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Yokoyama procedure for esotropia associated with high myopia: real-world data from a large-scale multicentre analysis

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ABSTRACT.

Purpose: **High myopic patients may develop strabismus due to globe dislocation out of the normal extraocular muscle cone. Surgical correction of this strabismus type is possible by joining the superior and lateral rectus muscles without the need for a scleral suture called the Yokoyama procedure. Data from large patient samples and the evaluation of a potential effect of an additional medial rectus recession (MRR) have been lacking so far.**

Methods: **We pooled retrospective patient data of 14 departments of ophthalmology in Germany and Switzerland and analysed determinants of postoperative results using multivariable regression models.**

Results: **We included 133 patients (mean age: 59.7 ± 13.4 years, surgery between 2008 and 2017) with a mean preoperative esotropia (both Yokoyama with and without MRR) of 23.8°±4.6°. The angle of preoperative esotropia increased with age. The postoperative esotropia was 8.7° ± 9.9°, and six patients were overcorrected. While preoperative esotropia was highly associated with postoperative results, we found no association of additional MRR with any of our postoperative outcome measures. The Yokoyama procedure had a higher absolute effect in patients with higher preoperative esotropia.**

Conclusion: **Our study confirms the positive effect of the Yokoyama procedure on strabismus due to high myopia in large-scale real-world data. In some cases, MRR may be needed because of muscle contracture, although additional MRR statistically did not affect the postoperative outcome. In patients with bilateral high myopic strabismus, correction of both eyes seems beneficial. The effect size of the Yokoyama procedure appears to be mainly driven by preoperative esotropia.**

Key words: esohypotropia – heavy eye – high myopia – muscle dislocation – strabismus fixus

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Introduction

High myopic patients have previously been reported to occasionally develop a horizontal and vertical strabismus during adulthood, mostly after the third decade of life. In these patients, axial length (AL) of the globe is usually more than 26.5 mm and motility can be reduced. The phenotypical appearance ranges from small-angle esotropia with mild abduction deficit to strabismus fixus with severe restriction (Kaynak et al. 1994; Sturm et al., 2008). In the majority of cases, the (more) myopic eye is hypotropic and turned inwardly. Exotropia is less frequent.

Kolling demonstrated the path of the lateral rectus muscle (LR) to be oblique from its insertion dorsally downwards using both in situ imaging and CT and MRI scans showing the nasal displacement of the vertical rectus muscles and, particularly, inferonasal displacement of the LR (Kolling 1993). The decisive innovation

introduced by Herzau was to normalize the pulling direction of the slipped LR by adding a retroequatorial myopexy of this muscle to the conventional recess and resect surgery (Herzau & Ioannakis 1996). Krzizok by MRI demonstrated that the path of the LR could be normalized by this procedure (Krzizok et al. 1997), which generated various case reports on this technique and modifications (Hayashi et al., 1999; Aoki et al., 2003; Rowe & Noonan 2006; Sturm et al., 2008).

Yokoyama et al. elaborated the fundamental idea by joining the lateral and superior rectus muscles by a muscle suture 15 mm behind the insertion (anterior to their pulleys, anterior muscle belly union, MBU). Avoiding the scleral suture is an advantage, especially for high myopic eyes with scleral thinning. In addition, the technique is preferable for surgeons who rarely perform myopexy (Yokoyama et al. 2000; Yamaguchi et al. 2010). Yamaguchi and colleagues showed by MRI the superotemporal shift of the posterior part of the globe out of the normal extraocular muscle cone and demonstrated that MBU of the superior rectus and LR restored their normal anatomic relationship (Yamaguchi et al. 2010). However additional medial rectus recession (MRR) was performed in 80% of the eyes (Yamaguchi et al. 2010). Due to further reports on these modifications (Yamada et al., 2002; Godeiro et al., 2009), LR myopexy lost popularity over time. Ranka and Steele summarized in their review: 'The Faden-OP (LR) showed good postoperative results, but this procedure is technically difficult, particularly in high myopes with thin sclera, whereas the Yokoyama procedure eliminates the risk of sclera perforation and minimizes the risk of anterior segment ischemia' (Ranka & Steele 2015).

So far, only smaller studies of patients with the Yokoyama procedure (≤25 patients) have been published (overview in Su et al. 2016). The aim of this study was to evaluate the effect of the Yokoyama procedure alone or combined with MRR in a large multicentre cohort for different subsets of patients.

Methods

Data acquisition

All university hospitals in Germany and two non-university hospitals with large orthoptic departments were approached as to previously performed Yokoyama surgeries, and whether they would like to participate in the study. We finally included data from 14 sites: university hospitals of Bonn, Dresden, Essen, Frankfurt, Giessen, Göttingen, Heidelberg, Köln, Leipzig, Lübeck, Rostock, Würzburg, hospitals of Esslingen, Germany, and St. Gallen, Switzerland. Patient data sets ranged from 2 to 23 patients per site who underwent surgery between 2008 and 2017. These included anamnestic data and preoperative and postoperative findings, that is horizontal and vertical angles of strabismus (measured with the alternating prism and cover test in 0.3m, if visual acuity was poor, with the Krimsky test), AL, eye motility, head position, further ocular disorders, details concerning Yokoyama surgery and potentially further surgeries. The Yokoyama procedure was defined as joining the superior rectus and LR muscles by an intermuscular suture. The performance of additional procedures such as MRR and the choice of the suture material was decided upon by the individual different departments. All amounts given for an optional MRR are given for the actual surgery. When both eyes were operated simultaneously or within a timeframe of four weeks, the given postoperative results are those for bilateral surgery.

Data analyses

The study was approved by the local institutional board of the University of Bonn. Data were pseudonymized and conveyed via Excel (Microsoft Excel 2010; Microsoft, Redmond, WA, USA) sheets to the Dept. of Ophthalmology of the University of Bonn.

Whenever angles of strabismus were provided in PD (Δ, pdpt, cm/m), they were converted in degree (°, deg) with the formula $angle/deg = tan^{-1}0.01\Delta$ (Basiakos et al., 2019). Due to the nonlinearity of the tangens function, the prism dioptre unit (cm/m) is not appropriate for statistical calculations.

Horizontal angles for esotropia are indicated with positive values, whereas negative values represent exotropia. Concerning values for the vertical deviation, in unilateral cases the given values indicate the amount of hypotropia of the affected eye, and in bilateral cases, the difference between the eyes.

Different groups (e.g. with and without MRR, with and without previous surgery) were compared using Student's *t*-test, Wilcoxon's test and the chi-square-test depending on data distribution.

In order to evaluate surgical effects, we defined four postoperative outcomes (for horizontal and vertical angles, respectively): the absolute postoperative angle, the absolute difference between pre- and postoperative angle, the relative difference between pre- and postoperative angle (defined as absolute difference divided by preoperative angle; only possible in horizontal angles, since vertical angles were zero for many patients) and whether the absolute postoperative angle was ≤ 5° (binary variable). Subsequently, we analysed determinants of the first three outcomes using multivariable regression modelling and for the binary outcome using Cox regression modelling. All models were adjusted for age, sex, AL, MRR, previous strabismus surgery, additional surgery, laterality (uni- vs. bilateral) and preoperative angle. The latter was not corrected in the analysis of relative difference, as it is part of the outcome. Moreover, we performed additional sensitivity analyses adjusting for different sites.

Analyses were performed using SPSS 25 (IBM Inc., Armonk, New York) and RStudio (R version 3.4.1; RStudio, Inc., Boston, MA; available in the public domain at https://www.rstudio.com/). A significance level was set to $p = 0.05$ for the group analyses and corrected for multiple testing for the regression analysis using the Bonferroni correction ($p = 0.05/8 = 0.00625$).

Results

We received data of 140 patients. Seven patients who had undergone atypical Yokoyama procedure joining other muscles than the LR and superior rectus were excluded. Of the included 133 patients, 100 (75%) were female. The mean age was 59.7 years (see Table 1), and 109 patients (82%) were ≥ 50 years of age.

About 37 patients (28%) had undergone prior eye muscle surgery. Of the 20 patients where we had details, 12 had combined convergence surgery (recess–resect) on the operated eye, 3 had surgery on the other eye and the remaining five had other surgeries.

Sixty two patients (47%) were pseudophakic; therefore, refraction was not analysed. Data on AL of the operated eye(s) were available in 109 patients (82%), AL of the fellow eye in 86 of the 124 patients with unilateral surgery, as some centres did not provide AL in (all of) their patients.

AL was ≥ 28 mm in all patients except two, who had typical reduced motility and were therefore included in the study. Patient characteristics and details are summarized in Table 1.

Patient characteristics and pre- and postoperative findings (133 patients, 124 unilateral surgery and 9 bilateral).

The preoperative angle of esotropia was associated with age, even when corrected for sex and AL, which themselves were not associated, respectively. Hence, with every year of increasing age, the esodeviation was 0.22° higher (95% confidence interval (CI): 0.01–0.44; p = 0.0385). There was no significant association of the vertical angles with age, sex or AL.

Six patients had preoperative esotropia of ≤ 5° (vertical angles 5.0–19.3°), and none of them had prior surgery for strabismus. Four of them had typically reduced eye motility, and AL ranged from 28.3 to 37.2 mm.

Surgery

Surgery was performed on the right eye in 69 patients, on the left eye in 55 patients and on both eyes in nine patients. Figure 1 displays an overview.

The suture material used for the Yokoyama procedure was non-resorbable in 125 patients (83 polyethylene terephthalate (Mersilene®; Ethicon, Somerville, USA), 24 polyester, 13 polyamide, 4 silk, 1 polypropylene), mostly 4-0 or 5-0, and resorbable (polyglactin/PGA) in 8 patients.

We found no differences between patients with and without prior strabismus surgery concerning sex, age, AL, preoperative angles of strabismus (horizontal and vertical) or suture material. More patients without than with prior strabismus surgery were pseudophakic (54% vs. 27%). Patients with bilateral surgery showed a tendency (p = 0.06) to have higher preoperative esotropia than patients with unilateral surgery [mean 35.7° ± 20.3° (median 25.0°) versus mean 23.0° ± 13.8° SD (median 19.3°), respectively].

In patients with unilateral surgery, AL was ≥ 28 mm in the fellow eye in 43/86 patients (50%) and ≥ 30 mm in 32/86 patients (37%).

Preoperative esotropia was larger in patients with MRR compared to those without MRR (32.6° ± 13.4 SD vs. 20.3° ± 13.6 SD; p < 0.00001). Moreover, patients with MRR were older, which was likely confounded by an increase in esotropia with age (see Table 2).

The choice to perform additional MRR (2.5 to 12 mm) was only dependent on the decision of the individual surgeons. In about half of the patients with additional MRR, the surgeons had decided this before surgery due to large horizontal angles. In the other half, MRR was performed because it was intraoperatively difficult to join the lateral und superior rectus muscle due to MR contracture.

There were no significant differences concerning sex or suture material, but we found a tendency to higher AL in the group with only Yokoyama surgery.

Table 1. Patient characteristics and pre- and postoperative findings (133 patients, 124 unilateral surgery and 9 bilateral)

	n	Mean ± SD	Median	Range	
Age (years)	133	59.7 ± 13.4	60.1	16	87
Axial length (AL) (mm)	109	32.3 ± 2.6	32.4	26.4	37.5
Preoperative esotropia (°)	133	23.8 ± 14.6	21.8	0	70.0
Postoperative horizontal angle (°)	133	8.7 ± 9.9	5.0	−11.5	35.0
Absolute effect (°) (horizontal)	133	15.2 ± 10.6	13.8	−2.3	50.0
Preoperative hypotropia (°)	133	8.0 ± 5.3	6.8	0	26.6
Postoperative vertical deviation (°)	133	2.8 ± 4.1	0	0	16.7
Absolute effect (°) (vertical)	133	5.2 ± 5.4	5.7	−9.1	20.0
	Preoperative			**Postoperative**	
Restricted ocular motility (abduction ≤ 15° and/or elevation ≤ 10°)	84/122	69%		38/100	38%
Abduction ≤ 15°	76/122	62%		38/100	38%
Elevation ≤ 10°	59/122	48%		33/100	33%
Relevant head turn ≥ 10°	22/129	17%		6/125	4%

Postoperative findings

Postoperative evaluation was aimed to include a follow-up of at least one month, but 29 patients did not show up for long-term follow-up or lived abroad, causing a shorter follow-up time. Follow-up ranged from 1 to 1260 days (median: 99 days, mean: 157 ± 225 days), and 92 patients had a follow-up time ≥ 8 weeks (see below). No surgical complications such as intraocular pressure rise, perforation or anterior segment ischaemia were reported. Postoperative findings are presented in Table 1.

The postoperative horizontal angle was strongly associated with the preoperative horizontal angle (see Fig. 2). For each degree of preoperative esotropia, we found a larger postoperative angle of 0.50° (95% CI: 0.39–0.56; p < 0.00001). Patients with unilateral surgery tended to have more residual postoperative esotropia as compared to patients with bilateral surgery (7.09°, 95% CI: 1.36–12.83, p = 0.02), while overall women showed a tendency to smaller postoperative angles (−3.24°; 95% CI: −6.55–0.06; p = 0.05), even with correction for AL. Both associations were not statistically significant after the Bonferroni correction.

There was no association of the postoperative horizontal angle with age, AL, prior surgery, MRR or additional surgeries.

The postoperative vertical angle (see Fig. 3) was strongly associated with the preoperative vertical angle (0.33°; 95% CI: 0.18–0.47; p < 0.0001), but not with age, sex, AL, laterality or prior strabismus surgery. Additional surgery showed a tendency to larger postoperative angles (95% CI: 0.71–5.57; p = 0.011).

We found comparable results for the absolute differences: for each degree of preoperative horizontal angle, the absolute difference between the pre- and postoperative angles increased by 0.50° (95% CI: 0.4–0.61; p < 0.00001). While women tended to have larger absolute differences (3.24°; 95% CI: −0.06 to 6.55; p = 0.05), unilateral surgery showed a tendency to be associated with smaller absolute differences between pre- and postoperative angles (−7.09°; 95% CI: −12.83 −1.36;

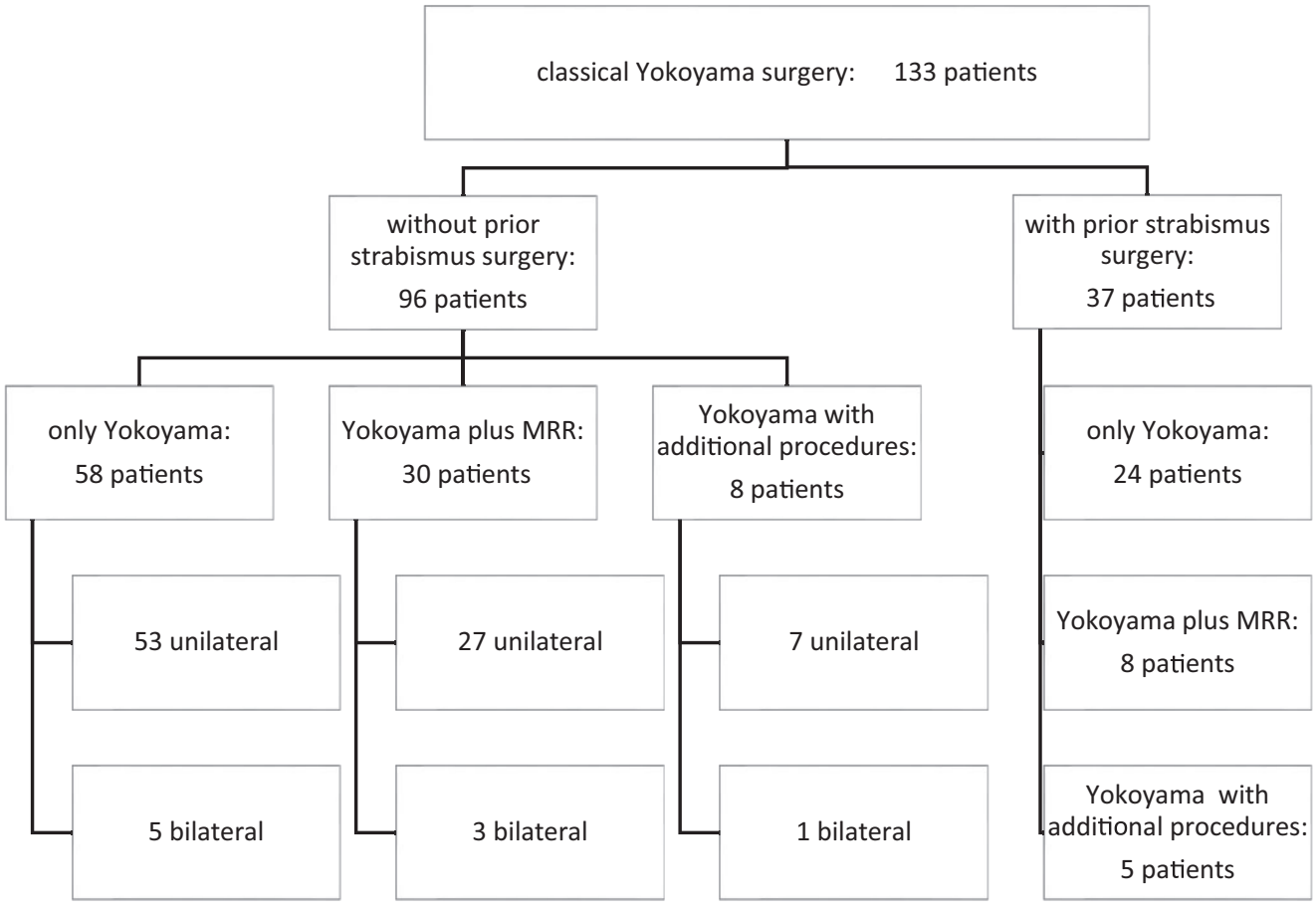

Fig. 1. Distribution of the 133 patients with classical Yokoyama procedure concerning prior strabismus surgery and additional medial rectus recession (MRR) or further procedures (plication of the lateral rectus (LR), plication of the LR and superior rectus muscle, revision of the LR, contralateral MRR). All patients with prior strabismus surgery had unilateral Yokoyama procedure.

Table 2. Comparison between pre- and postoperative data for patients with and without additional medial rectus recession (MRR)

	Without medial rectus recession					With medial rectus recession					p
	n	Mean ± SD	Median	Min	Max	*n*	Mean ± SD	Median	Min	Max	
Age (years)	95	58.07 13.74	58.60	16.20	86.60	38	63.84 11.80	63.05	20.80	83.40	0.02*
Axial length (AL) (mm)	75	32.66 2.48	32.78	27.00	37.50	34	31.38 2.56	31.29	26.43	35.90	0.02*
Preoperative esotropia (°)	95	20.33 13.57	16.70	0	70	38	32.61 13.37	33.51	9.00	60.00	P < 0.001*
Postoperative horizontal angle (°)	95	7.53 9.51	4.57	−11.50	30.96	38	11.56 10.24	9.55	−5.00	34.99	0.04*
Absolute effect (°) (horizontal)	95	12.80 9.53	11.31	−2.29	47.71	38	21.05 10.87	19.92	5.39	50.00	P < 0.001*
Preoperative hypotropia (°)	95	7.87 5.20	6.84	0	21.80	38	8.21 5.47	9.05	0	26.57	0.64
Postoperative vertical deviation (°)	95	2.46 3.66	0	0	16.70	38	3.54 4.88	0.29	0	16.70	0.44
Absolute effect (°) (vertical)	95	5.41 5.42	5.71	−8.35	20.00	38	4.67 5.34	5.66	−9.09	15.00	0.47

p = 0.02). Patients with MRR showed larger absolute differences, which is in accordance with the higher preoperative esotropia and showed no effect in the multivariable analysis (see Table 2). For the vertical deviation, the preoperative angle was the strongest determinant as well, while additional surgery showed a tendency to cause smaller differences.

We found no influence of age, sex, AL, prior surgery, MRR or additional

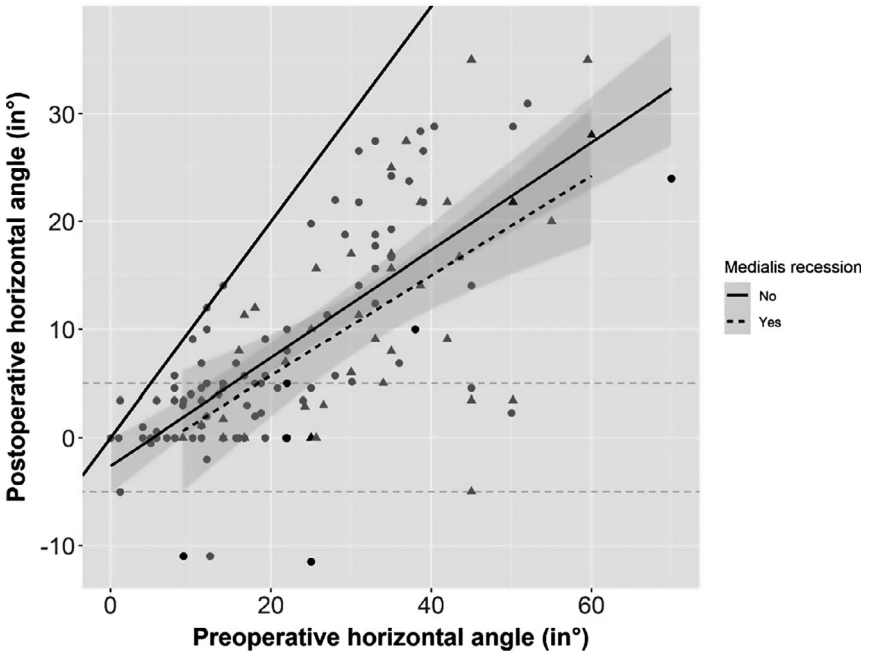

Fig. 2. Scatterplot of pre- and postoperative horizontal angles [in degree] of 133 patients, with regression lines and 95% confidence intervals. ● Patients with the Yokoyama procedure only (n = 95, grey = unilateral, black = bilateral). ▲ Patients with additional MRR (2.5 to 12.0 mm, mean 5.5 ± 3.5 mm, median 6.0 mm) (n = 38, grey = unilateral black = bilateral). Dark line = linear slope (indicates no change). Dark grey field = target angle (−5° to 5°).

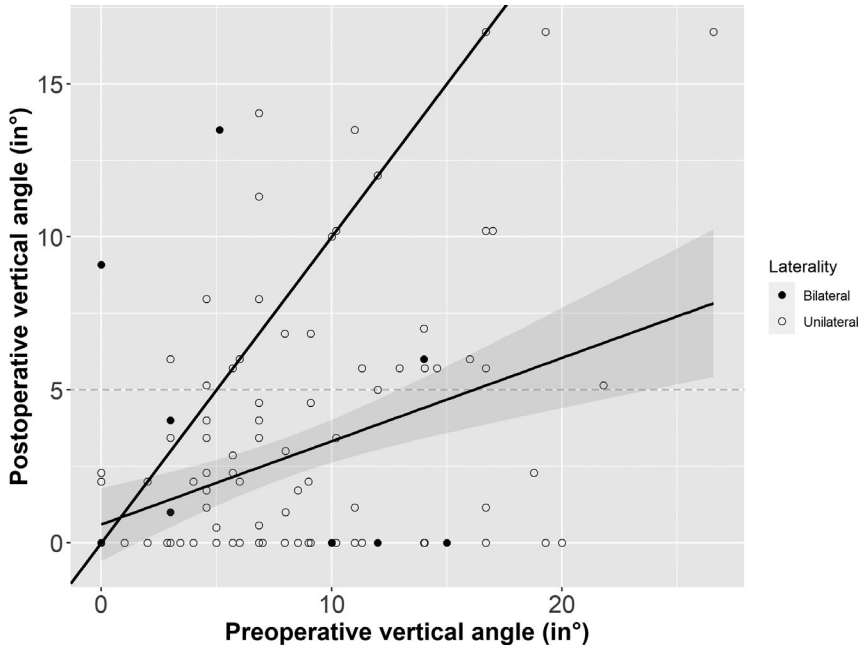

Fig. 3. Scatterplot of pre- and postoperative vertical angles [in degree] of 133 patients, with regression lines and 95% confidence intervals. grey = unilateral surgery, black = bilateral. Dark line = linear slope (indicates no change). Grey dotted line = target angle (≤5°).

surgeries on the relative difference. There was a tendency ($p = 0.02$) towards a higher relative effect of the surgery in patients with bilateral surgery compared to those with unilateral surgery, which did not reach statistical significance.

In our cohort, 48 % of patients showed a postoperative horizontal angle between −5° and 5°.

Larger preoperative esotropia was associated with a smaller odds ratio for an absolute postoperative horizontal angle ≤ 5° (OR: 0.89; 95% CI: 0.85–0.94; $p < 0.0001$; Fig. 4), while no other factor appeared to be associated.

For all postoperative outcomes, we performed sensitivity analyses adjusting for treatment site and did not find any relevant effect. In an additional sensitivity analysis, we excluded patients with a follow-up shorter than 8 weeks (56 days) and recalculated our models with the remaining 92 patients. The preoperative angle remained by far the strongest determinant and showed comparable effect sizes, while other non-significant trends vanished. Hence, the short follow-up time in some patients did not relevantly change our results.

Of the six patients with preoperative esotropia of ≤ 5°, one patient had a postoperative exotropia of −5°, the others had a postoperative esotropia between 0 and 3.4° (median: 0.5°), and vertical angles ranged from 0 to 16.4° (median: 1°). Motility was improved in all patients who had significantly reduced motility before the surgery.

Postoperative exotropia between 2° and 11.5° occurred in further five patients with preoperative esotropia between 9 and 45°. Two of these had MRR during their combined surgery before the actual procedure, in one patient the actual MRR was 10 mm (for an initial esotropia of 9°). Two of the patients had bilateral surgery with bilateral high myopia. Concerning the surgical effect on the vertical angle, in three patients the postoperative vertical angle was substantially larger than the preoperative, two of these with bilateral surgery. One patient had a postoperative exotropia and higher vertical deviation, in this patient additional myopexia of the lateral rectus muscle to the sclera had been performed.

In 26 patients, further strabismus surgery was performed (Eight combined recess–resect surgery other eye, six additional MRR, three revisions of Yokoyama surgery, two Yokoyama surgery other eye and seven other procedures). In another eight patients, further strabismus surgery was planned or discussed with the patient.

Discussion

Our study provides large-scale results of the Yokoyama procedure for

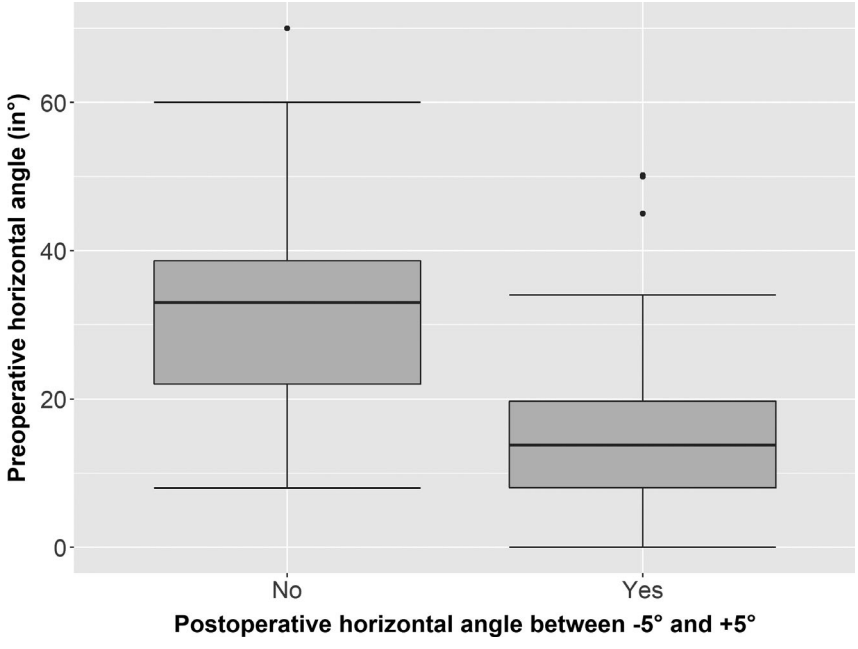

Fig. 4. Boxplot of preoperative esotropia and postoperative target angle (absolute horizontal deviation ≤ 5°).

correcting esohypotropia in patients with high myopia using data from 14 centres.

Most of our patients were 50 years or older, and magnitude of preoperative esotropia increased with age. We found the effect of the Yokoyama surgery to be dependent on the magnitude of preoperative esotropia, whereas age, sex, AL, prior strabismus surgery and even additional MRR were not associated. Patients with larger esotropia underwent additional MRR more frequently, but we found no effect of MRR on the surgical outcomes.

First results on the procedure were published by the group of Yokoyama with results of 14 patients (23 eyes) (Yamaguchi et al. 2010) after their initial presentation of the surgical principle in 2000 (Yokoyama et al. 2000). Further studies comprising 7 to 25 patients were published (Akar et al. 2014; Fresina et al. 2014; Atili et al. 2016; Zou et al. 2017), as well as a few case reports and small case series (Wong et al. 2005; Rowe & Noonan 2006; Basmak et al. 2008; Durnian et al. 2010; Shih et al. 2012; Akbari et al. 2013; Su et al. 2016). Another Chinese study presented 16 patients, but details except the abstract could not be evaluated as the study was published in Chinese (Yang & Liu 2017). Hence, adding up patients with Yokoyama procedure from all publications so far, we found 108. Data of these studies are presented in Table 3.

Place table 3 here: Data of studies with more than ten patients with Yokoyama procedure.

In this study, we analysed all angles of strabismus and thus the effects of surgery in degree (°) and not in cm/m, as the unit degree represents the true eye position or change in position, respectively, and not its tangential projection (Basiakos et al. 2019).

Comparing our data with the literature (see Table 3), we confirm a good effect of the Yokoyama procedure procedure in a large group of patients with esohypotropia due to high myopia. Our patients had smaller mean preoperative esotropia than the initial study of Yamaguchi et al. (2010). This is partly due to the fact that there were six patients in our cohort with very small preoperative esotropia (four with typical ocular motility restriction and two with vertical angles of > 15°), but the potential effect of surgery on esotropia therefore was low in these patients in the first place.

On the other hand, we had fewer bilateral surgeries compared to the other studies with the Yokoyama technique and bilateral surgery tended to have a higher effect. Our data indicate that a large proportion of our patients had in fact bilateral high myopia, but had surgery only in one eye. We do not know the reasons for this in our data. For example, patients may not have had typical muscle and motility features of high myopes in their fellow eye or surgeons may have decided to operate one eye at a time with this rather new surgical technique. Nevertheless, 26 patients had further strabismus surgeries, two of them had Yokoyama surgery on the fellow eye. Our data seem to indicate that in bilateral high myopia, bilateral Yokoyama procedure has a larger effect than unilateral surgery, especially in patients with large preoperative angles, as overcorrection was generally rare and occurred in patients with smaller preoperative angles. In contrast, at least 35% of our patients with unilateral Yokoyama procedure had unilateral high myopia with an AL of less than 28 mm in the fellow eye. In the general population, unilateral high myopia is less frequent than bilateral disease (Weiss 2003). Data concerning prevalence in different populations are lacking, so we cannot rule out different prevalences concerning the East-Asian and European population.

Most studies agree about manifestation of this form of strabismus typically in a higher age group (see Table 3), although the results of Yokoyama procedure in three children have been published (Acar & Altintas 2015; Shenoy et al. 2015).

None of the other studies evaluated the effect of an additional MRR compared with pure Yokoyama procedure, probably due to the small number of individuals in each group. However, some studies indicate that MRR was performed when the forced duction test was suggestive of strong contracture of the MR or when it was technically difficult to perform muscle union of the superior rectus and LR muscles due to this restriction, as some surgeons in this study indicated as well (Yamaguchi et al. 2010; Akar et al. 2014).

Patients with additional MRR showed larger preoperative angles. This, however, was based on the surgeon's choice, who seem to have chosen MRR in case of large preoperative angles. Our data do not support an additional effect of MMR on our postoperative outcome measures.

We cannot conclude from our data whether MRR may have an additional

Table 3. Data of studies with more than ten patients with Yokoyama procedure

	n	Age [years]	Prior surgery	Uni/bilateral	MRR (eyes/patients) [mm]	Pre-op horizontal deviation	Post-op horizontal deviation
Yamaguchi 2010	14	63.8 ± 8.3	0	5/9	19/10 (5–8 mm, in 3 cases in a second surgery)	58.8° ± 36.0°	0.7° ± 9.0°
Akar 2014	20	34.8 ± 3.1	0	5/15		58.6**PD** ± 2.5**PD***	6.8**PD** ± 1.4**PD***
Fresina 2014	26	48.3 ± 15.8	0	19/7	33/26, 5–12 mm	46.2**PD** ± 15.5**PD***	7.36**PD** ± 9.09**PD***
Zou 2017	25	Median 46 (35–64)	0	17 (4 with Rec/res contralat)/8	29 / 21, 5–8 mm	42.6° ± 2.3° $^{+}$	6.3° ± 4.9° $^{+}$
Present study	133	59.7 ± 13.4	37/133	124/9	41/38 (2.5 to 12 mm)	23.8° ± 14.6°	8.7° ± 9.9°

In this study, we analysed all angles of strabismus and thus the effects of surgery in degree (°) and not in cm/m, as the unit degree represents the true eye position or change in position, respectively, and not its tangential projection (Basiakos et al. 2019)
* Recalculation of the data from cm/m in degree not possible, as individual pre- and postoperative angles not given in the paper,
$^{+}$ recalculated from the individual data in cm/m in the paper.

effect when performed in a second surgery in case of insufficient effect of the first surgery.

Shenoy et al. (2015) published 15 patients (26 eyes), who received a modification of the original Yokoyama procedure: they used a silicone band loop, which was sutured to the sclera. In two patients, the silicone band had to be removed due to foreign body sensation. However, results are not directly comparable, as one of the main advantages of the Yokoyama procedure is that there is no need of a scleral suture. Moreover, the mean age of patients was 27.9 years (±16 years); therefore, patients were younger than in most other publications. For comparison, mean preoperative esotropia was 36.8°±11.7° (range: 16–50°), which improved to 9.3°±9.3° (range: 0–27°) (recalculated from the original data in cm/m).

The need for a scleral suture in high myopic eyes is also the reason why the classical equatorial myopexy of the LR lost popularity in recent years, although the results of this surgery performed by experienced surgeons were satisfactory: for comparison, esotropia was reduced from 21.0°±15.0° to 3.2°±11.1° in 35 patients with a mean age of 60.3 ± 9.9 years by LR myopexy (superior border of LR only) combined with MRR (Gräf & Lorenz 2015).

The strength of our study is the large sample size with real-world clinical data on the Yokoyama procedure with and without additional MRR in a European population. We included 133 patients, which is much larger than all patients from the above-mentioned studies together. To our knowledge, this is the only study comparing these procedures on such a large-scale level. Due to different indications according to different centres, comparisons concerning additional procedures (especially MRR) or bilateral surgery were possible.

However, we need to acknowledge several limitations: as data were collected in a clinical setting, not all data sets were complete (especially AL, motility and MRI). Moreover, different sites may have different in-house standards considering the measurement of angles and indication or performance of surgery, although we could not find a relevant effect in our data.

In conclusion, to our knowledge this study provides data from the largest sample of patients with Yokoyama procedure and potential additional MRR. Patients with smaller preoperative esotropia had a higher probability of postoperative horizontal angles of ≤ 5 degrees and bilateral Yokoyama procedure appeared to have a higher effect in patients with bilateral myopic esohypotropia. An additional MRR may be helpful when MR restriction hampers adequate union of the superior rectus and LR, although MRR had no additional effect on our postoperative outcomes compared with the pure Yokoyama procedure and may lead to overcorrections. The Yokoyama procedure showed a higher effect (but also more residual esotropia) in patients with higher preoperative esotropia, indicating that the effect of this procedure mainly depends on the preoperative angle.

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