases and eye diseases, which may lead to insufficient accommodation. Among them, we may distinguish: encephalitis, multiple sclerosis, diabetes, anaemia, intoxications, sinusitis, facial palsy, Parkinson's disease, damage to the central nervous system (the area of the brain stem, pineal gland), and ocular diseases such as glaucoma, inflammation of the iris and sclera [6]. No difference between the patients with their own lenses and those after phacoemulsification indicates that cataract surgery has no influence on convergence, and the accommodation-convergence reflex is preserved. This observation is significant with reference to sight development in young children with performed surgery on a congenital cataract.

Many factors can impair the process of convergence, and neurological disorders are among them. Ongoing disease processes in the central nervous system affect the extraocular muscles. Damage to the posterior commissural area in the course of haemorrhagic or ischemic stroke of the thalamus, hydrocephaly, neoplasia, metabolic diseases, degenerative, neuroinfective or demyelinating changes in multiple sclerosis, contribute to limiting the scope of eye movements vertically, especially upwards. Convergent-retractive nystagmus in the form of asynchronous, concurrent saccades, particularly when looking upwardly are also observed. Vergentive movements are impaired, convergence or divergence paralyse, resulting in spastic, convergent setting of the eyeballs. Ophthalmoplegia disorders, including the failure of convergence are one of the criteria for diagnosing progressive supranuclear palsy [7]. Therefore, patients with neurological diseases were excluded from the analysed group.

When looking at objects that are close, there is an accommodative convergent reflex, independent from visual acuity, which means that with a preserved response to light, the convergent accommodative response is not impaired. It is a consensual reflex, therefore, both eyeballs react to a stimulus simultaneously. The location of the brain centers responsible for this response has not been found yet. There are some opinions that it is located somewhere within the frontal or occipital lobe, but the most probable location seems to be the vicinity of the pretectal nucleus which is located ventrally to the center for pupil response to light. Known areas that contain cells activated during accommodation are the frontal eye field (Brodmann area 8), medial nucleus reticularis tegmenti pontis, central thalamus, fastigial nucleus (FN), posterior interposed nucleus (IPN) and motoneurons of the medial rectus muscles [8]. An afferent and an efferent pathway of this response can be distinguished.

The first of these – the afferent one runs in the initial segment within the optic nerve, and the route of the efferent path runs in the oculomotor nerve. The reflex arc for convergence and accommodation is much lon-



ger than the reflex to light, taking into account the location of the nerve fibers, which conduct impulses of the response. The nerve path of the accommodation arc begins at the neuroreceptors of the retina, from which the information processed into electrical impulses enter the precinct of the lateral geniculate nucleus (LGN) using axons, and next to the primary visual cortex – by Brodmann area 17 around the calcarine sulcus then to the associative visual cortex (Brodmann areas 18, 19) to the superior colliculus cover where they converge at the Edinger-Westphal nucleus. From there, the axons of the parasympathetic preganglionic motoneuron are sent into the ciliary ganglion innervating specific muscles, which cause: (1) the ciliary muscles to make the lens change its curvature, thus becoming convex, (2) the pupillary iris sphincter muscle to narrow out, resulting in improved visual acuity – accommodation. Simultaneously, the primary visual cortex, association visual area (Brodmann areas 18, 19) and the parietal cortex are bound by association fibres with Brodmann area 8 – frontal eye fields (FEF). Subsequently, frontal eye fields are connected with deep cerebellar nuclei: the posterior interposed nucleus and the fastigial nucleus via the medial nucleus reticularis tegmenti pontis. The supraoculomotor area and supraocular nucleus receive neurons from the following cerebellar nuclei, which are connected with the somatic III cranial nerve supplying the medial rectus muscle responsible for convergent eye movement [1,8,9,10,11]. The central thalamus projects and receives axons from the posterior interposed nucleus (IPN), which is suggested to be involved in the control of far response. Stimulation of the IPN leads to eye divergence and decreased accommodation [8]. However, there are still some conjectured connections: (1) between the FEF and central thalamus; (2) the association visual area, parietal cortex and FEF project neurons to the supraoculomotor area; (3) the supraoculomotor area projects neurons to the Edinger-Westphal nucleus [1,8,9,10,11,12].

From the analysis of the excluded patients with strabismus, it is known that weakening of convergence is observed with age in patients with hidden strabismus and can cause manifestation of strabismus and diplopia, which in specific cases, may require surgical treatment. Moreover, the weakening of convergence while working close up causes blurred vision and fatigue. Improvement can be achieved by using prismatic lens glasses for near vision. Therefore, it is important to examine the ability of convergence in each patient who complains of poor vision. In some patients, distraction of reflex accommodation and convergence is observed, during which proper accommodation is not accompanied by convergence or with poor accommodation; the effort used for working at a close distance causes excessive convergence, strabismus and diplopia [6]. The research performed by

Bruce et al., concerning the effect of age on convergent accommodation, confirmed an increase in the AC/A ratio (accommodative convergence/accommodation) and a decline in the CA/C (convergence accommodation to convergence) with age. The authors wanted to confirm current theories of presbyopia development. A group of 23 people, aged from 17 to 42 years with normal binocular vision was selected. Changes in the response to accommodation and convergence were stimulated by lenses (-1.00 DS and -2.00 DS) and prisms (4 and 8 prism diopters), respectively. A moderate linear relationship between the AC/A ratio and age ( $p < 0.002$ ) was demonstrated, and a strong linear relationship between the CA/C ratio and age ( $p < 0.0001$ ) was observed. A mutual relationship was also observed between AC/A and CA/C, where the AC/A ratio increases, and the CA/C ratio decreases in patients between 20 and 40 years of age. This may be due to the fact that with age stronger contraction of the ciliary muscle is required to accommodate occurring changes. Assessment of a strengthening accommodation reaction and convergence response with age were performed in this study and did not reveal differences between older and younger patients [13].

According to Hess-Gullstrand's theory explaining the cause of presbyopia, it is the accommodative convergence and accommodation that are dependent upon the activity of the ciliary muscle. Contraction of the ciliary muscle causes accommodation. Poor accommodation makes it very difficult to focus light on the retina when changing focus between objects located near and far [13].

Numerous analyses aimed at assessing the most appropriate treatment of inefficient ocular convergence have been carried out. However, there is little scientific evidence to support the efficacy of the proposed treatment. A prospective, randomized, double-blind clinical study examining convergence insufficiency was conducted on 72 children, aged 9 to 18. Two groups of children with convergence insufficiency, one treated with glasses for the correction of hyperopia and the other treated with glasses without a correction value (placebo), were examined and compared. The study showed that converging lenses do not effectively relieve symptoms resulting from impaired convergence in a child compared to lenses without a correction value. Neither group demonstrated a clinically significant decrease in symptoms. These data indicate the probability of the placebo effect in the group of children. However, it should be noted that the effects of treatment may be different in an adult population [14].

In another study, the effect of sensory deprivation on binocular vision after bilateral cataract surgery with an intraocular lens implantation was shown. The study group comprised 50 patients, and examinations were



carried out 6 weeks after the second surgery. The patients were divided into 3 groups: a time between operations of less than 12 months, 12–24 months and more than 24 months. Binocular vision was assessed according to the time elapsed between operations, taking into consideration the convergence range, stereopsis, motor merging range, the presence of asthenopia symptoms, squint angle for distant and near vision. Significant differences in the parameters of binocular vision depending on the time between operations were found. The longer the period, the more patients with symptoms of asthenopia, exophoria and reduced range of convergent fusion, measured by synoptophore [15]. The outcomes of that study were published after our patients were tested, thus the time-related change of convergence after cataract was not considered.

Other authors found clinically insignificant accommodation in patients with pseudophakia, which was observed by the use of objective methods – with an autorefractometer. In addition, it was subjectively noticed (test table) that there was accommodation of

0.5 D, which was higher than in those with their own lens. This was explained by the existence of corneal aberrations associated with aging (the average age of people with their own lens was 36.34 years, in patients with pseudophakia – 69.8 years), and contraction of the muscles during pupillary constriction in patients with pseudophakia [16]. The performed analysis showed a preserved convergence reflex in pseudophakic eyes. It can be concluded that pseudophakia does not provide an indication for convergence examination among patients without asthenopia.

## CONCLUSIONS

1. Presbyopia is not associated with a loss of convergence ability for both phakic and pseudophakic eyes.
2. Convergence is not dependent on age.

### Author's contribution

Study design – D. Pojda-Wilczek, M.P. Jaworski, T. Tomczyk, S. Gładysz, A. Babik, K.M. Wilczyński, T. Kirmes

Data collection – M.P. Jaworski, T. Tomczyk, S. Gładysz, A. Babik, K.M. Wilczyński, T. Kirmes

Data interpretation – M.P. Jaworski, T. Tomczyk, S. Gładysz, A. Babik, K.M. Wilczyński, T. Kirmes

Statistical analysis – K.M. Wilczyński

Manuscript preparation – M.P. Jaworski, T. Tomczyk, S. Gładysz, A. Babik, K.M. Wilczyński, T. Kirmes, D. Pojda-Wilczek

Literature research – M.P. Jaworski, T. Tomczyk, S. Gładysz, A. Babik, K.M. Wilczyński, T. Kirmes

## REFERENCES

1. Singh V. Visual System. In: Singh V. Textbook of Clinical Neuroanatomy. Elsevier India 2014, 217–218.
2. Davson H. The muscular mechanisms. In: Davson H. Physiology of the eye. U.S. Academic Press 1980, 383–500.
3. Kinoshita J.H. Mechanisms initiating cataract formation. Proctor Lecture. Invest. Ophthalmol. Vis. Sci. 1974; 13(10): 713–724.
4. Gimbel H.V. Divide and conquer nucleofractis phacoemulsification: Development and variations. J. Cataract Refract. Surg. 1991; 17(3): 271–291.
5. Millodot M. Dictionary of Optometry and Visual Science. Butterworth-Heinemann, New York 2009.
6. Przekoracka-Krawczyk A., Naskręcki R. Dysfunkcja akomodacji i metody jej badań. Optyka (Nauka). 2010; 6(7): 24–30.
7. Jadanowski K., Budrewicz S., Koziorowska-Gawron E. Zaburzenia gałkorochove w chorobach ośrodkowego układu nerwowego. Pol. Przegl. Neurol. 2010; 6(4): 202–211.
8. Gamlin P.D. Neural mechanisms for the control of vergence eye movements. Ann. N.Y. Acad. Sci. 2002; 956: 264–272.
9. Kozicz T., Bittencourt J.C., May P.J., Reiner A., Gamlin P.D., Palkovits M., Horn A.K., Toledo C.A., Ryabinin A.E. The Edinger-Westphal nucleus: a historical, structural, and functional perspective on a dichotomous terminology. J. Comp. Neurol. 2011; 519(8): 1413–1434.
10. Schall J.D., Morel A., King D.J., Bullier J. Topography of visual cortex connections with frontal eye field in macaque: convergence and segregation of processing streams. J. Neurosci. 1995; 15(6): 4464–4487.
11. Gamlin P.D., Yoon K. An area for vergence eye movement in primate frontal cortex. Nature 2000; 407(6807): 1003–1007.
12. Savaki H.E., Gregoriou G.G., Bakola S., Moschovakis A.K. Topography of Visuomotor Parameters in the Frontal and Premotor Eye Fields. Cereb. Cortex 2015; 25(9): 3095–3106, doi: 10.1093/cercor/bhu106.
13. Bruce A.S., Atchison D.A., Bhoola H. Accommodation-convergence relationships and age. Invest. Ophthalmol. Vis. Sci. 1995; 36(2): 406–413.
14. Scheiman M., Cotter S., Rouse M., Mitchell G.L., Kulp M., Cooper J., Borsting E. Randomised clinical trial of the effectiveness of base-in prism reading glasses versus placebo reading glasses for symptomatic convergence insufficiency in children. Br. J. Ophthalmol. 2005; 89(10): 1318–1323.
15. Rajská K., Loba P., Broniarczyk-Loba A. The influence of sensory deprivation on binocular vision after bilateral cataract extraction with intraocular lens implantation. Klinika Oczna 2012; 4: 261.
16. Nemeth G., Lipecz A., Szalai E., Berta A., Modis L. Jr. Accommodation in phakic and pseudophakic eyes measured with subjective and objective methods. J. Cataract Refract. Surg. 2013; 39(10): 1534–1542.