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BINOCULAR FUNCTION IN ADULTS BEFORE AND AFTER STRABISMUS SURGERY

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SUMMARY

Purpose: To evaluate the state of binocular vision, the amount and direction of the ocular deviation before and after strabismus surgery in adult patients and to monitor the occurrence of postoperative complications.
Methods: The retrospective study of 58 adult patients with selected types of strabismus who were surgically treated in the Eye Department of the Tomas Bata Regional Hospital in Zlín. We evaluated the amount and the degree of the primary ocular deviation and the binocular alignment before and after surgery, as well as the state of binocular vision after surgery and the occurrence of postoperative complications.
Results: The average deviation in convergent strabismus before surgery was +23.46 degrees, after surgery +6.6 degrees, in divergent strabismus it was -21.5 degrees, after surgery -1.48 degrees, for vertical strabismus before surgery +12.5 degrees and +3.75 degrees after surgery and in paralytic strabismus +20 degrees before surgery and +3 degrees postoperatively.
Preoperatively there was effectively no binocular vision in up to 63.9% of patients, superposition occurred in 31%, fusion in 5.1%. No patient had stereopsis before surgery. After surgery, superposition was present in 39.7%, fusion in 31% and stereopsis in 6.9% of patients. Only 22.4% of patients experienced no binocular vision after surgery.
Of the selected 21 patients out of 58 with an observation period of at least 3 years, we observed an improvement or development of binocular vision functions after surgery in 12 patients and no improvement of binocular vision functions in 9 patients. In the first group, 58.3% had a stable deviation throughout the follow-up period. While in the second group the deviation was stable in only 33.3%. We can assume that the improvement in binocular vision function after strabismus surgery, leads to a greater longer-term stability of postoperative deviations.
Conclusion: Strabismus surgery in adult patients is an effective and safe method, which is not only a cosmetic procedure used to adjust the position of the eyes, but also enables us to induce or improve the state of binocular vision functions.
Key words: strabismus, JBV, simple binocular vision, binocular function, deviation

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INTRODUCTION

Simple binocular vision (SBV) is a coordinated sensorimotor activity of both eyes in which a fusion of retinal images from the right and left eye produces a single spatial perception of the observed object in the brain. It is not innate, but develops and becomes fixed in the first decade of life.

There are three degrees of SBV: The first degree is constituted by **simultaneous perception**, i.e. the ability to see two different images which belong to one another simultaneously, and **superposition**, i.e. the ability to overlap these images. The second is **fusion**, which means the ability to combine two almost identical images into a single perception, and the third degree of SBV is **stereopsis**. This is the ability to create an in-depth perception through a combination of images of the same object, which is seen from two slightly different angles.

Strabismus is a dysfunction of the parallel positioning of the eyes, in which the axes of vision of both eyes do not bisect in the same point. One eye is directed towards the fixation point and is called the fixating or dominant eye, and the other eye deviates and is therefore known as the deviating or non-dominant eye. The angle formed by the axes of both eyes is called the angle of deviation. Dysfunction of SBV is also always present [1,2]. Strabismus can usually be treated successfully also in adult patients [3]. Whereas in children the primary goal is to correct the refractive error, treat blunt-sightedness and subsequently to train binocular functions, in adults, in addition to correction of the refractive error, we also have the option of prescribing

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prismatic glasses and surgical treatment [1,4,5].

Even today, some ophthalmologists still consider strabismus surgery for adult patients to be a purely cosmetic procedure, which leads to an adjustment of the position of the eyes but has no influence on binocular functions, regardless of the type of strabismus or the age of its origin. However, this opinion has been refuted by an ever-increasing number of clinical trials, which demonstrate that it is possible to improve or restore binocular functions following strabismus surgery in adulthood [6,7]. Kushner et al. state that if the development of binocular vision is established in patients after strabismus surgery, this contributes also to long-term stability of the postoperative deviation [8].

The success rate for treatment of strabismus in adult age is high, and in addition to improving the positioning of the eyes it also brings with it certain functional advantages in the form of development or improvement of binocular functions, extension of the binocular visual field, elimination of diplopia and indisputably also psychosocial benefits and a positive impact on quality of life [3,9,10–15]. The risks of surgery are relatively low, and serious complications are extremely rare.

METHOD

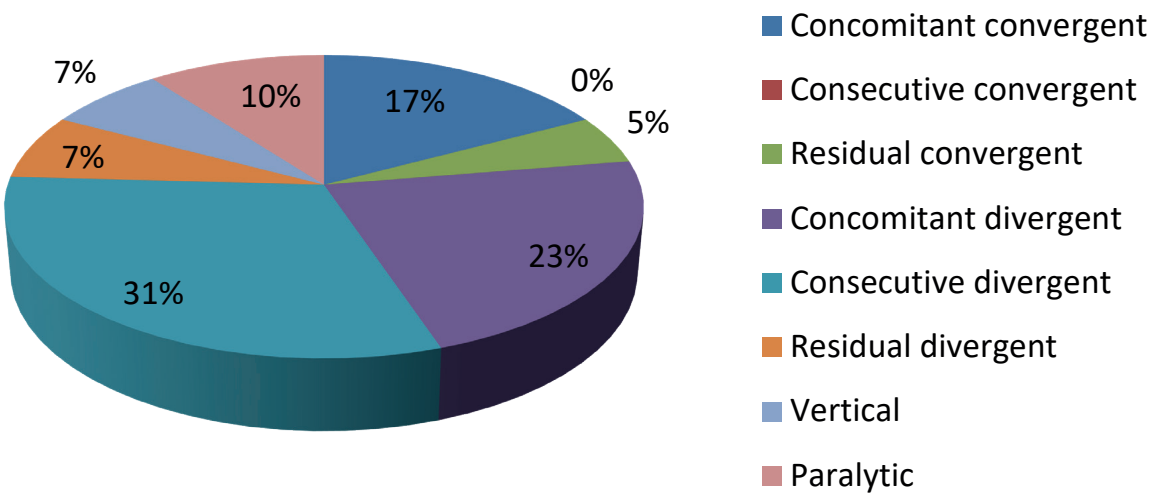
The retrospective study incorporated 58 adult patients, of whom 36 were women (62%) and 22 were men (38%), with various types of dynamic and paralytic strabismus. The patients were operated on at the Department of Ophthalmology at the Tomas Bata Regional Hospital in Zlín over the period of 2011 to 2019. The age of the patients at the time of surgery was from 20 to 83 years (mean age 49 years), and the mean postoperative observation period was 3 years (1 to 9.5 years). We included adult patients with strabismus in the study, aged over 18 years with a minimum observation period of 1 year, for whom complete preoperative and postoperative data, and results of the examinations were available. Before the procedure and at all postoperative follow-ups, all patients underwent a complete eye examination, including recording of medical history, measurement of refraction on an autorefractometer, noncontact measurement of intraocular pressure, examination of uncorrected and best corrected distance and near visual acuity (VA), complete orthoptic examination and measurement of deviation of strabismus with the aid of prisms, examination of binocular vision with the aid of Bagolini striated glasses, measurement on a troposcope and examination of the anterior segment and ocular fundus of both eyes in artificial mydriasis. All the operations were performed under general anesthesia, a maximum of two muscles were operated on in a single eye. In 91.4% of cases (53 out of 58 patients), adjustable sutures were used. The postoperative follow-up examinations were conducted after 1 week, 1 month, 3 months, 6 months, 1 year, and subsequently at annual intervals. We monitored the size of the deviation of strabismus in the primary position, and the state of binocular functions before and after surgery, the stability of the deviation after surgery, the incidence of postoperative diplopia and other postoperative complications.

In the statistical evaluation we used a t-test, a Wald test for testing equality of probability and a Wald test for testing the correlation coefficient. Conclusions on the hypotheses were drawn on the basis of the p-values. The statistical data were processed with the aid of the R language and an Rstudio interface (Rstudio, Inc.).

RESULTS

Representation of refractive errors

In our cohort the most common refractive error was astigmatism, which occurred in various different forms in as many as 35% of patients. Emmetropia, which was considered to be within the range of +0.5 D to -0.5 D, was present in 28%, hypermetropia in 27% and myopia in 10% of patients.



Graph 1. Type of strabismus (concomitant strabismus = not yet operated, consecutive = subsequent strabismus after previous surgery, residual = residual strabismus after previous surgery)

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Representation of individual types of strabismus

As regards the type of strabismus, the most widely represented type was divergent strabismus. The complete representation of the individual types of strabismus in the studied cohort is illustrated in Graph 1. In all our patients with paralytic strabismus, the cause of origin was trauma (most often a traffic accident), and in most cases this concerned paralysis of the sixth cranial nerve.

Best corrected visual acuity

Almost 3/4 of patients had best corrected VA of 6/6. In 15% of eyes, best corrected VA was 6/12 or less. The worst corrected VA was 6/60 in 2 eyes.

Previous strabismus surgery

Almost half of our patients (46.5%) had not undergone any strabismus surgery in the past. One previous strabismus operation was recorded in the medical history of 32.5% of patients, and more than one strabismus operation was stated by almost 21% of patients (two operations 17.2% and three strabismus operations 3.6%).

Average size of deviation before and after surgery for individual types of strabismus

The average deviation in convergent strabismus before surgery was +23.46 degrees (+9 to +50 degrees), after surgery this was reduced to +6.6 degrees (+2 to +10 degrees). In patients with divergent strabismus the average size of the deviation before surgery was -21.5 degrees (-3 to -50 degrees), and after surgery -1.48 degrees (-18 to +10 degrees). In the case of vertical strabismus, there was a reduction of the average size of the deviation from preoperative +12.5 degrees (+4 to +28 degrees) to +3.75 degrees (+1 to +9 degrees) after surgery, and in the paralytic type of strabismus from +20 degrees (+6 to +34 degrees) before surgery to +3 degrees (0 to +5 degrees) postoperatively (Graph 2).

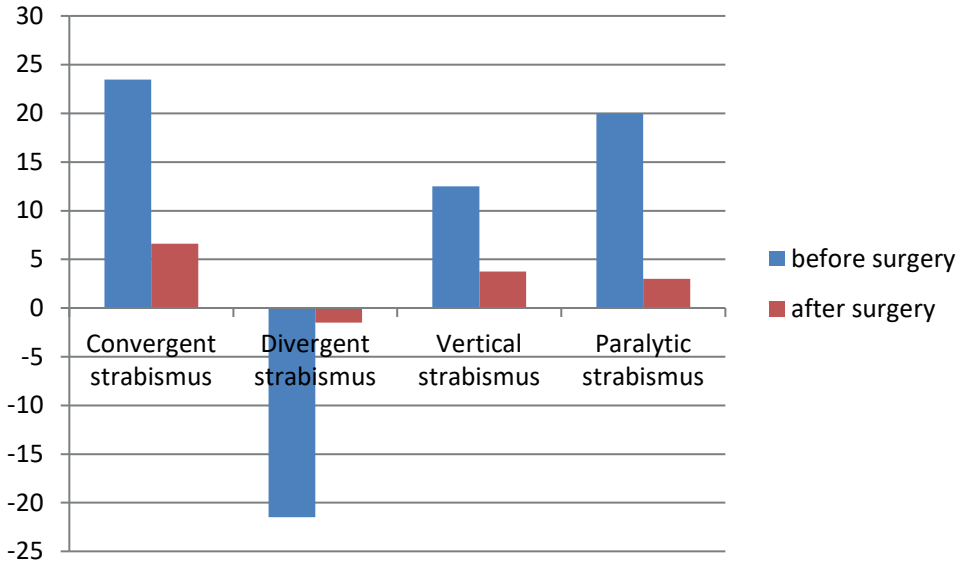
In the statistical processing here we are testing the hypothesis concerning differences of averages. We draw our conclusions on the hypothesis on the basis of the p-values, in which the resulting p-value for convergent, divergent and paralytic strabismus was <0.001, and for vertical strabismus 0.194. On the basis of the p-values and on a level of significance of 0.95 (95%), the difference in the preoperative and postoperative deviations for convergent, divergent and paralytic strabismus is statistically significant. We cannot draw this conclusion for vertical strabismus on the basis of the p-value. This does not mean that the difference is statistically insignificant, but in this case the sample is simply too small (4 patients).

The following images show a comparison of the position of eyes before and after the surgical procedure in some of the patients from our cohort (Fig. 1–5).

State of binocular functions before and after strabismus surgery

Preoperatively as many as 63.9% of patients had no binocular vision, superposition was present in 31% of patients and fusion in 5.1% of patients. None of the patients had stereopsis before surgery. After surgery we recorded both an establishment of SBV and an improvement of the quality of binocular functions. Superposition was present in 39.7% of patients, fusion in 31% and stereopsis in 6.9% of patients. Only 22.4% of patients had no binocular vision after surgery (Graph 3).

Here we are testing the hypothesis concerning equality of probability. We draw our conclusions on the hypothesis again on the basis of the p-values. The resulting p-value for superposition was 0.330, for fusion < 0.001, for stereopsis 0.038 and for no binocular vision < 0.001. Based on the stated p-values and the level of significance of 0.95 (95%), we can state that in the case of fusion, stereopsis and no binocular vision, the postoperative changes are statistically significant. In the case of superposition, as with the previous hypothesis, this does not mean that no improvement took place; nevertheless, for the



Graph 2. The average deviation in individual types of strabismus before and after surgery

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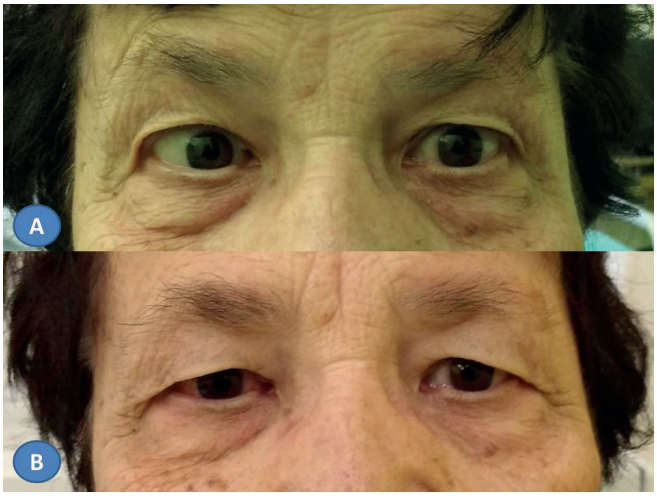


Figure 1. (**A**) Female patient (72-years-old) with convergent strabismus before surgery with deviation on troposcope +20 degrees and with diplopia and (**B**) after retroposition of the medial rectus muscle with an adjustable suture and resection of the lateral rectus muscle on the right eye with parallel eye position and no diplopia



Figure 2. (**A**) Male patient with divergent strabismus before surgery, with lagophthalmos and ectropion of the lower eyelid on the right (postoperative paresis of the facial nerve on the right side after parotidectomy for parotid gland adenoma in the past) and (**B**) after retroposition of the lateral rectus muscle with an adjustable suture and resection of the medial rectus muscle on the right eye



Figure 3. (**A**) Female patient (35-years-old) with divergent strabismus and deviation -65PD (prism dioptres) before surgery, (**B**) the second day after retroposition of the lateral rectus muscle with an adjustable suture and resection of the medial rectus muscle on the left eye and (**C**) after 3 years since the surgery, with deviation on troposcope -2 degrees, without diplopia, subjectively satisfied



Figure 4. (**A**) Female patient (53-years-old) before and (**B**) after strabismus surgery with adjustable suture

result to be statistically significant the differences in the pre and postoperative states would need to be more pronounced, or larger samples would be required.

Incidence of diplopia and other complications after strabismus surgery

Before surgery, diplopia was present in almost 19% of patients (11 out of 58). After the performance of the operation, diplopia appeared and persisted in 2 patients (3.4%). In one of these we corrected it by prescribing prismatic glasses and in the other patient diplopia is manifested only occasionally, especially during fatigue, and otherwise the patient does not suffer from it. Other than diplopia and transitional conjunctival injection after the procedure, we did not record any other postoperative complications in our cohort of patients.

Stability of deviation depending on the state of binocular functions after surgery

In our patients we focused also on monitoring the stability of the deviation, depending on the level of binocular functions after surgery. We investigated whether patients with

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Figure 5. (**A**) Male patient with divergent strabismus before surgery and (**B**) the second day after surgery immediately after setting the suture in the right eye

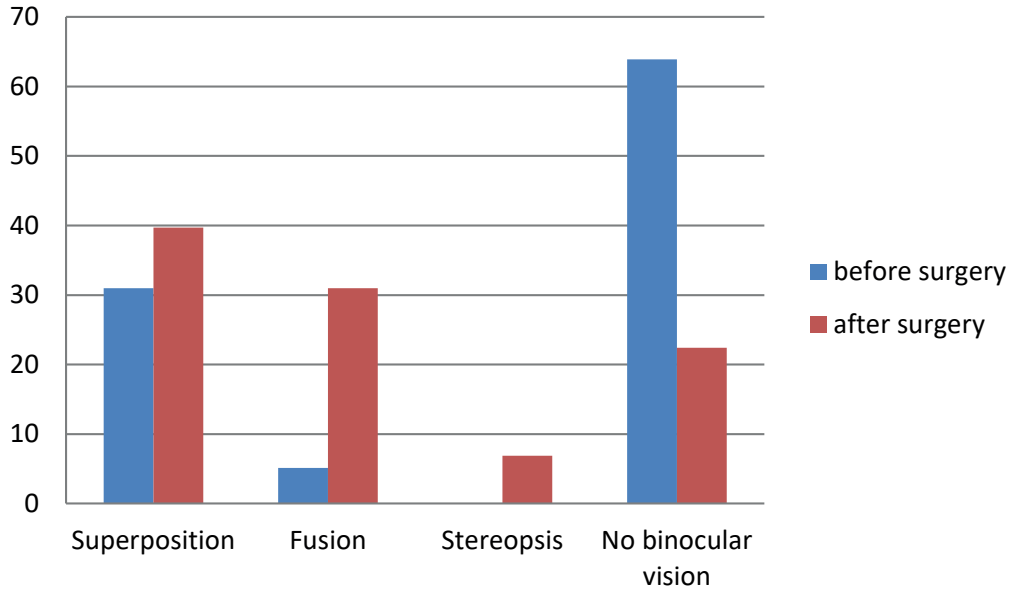
an improvement of the level of binocular functions after surgery would have a more stable deviation over the course of the years than patients in whom no improvement was achieved. With regard to the fact that we wished to evaluate this stability from a longer-term perspective, we set ourselves a minimum observation period of 3 years or more in this case. This condition was met by a total of 21 patients out of a total number of 58 (36.2%). In 12 of these (57.1%) we achieved an establishment or improvement of binocular functions, and in 9 patients (42.9%) these functions did not improve. In the first group the deviation was stable throughout the entire observation period in 58.3% of patients (7 out of 12), whereas in the other group, in which there was no improvement of binocular functions, the deviation remained stable over the long term in 33.3% of patients (3 out of 9).

In order to determine the correlation between the state of binocular functions and the long-term stability of postoperative deviation, we are testing the hypothesis concerning a correlation coefficient equal to zero. We again draw our conclusion on the basis of the p-value. The resulting p-value of the correlation coefficient was 0.279. On the basis of the stated p-value and on a level of significance of 0.95 (95%), we cannot reject the zero hypothesis. As in the previous cases this does not mean that no correlation exist between the variables, but in order for us to reject the zero hypothesis the correlation coefficient would need to be greater, or we would require a larger sample. We nevertheless believe, on the basis of the results published in international studies, as well as on the basis of our own results, that the establishment or improvement of binocular functions after surgery should lead to better and longer-term stability of the postoperative deviation. However, in order to verify this assertion, specifically in our own cohort, we would require a larger group of patients, and in certain cases also undoubtedly a longer observation period.

DISCUSSION

The issue of strabismus surgery for adults is receiving an ever-increasing amount of attention. This is attested to also by the growing number of studies and articles dealing with this topic, from the perspective of the cosmetic or functional results of strabismus surgery, the potential postoperative complications and psychosocial benefits. For this reason also, we have decided to analyze our adult patients and compare the results of this analysis with the currently available Czech and foreign studies.

The published studies consider strabismus surgery to be cosmetically successful if the resulting primary position of the eyes is within 10 prismatic diopters (PD) without subjec-



Graph 3. Status of binocular functions before and after strabismus surgery

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tive complaints and without diplopia after a single surgical procedure [9,16]. According to the available sources, approximately 80% of patients fit into this category [7,9,17–19]. In our cohort, more than half of the patients had already undergone a previous strabismus operation in the past. Only 46.5% (27 out of 58) of our patients had not undergone previous strabismus surgery. If we are to evaluate only those patients who had not yet undergone any strabismus procedure, then a single one of our operations achieved a resulting eye position of up to 10 PD, without diplopia or other complaints in 22 out of 27 patients (81.5%). This number is comparable also with the following studies. In the study conducted by Mills et al., 83% of patients attained a resulting eye position of up to 10 PD after one operation [20], while in the study by Keech et al. the success rate was 72%, even despite the fact that it incorporated a large number of patients with complex forms of strabismus [18]. Kushner states a position of up to 10 PD in 87% of patients after a single operation, and an overall success rate of up to 97% after one or two performed strabismus procedures [16]. Pellarová et al. describe a position of up to 10 PD in almost 100% of patients after one or two strabismus operations [6].

In our cohort of 58 patients was achieved an improvement of the level of binocular function after strabismus surgery, regardless of the specific type of strabismus, the size of the deviation before surgery and any applicable presence of amblyopia. Before the operation was performed, 36.1% of patients had a certain degree of binocular vision, while none of the patients had stereopsis. After strabismus surgery a certain level of binocular vision was present in 77.6%, and stereopsis was established in 6.9%. We did not observe a decrease of binocular functions after the performance of the procedure in any of our patients. With regard to fusion and stereopsis, and in the case of no binocular vision, the postoperative changes were statistically significant.

Mets et al. describe an improvement of binocular functions in 42% of adult patients following strabismus surgery, as well as a decrease of these functions in 6%. However, in virtually all of these patients the decrease was caused by another ocular pathology [21]. Hromádková describes preoperative fusion in 8 patients out of her cohort of 24 adults. After the performance of strabismus surgery she recorded fusion in 12 patients, and the establishment of stereopsis in 4 patients [22].

Comparable results to ours, but in a far larger cohort, are described by Pellarová et al. They evaluated the long-term results (with an observation period of 2–15 years) of surgical treatment of various types of dynamic and paralytic strabismus in 257 adult patients aged 18 to 65 years. In their cohort there was a statistically significant improvement of binocular functions, in which before surgery simple binocular vision was present in instrumental examination in 34.6% of patients, increasing to 80% of patients after surgery. In this they are in accordance with other studies which also demonstrate that strabismus surgery in adults not only has a beneficial cosmetic effect and psychosocial consequences, but also enables the establishment of binocular vision or an improvement of its quality [6].

Kushner and Morton analyzed a group of 359 patients aged over 21 years in whom the postoperative deviation was less than 10 PD. They measured SBV with the aid of Bagolini striated glasses, and in 86% of patients demonstrated a certain improvement of binocularity within 6 weeks of the performance of strabismus surgery, regardless of the type of strabismus, the size of the preoperative deviation or the presence of amblyopia. They recorded the highest percentage of patients with SBV after surgery in the case of primary exotropia (92%). They also state that in the patients in whom an improvement of binocular functions was achieved, the size of the postoperative deviation appeared to be more stable 10 years after surgery in comparison with the group in which binocular functions did not improve [8]. In our cohort also, we recorded a somewhat more stable postoperative deviation in the group of patients who experienced an improvement of binocular functions in comparison with the group in which no improvement of these functions was achieved. It is necessary to note that our cohort was incomparably smaller and the observation period incomparably shorter. Nevertheless, we believe that the improvement of the level of binocular functions after strabismus surgery in adults leads to greater and longer-term stability of the postoperative deviation.

According to various different sources, diplopia appears in 1–7% of cases after strabismus surgery in adults, of which unsolvable diplopia constituted only a negligible proportion [20,23–25]. The value of 3.4% determined in our group also comes within the above range. We did not record any case of unsolvable diplopia.

Kushner reports only 0,7% of cases of unsolvable diplopia in a study of 424 adult patients who have undergone strabismus surgery [25].

Scot et al. observed what was probably the largest published cohort of patients with various different types of strabismus. Their study incorporated 892 patients aged from 9 to 89 years, who were divided into two groups. The first covered patients with the onset of strabismus before "visual maturity" (the age limit was set at 9 years) with a preoperative incidence of diplopia of 21%, and the second covered patients with the onset of strabismus after visual maturity, in which preoperative diplopia was present in as many as 81%. After strabismus surgery, postoperative diplopia was present in only 2% in both groups, of which 1% constituted unsolvable diplopia. The second group comprised a total of 462 patients, of whom 92% attained fusion after the performance of strabismus surgery [19].

A meta-analysis conducted by the American Academy of Ophthalmology in 2004 incorporated data from reports describing the results in adult patients who had undergone strabismus surgery. In this it was determined that the surgical procedure resolved preoperative diplopia in 527 out of 688 patients (72%) [20].

If strabismus surgery is performed before the patient has reached visual maturity, there should be no doubt concerning the potential functional benefits. If surgery is performed after the patient has reached visual maturity,

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these functional benefits should theoretically depend on whether strabismus appeared before or after visual maturity. In the case of onset of strabismus after visual maturity, patients frequently report diplopia. The erroneous perception still remains widespread that a surgical procedure performed on an adult individual with strabismus, mainly with its origin before visual maturity, has only a cosmetic effect. Numerous studies, of which we have at least a fraction in this case report, present findings that contradict of this view, and demonstrate that even if strabismus is long-term, most adult patients record an establishment or certain improvement of binocular functions after strabismus surgery, regardless of the type of strabismus and the age of its origin. They also provide evidence that strabismus surgery in adults is very effective, has functional and psychosocial benefits, and entails only a low risk of complications. This was confirmed to a large extent also in our cohort of adult patients.

CONCLUSION

In the above retrospective overview we observed the state of binocular functions and the size of the deviation of strabismus before and after strabismus surgery in adult patients, as well as the stability of the postoperative deviation depending on the level of binocular functions and the incidence of postoperative complications. We recorded both an improvement of eye position, which was statistically significant for convergent, divergent and paralytic strabismus (in the case of vertical strabismus the cohort of patients was too small to evaluate), and also a statistically significant improvement of the level of binocular functions after the performance of surgery, regardless of the type of strabismus, the time of its origin, age of the patient and any applicable presence of amblyopia. Based on the results in our cohort, we also believe that an improvement of the state of binocular functions after strabismus surgery leads to greater and longer-term stability of the postoperative deviation. In accordance with the available studies, we also did not record any serious complications after surgery.

In conclusion it is therefore possible to state that strabismus surgery in adults is not merely a cosmetic procedure serving to adjust the position of the eyes. It is a safe and effective method which also enables the establishment or improvement of the state of binocular functions. The success rate of treatment is high, the risks of surgery relatively low, and serious complications extremely rare. Last but not least, strabismus surgery brings with it significant psychosocial benefits, which have a positive impact on the patient's quality of life.

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