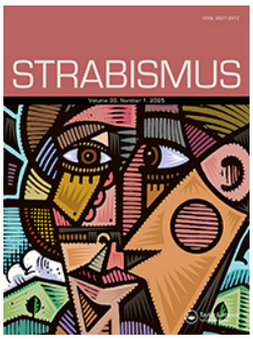

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Prism adaptation versus conventional orthoptic measurement for symptomatic esophoria: a retrospective study

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ABSTRACT

Purpose: Symptomatic esophoria (SE) is a latent esodeviation that progresses into a manifest esotropia, causing substantial discomfort such as diplopia, headaches, and asthenopia. Surgery for esophoria is prone to undercorrection, necessitating repeated interventions. Addition of preoperative prism adaptation testing (PAT) reveals significantly larger angles of deviation (AOD). The aim of this retrospective study was to compare rates of repeated surgical interventions in SE patients with or without PAT as a supplement to standard orthoptic evaluation. *Methods:* We reviewed records of patients with SE who underwent surgery at the Department of Ophthalmology, Rigshospitalet, Glostrup, Denmark, from January 1, 2017, to August 31, 2023. We collected information on whether PAT was conducted, demographics, and medical and ophthalmological history. Primary outcome was the need for repeated intervention either by reoperation or by postoperative adjustment of sutures. *Results:* One hundred and five SE patients were included, with 61 in the non-PAT group and 44 in the PAT group. Repeated surgical interventions were less frequent in the PAT group (23%) compared to the non-PAT group (48%) (P 0.009). PAT resulted in an increase in median AOD at near and distance by 14PD and 16PD, respectively ($p < .001$ and $p < .001$). *Conclusions:* In this observational study, SE patients undergoing PAT had significantly lower rates of repeated surgical interventions and a significant increase in baseline AOD, compared to those who did not undergo PAT.

KEYWORDS

Adjustable suture; diplopia; esodeviation; orthoptics; reoperation

Introduction

Esophoria is a latent esodeviation that allows normal bifoveal fusion, maintaining parallel visual axes, typically allowing patients to experience normal binocular vision without diplopia.[1] Esophoria may be symptomatic, presenting as asthenopia or headaches,[2] as individuals exert effort to engage their compensatory mechanisms. In some patients with esophoria, compensatory mechanisms driven by divergence fusional amplitudes may fail for varying periods throughout the day.[1,3] During these intervals, patients become symptomatic with diplopia due to loss of the ability to maintain parallel visual axes.[1–4] Decompensated esophoria may lead to significant discomfort, including diplopia, headache, and asthenopia.[1–4] Particularly, diplopia poses challenges in daily activities, driving, and even concerns regarding maintaining employment.[5]

Prism adaptation testing (PAT) was first popularized by Jampolsky in 1971,[6] aiming to determine the maximum deviation angle and the potential for fusion in patients with acquired esotropia, as well as to reduce the risk of surgical undercorrection.[7] The dynamic compensatory mechanisms in esophoria complicate the measurement of the strabismus angle, which is fundamental for planning surgical treatment. These dynamic compensatory mechanisms consist of a combination of motor fusion, tonic vergence and vergence adaptation which contributes to the neural integration in order to reduce the baseline phoria, resulting in a more stable binocular vision.[8] Undercorrection following esophoria surgery is common,[2] as the measured angle of deviation with alternating prism-cover test (PACT) often tends to be underestimated due to the patient's compensation

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mechanisms. An underestimation of the impact of phoria adaptation may increase the likelihood of requiring reoperation.[8] PAT is a method to relax the compensatory mechanisms in esophoria, allowing for a more accurate measurement of the strabismus angle,[9] which forms the basis for subsequent surgery.[1]

Only a few studies have examined the use of PAT in patients with esophoria.[4,9] Prism adaptation in decompensated esophoria has been investigated in a recent retrospective study, revealing that significantly larger deviation angles could be used as the basis for surgery when prism adaptation was employed.[9] The primary aim of this chart-based retrospective, observational study was to compare the frequency of repeated interventions (reoperations and suture adjustments) between patients who underwent PAT in addition to conventional orthoptic measurements and those that did not. The secondary aim was to measure the changes in the angle of deviation after PAT and the surgical outcome.

Methods

Data collection

Patient selection

Data was collected through a review of patient records from patients with symptomatic esophoria who underwent surgery at the Department of Ophthalmology, Rigshospitalet Glostrup, Copenhagen University Hospital, Denmark (DeptOphth), between January 1, 2017, and August 31, 2023. Patients were assigned to the PAT group and the non-PAT group, based on whether they underwent PAT. In our department, PAT was introduced as a standard part of the orthoptic evaluation for patients with esophoria in 2021. Thus, the majority of patients in the PAT group were seen after that year.

We included patients with symptomatic esophoria (compensated or decompensated) who had double vision, asthenopia, or headache related to esophoria. We excluded all patients with myopia >10 diopters, patients who had received botulinum toxin in an eye muscle within 4 months prior to surgery, previous strabismus surgery, myogenic diseases (including Myasthenia Gravis), restrictive strabismus (including previous eye muscle trauma or Graves' orbitopathy), neurological disease, or extraocular muscle palsies.

Demographics and follow-up

Demographic information, including age and sex, as well as comprehensive systemic, ophthalmological and medical histories, was collected for all participants enrolled in the study. Clinical assessments comprised the following parameters: best-corrected visual acuity, refraction (with and/or without cycloplegia if relevant), refraction of glasses and prism power if present, stereopsis (using Lang I/II or TNO test), near and distance deviation in prism diopters (PD) in five gaze positions before and after PAT with PACT. Symptomatology was meticulously documented, including diplopia, headache, asthenopia, or the absence of symptoms altogether. Two types of follow-up were recorded. The first type, follow-up for visits, records were collected from baseline and at the latest subsequent consultation, ranging from 1 to 12 months or more postoperatively. The duration was defined as the time from surgery to the most recent consultation. The second type, follow-up for reoperations, was defined as the duration from the date of surgery to June 1, 2024, based on chart review. All patients had a minimum of 12 months follow-up after surgery.

Surgery and reoperations

We recorded type of anesthesia, procedure type, surgical doses (measured in millimeters), number of eye muscles operated on, target of the operation in PD, and whether adjustable sutures were utilized. Any serious complication was documented.

We recorded the number of reoperations required for consecutive exodeviation or esodeviation, as well as the time elapsed from the primary surgery to each reoperation. A reoperation was defined as the necessity for a subsequent surgical intervention or the injection of botulinum toxin A into one or more eye muscles. Repeated surgical interventions were defined as the need for reoperation or postoperative adjustment.

Prism adaptation test

PAT was carried out following standard orthoptic evaluation, adhering to the standard time range, which typically lasts from one-half to 2 h within our department. The deviation identified through standard orthoptic assessment is utilized, and prism power is gradually increased while the squint angle is determined using PACT. For each measurement, a prism value matching the maximum measured squint angle is fitted onto the glasses or in a separate frame. PAT was terminated when exodeviation is observed during an alternating cover test, with the highest prism value before transition exodeviation was defined as the maximum squint angle.

Surgery

Surgery was performed under general anesthesia in children and in adults not suitable for local anesthesia. The choice of surgical approach, the number of muscles operated on, and the target angle of deviation were based on standard surgical tables used in our department and the surgeons' experience. The target angle was based on distance deviation in both groups. Adjustable sutures were used in cases with uncertainty about surgical outcomes, and subsequent adjustment was made within 7 days after surgery, primarily under local anesthesia.

Statistical analysis

Study data were collected and managed using REDCap (Research Electronic Data Capture), hosted at DeptOphth.

Statistical analyses were performed in R (version 4.2.2). Counts and percentages were used for categorical data. For continuous data, the median, interquartile range [IQR] and range were reported. The chi-square (χ^2) test or Fisher's exact test was used to compare categorical data between two groups, with the choice of test depending on the size of the groups (the chi-square test used when all groups had at least five expected values). Statistical analyses of changes in median from baseline and differences in median between groups were performed using the Wilcoxon signed-rank test. For survival analysis, we used the log rank test.

Ethical considerations

The research followed the provisions of the Declaration of Helsinki. Approval was obtained by the Team for Medical Records Research, Center for Health, Capital Region (ref.nr: *R*-23047803).

Results

We included 105 patients, with 61 in the non-PAT group and 44 in the PAT group. Demographic data are summarized in Table 1.

Our primary outcome, reoperations, were more common in the non-PAT group (34%, $n = 21$) than in the PAT group (11%, $n = 5$) ($p = .007$). All 21 reoperations in the non-PAT group were due to esodeviation, while three of the five reoperations in the PAT group were due to exodeviation. The majority of reoperated patients (81%, $n = 17/21$) in the non-PAT group underwent one-muscle surgery, while none of the reoperated patients in the PAT group did ($p = .0019$). The total number of visits to the operation theater for repeated surgical interventions was significantly higher in the non-PAT group (48%, $n = 29$) compared to the PAT group (23%, $n = 10$) ($p = .009$). There was no significant difference in reoperations for exodeviations between the groups (three in the PAT group and none in the non-PAT group) ($p = .07$). In the three patients reoperated for a consecutive exodeviation in the PAT group, the surgical target (28PD [IQR 23–29.3]) was higher than the baseline squint deviation after PAT at near (27PD [IQR 15–50]) and at distance (25PD [IQR 25–40]).

Supplementary analysis – restricting the sample to those with 2 years of available follow-up for reoperations (18 in the PAT group and 57 in the non-PAT group) – revealed an unchanged proportion of reoperated patients between the two groups ($p = .039$) but showed no statistically significant difference in rates of repeated surgical interventions ($p = .086$) or adjustment alone ($p = .7$). This can probably be explained by the small proportion of patients in the PAT group at the time compared to the non-PAT group ($n = 18/n = 57$). No serious

Table 1. Baseline demographics for both non-PAT group and the PAT group.

Characteristic	Non-PAT Group, *N* = 61	PAT Group, *N* = 44	*P value*
Demographics			
Sex, n (%)			
Female	40 (66%)	27 (61%)	0.7[1]
Male	21 (34%)	17 (39%)	0.7[1]
Age (years), Median [IQR], (Min-Max)	*N* = 61, 35 [20, 51], (7–82)	*N* = 44, 28 [16, 49], (9–75)	0.4[2]
BCVA o.dxt, Median [IQR], (Min-Max)	*N* = 61, 1.00 [1.00, 1.00], (0.4–1.5)	*N* = 44, 1.00 [1.00, 1.10], (0.8–1.5)	0.038*[2]
BCVA o.sin, Median [IQR], (Min-Max)	*N* = 61, 1.00 [1.00, 1.00], (0.4–1.6)	*N* = 44, 1.00 [1.00, 1.10], (0.3–1.6)	0.009**[2]
Spherical equivalent o.dxt, Median [IQR], (Min-Max)	*N* = 47, −1.25 [−3.38, −0.25], (−8.63–3.50)	*N* = 36, −0.44 [−1.81, 0.13], (−9.63–6.38)	0.2[2]
Spherical equivalent o.sin, Median [IQR], (Min-Max)	*N* = 47, −1.38 [−3.50, −0.13], (−10.50–2.50)	*N* = 36, −0.81 [−2.44, 0.38], (−9.88–4.00)	0.3[2]
Amount of prism in glasses (PD), Median [IQR], (Min-Max)	*N* = 20, 12.0 [8, 14], (2–16)	*N* = 11, 6 [5, 9], (2–13)	0.007**[2]
TNO, Median [IQR], (Min-Max)	*N* = 49, 240 [60, 1,980], (30–1,980)	*N* = 37, 240 [60, 480], (60–1,980)	0.5[2]
LANG I/II, Median [IQR], (Min-Max)	*N* = 4, 400 [200, 600], (200–600)	*N* = 3, 200 [200, 600], (200–600)	0.8[2]
PACT at near (1/3 m)(PD), Median [IQR], (Min-Max)	*N* = 61, 18 [12, 25], (4–48)	*N* = 44, 14 [8, 19], (2–40)	0.003**[2]
PACT at distance (4/6 m)(PD), Median [IQR], (Min-Max)	*N* = 61, 18 [14, 24], (4–35)	*N* = 44, 16 [12, 18], (2–25)	<0.001***[2]
PACT after PAT at near (1/3 m)(PD), Median [IQR], (Min-Max)		*N* = 43, 29 [21, 36], (12–50)	
PACT after PAT at distance (4/6 m)(PD), Median [IQR], (Min-Max)		*N* = 44, 30 [25, 35], (10–48)	
Symptoms (Diplopia), n (%)	58 (95%)	44 (100%)	0.3[3]
Symptoms (Asthenopia, blur or headache), n (%)	7 (11%)	9 (20%)	0.2[1]

[1]Pearson's Chi-squared test.
[2]Wilcoxon rank sum test.
[3]Fisher's exact test.
*$p < .05$; **$p < .01$; ***$p < .001$.
BCVA = Best corrected visual acuity, PACT = Prism alternating cover test, PD = Prism diopters, IQR = Interquartile range, AS-20 = Adult Strabismus-20 Questionnaire.

complications were recorded. Reoperation data are summarized in Table 2.

Log rank test comparing the time from surgery to the last follow-up visit or reoperation showed a significant difference between the PAT group and the non-PAT group ($p < .0001$ and $p = .01$, respectively). The utilization of PAT began primarily after February 2021. When comparing the groups after this date, there was no significant difference in the time from surgery to the last follow-up visit or from surgery to reoperation between the groups ($p = .08$ and $p = .8$, respectively). These findings may be

Table 2. Reoperation data for both non-PAT group and the PAT group.

Characteristic	Non-PAT Group	PAT Group	*P value*
Reoperation data			
Need for reoperation, n/N (%)	21/61 (34%)	5/44 (11%)	0.007**[1]
Need for adjustment, n/N (%)	11/61 (18%)	6/44 (14%)	0.5[1]
Need for reoperation or adjustment, n/N (%)	29/61 (48%)	10/44 (23%)	0.009**[1]
Reoperation/s for esodeviation, n (%)	21 (100%)	2 (40%)	<0.001***[2]
Reoperation/s for exodeviation, n (%)	0 (0%)	3 (60%)	0.07[2]
One- or two-muscle surgery, n (%)			0.0019**[2]
One-muscle surgery	17 (81%)	0 (0%)	
Two-muscle surgery	4 (19%)	5 (100%)	
Reoperated patients baseline PACT at near (1/3 m)(PD), Median [IQR], (Min-Max)	18 [14, 23], (5–35)	7 [6, 10], (2–40)	0.078[3]
Reoperated patients baseline PACT at distance (4/6 m)(PD), Median [IQR], (Min-Max)	19.0 [16.0, 20.0], (9–25)	12.0 [8.0, 15.0], (2–18)	0.014*[3]
Reoperated patients baseline PACT after PAT at near (1/3 m)(PD), Median [IQR], (Min-Max)		27 [15, 40], (15–50)	
Reoperated patients baseline PACT after PAT at distance (4/6 m)(PD), Median [IQR], (Min-Max)		30.0 [25.0, 40.0], (25–43)	
Surgical target in reoperation patients (PD), Median [IQR], (Min-Max)	16.5 [14.0, 19.0], (11.5–33)	28.0 [23.0, 33.0], (18–39.3)	0.015*[3]
Days from surgery to first reoperation, Median [IQR], (Min-Max)	462 [301, 714], (140–1,423)	125 [105, 238], (104–571)	0.023*[3]

[1]Pearson's Chi-squared test.
[2]Fisher's exact test.
[3]Wilcoxon rank sum test.
*$p < .05$; **$p < .01$; ***$p < .001$.
PD = Prism diopters, PACT = Prism alternating cover test, PAT = Prism adaptation test, IQR = Interquartile range.

explained by the longer waiting times for clinical consultations and operations during the period from 2017 to 2021, when most patients did not undergo PAT (figure not shown). The median follow-up time for reoperations from the date of surgery to the end of data collection was 1335 days [IQR 1129–1689] in the non-PAT group and 657 days [IQR 567–784] in the PAT group ($p < .001$). At the end of the study 92% ($n = 56$) in the non-PAT group and 95% ($n = 42$) in the PAT group had an address in the same administrative region. The difference in follow-up time for reoperations from the date of surgery to the end of data collection may be explained by the later introduction of PAT as part of the standard orthoptic evaluation.

The deviation after PAT was our first secondary outcome. PAT resulted in an increase in median AODn and AODd by 14 [IQR 10–20] and 16 PD [IQR 10–22], respectively ($p < .001$ and $p < .001$). This may explain the significant difference in the surgical target between the groups. The target in the non-PAT group was a median of 19 PD [IQR 14–23] compared with 24 PD [IQR 19–33] in the PAT group ($p < .001$). Two-muscle surgery was less frequent in the non-PAT group (36%, $n = 22$) than in the PAT group (68%, $n = 30$) ($p < .001$). Surgery data are summarized in Table 3.

Our second secondary outcome, squint deviation, was significantly lower in the PAT group (AODn = 4 PD [IQR 0–7] and AODd = 2 PD [IQR 0–6]) compared to the non-PAT group (AODn = 6 PD [IQR 2–12] and AODd = 6 PD [IQR 3–14]) at the last follow-up visit after surgery ($p = .011$ and $p < .001$ for AODn and AODd, respectively) (Figure 1).

Stereovision measured with TNO significantly improved in the PAT group at the last follow-up compared to baseline ($p = .02$); however, no significant improvement was observed in the non-PAT group ($p = .06$). Overcorrection by more than 8PD of exodeviation at near or distance was 1.7% ($n = 1/59$) in the non-PAT group compared with 11.6% ($n = 5/43$) in the PAT group ($p = .08$). The one patient in the non-PAT group was overcorrected to an exophoria, while the five patients in the PAT group were overcorrected to exophoria ($n = 3$) and exotropia ($n = 2$). Of the latter five patients, two with exotropia and one with exophoria underwent reoperation. Ninety-seven percent ($n = 102/105$) of patients had at least 6 weeks of follow-up. Follow-up data are summarized in Table 4.

Discussion

The present study is the first to compare reoperation rates between surgery based on conventional orthoptic measurements and surgery based on supplemental PAT in patients with symptomatic esophoria.

We found a statistically significant lower need for reoperation alone, or for repeated surgical interventions, in the PAT group compared to the non-PAT group. Pichler et al. reported motoric failure (AOD > 10 PD) in 7.5% ($n = 4/53$) of patients after 3 months and 12% ($n = 3/25$) after 1 year in the 1–5-h PAT group. However, no data on reoperations or overcorrections were reported.[9] In the study by Gietzelt et al., only preoperative data was presented.[4] The discrepancy in the reoperation rates between the groups in our study may be attributed to the lower

Table 3. Surgical data for both the non-PAT group and the PAT group.

Characteristic	Non-PAT Group, $N = 61$	PAT Group, $N = 44$	*P value*
Surgical data			
Operation in local or general anesthesia, n/N (%)			0.5[1]
General Anesthesia	54/61 (89%)	40/43 (93%)	
Local Anesthesia	7/61 (11%)	3/43 (7%)	
Adjustable suture used, n/N (%)	52/61 (85%)	38/44 (86%)	0.9[2]
Postoperative adjustment, n/N (%)	11/52 (21%)	6/38 (15%)	0.5[2]
Surgical target (PD), Median [IQR], (Min-Max)	$N = 61$, 19 [14, 23], (7–46)	$N = 44$, 24 [19, 33], (12–48)	<0.001***[3]
One- or two-muscle surgery, n/N (%)			0.001**[2]
One-muscle surgery	39/61 (64%)	14/44 (32%)	
Two-muscle surgery	22/61 (36%)	30/44 (68%)	

[1]Fisher's exact test.
[2]Pearson's Chi-squared test.
[3]Wilcoxon rank sum test.
*$p < .05$; **$p < .01$; ***$p < .001$.
PD = Prism diopters, IQR = Interquartile range.

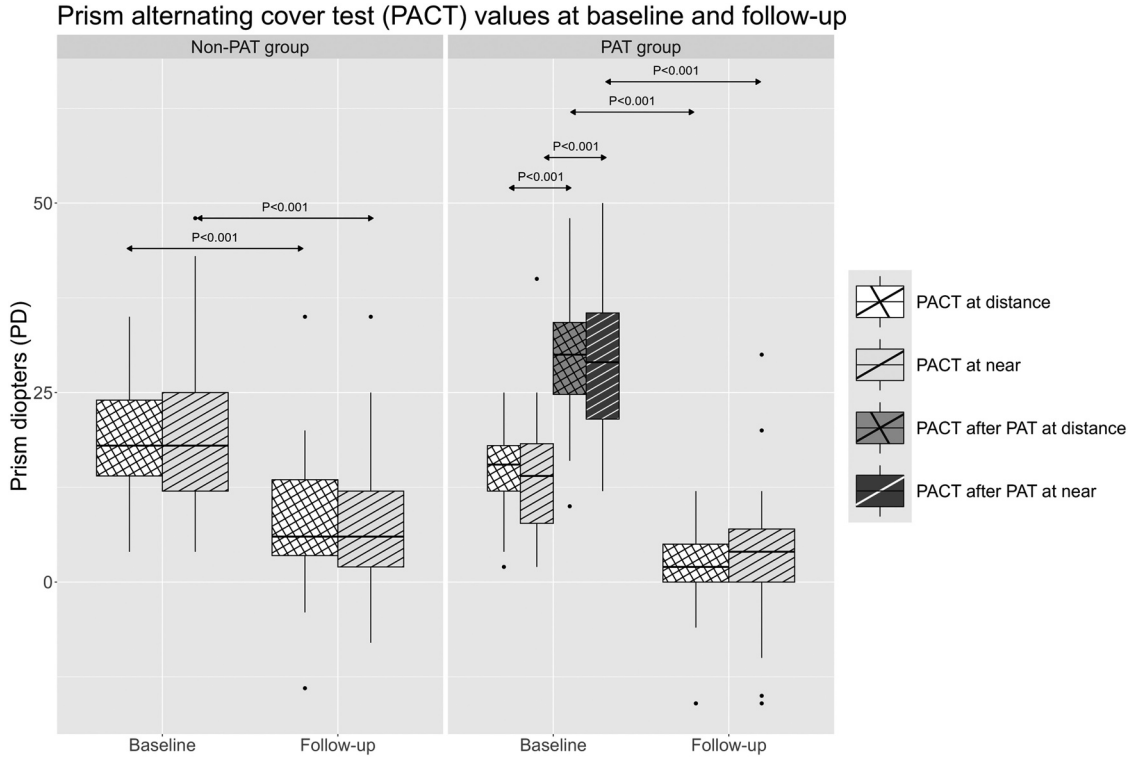

Figure 1. Boxplot showing prism alternating cover test (PACT) values at baseline and last follow up visit for both the non-PAT group and the PAT group. There was a significant increase in angle of deviation at near (AODn) and distance (AODd) after prism adaptation test (PAT) in the PAT group ($p < .001$). In the non-pat group, there is a significant decrease in AODn and AODd at last follow-up visit compared with baseline ($p < .001$). In the PAT group there was also a significant decrease in AODn and AODd after PAT compared with last follow-up ($p < .001$).

Table 4. Follow-up data for both non-PAT group and PAT group.

Characteristic	Non-PAT Group, $N = 59$	PAT Group, $N = 43$	*P value*
Follow-up data			
Time from surgery to last follow-up (days), Median [IQR], (Min-Max)	$N = 59$, 195 [110, 323], (47–1363)	$N = 43$, 105 [86, 148], (51–517)	<0.001***[1]
PACT at near (1/3 m)(PD), Median [IQR], (Min-Max)	$N = 59$, 6 [2, 12], (−8–35)	$N = 43$, 4 [0, 7], (−16–30)	0.011*[1]
PACT at distance (4/6 m)(PD), Median [IQR], (Min-Max)	$N = 59$, 6 [3, 14], (14–35)	$N = 43$, 2 [0, 6], (−16–12)	<0.001***[1]
LANG I/II, Median [IQR], (Min-Max)	$N = 2$, 340 [200, 480], (200–480)	$N = 1$, 200 [200, 200], (200–200)	>0.9[1]
TNO, Median [IQR], (Min-Max)	$N = 38$, 120 [60, 480], (60–1980)	$N = 39$, 60 [60, 240], (15–1980)	0.2[1]
Symptoms, n/N (%)	30/59 (51%)	11/43 (26%)	0.010*[2]
Symptoms (Diplopia), n/N (%)	27/59 (46%)	10/43 (23%)	0.020*[2]
Symptoms (Asthenopia, blur or headache), n/N (%)	5/59 (8.5%)	4/43 (9.3%)	>0.9[3]

[1]Wilcoxon rank sum test.
[2]Pearson's Chi-squared test.
[3]Fisher's exact test.
*$p < .05$; **$p < .01$; ***$p < .001$.
PD = Prism diopters, PACT= Prism alternating cover test, IQR = Interquartile range, AS-20 = Adult Strabismus-20 Questionnaire.

surgical target in the non-PAT group, leading to a preference for one-muscle surgery, thus resulting in undercorrection. This hypothesis is supported by the reoperation data which show that all patients in the non-PAT group undergoing reoperation had residual esodeviation. Eighty-one percent of reoperated patients in the non-PAT group underwent single muscle surgery, all but one medial recession. Conversely, all patients in the PAT group underwent primary surgery on two muscles. All three reoperations for overcorrection to exodeviation were in the PAT-group. In one of these, the medial rectus

(originally recessed) was found 15 mm behind the limbus with a 5 mm stretched scar at reoperation. Another reoperation was treated with botulinum toxin A (2,5 International units) in a lateral rectus muscle for exophoria. For patients in the PAT group who were reoperated for an exodeviation, the median surgical target angle retrospectively exceeded the maximum PAT value for both AODn and AODd, which might explain the overcorrection observed in these patients. The main purpose of performing PAT in esophoria is to ensure that the entire latent esodeviation is uncovered. Surgical correction of the entire maximum PAT deviation or more might increase the risk of overcorrection postoperatively due to the potential natural fluctuation in the measured angle of deviation preoperatively. It is the authors' impression that patients often tolerate a minor residual esophoria better than exodeviation after surgery based on PAT. If PAT is not performed, a larger residual esophoria may be present, even when postoperative measurements with PACT are relatively small, thus making patients more prone to symptoms when their ability to compensate fails.

Consecutive exotropia may develop months to years after successful surgery for esotropia.[10,11] It is plausible to assume that overcorrections in esotropic patients during the immediate postoperative period, particularly in the absence of fusion, could lead to a progression of the deviation over time, potentially necessitating reoperation. In our study, the rate of overcorrection by more than 8PD exodeviation was not statistically significantly higher in the PAT group compared to the non-PAT group. The one patient in the non-PAT group who was overcorrected by more than 8PD of exophoria did not undergo reoperation, while three of the five patients with overcorrection in the PAT group did. The fact that not all exodeviations were reoperated might be explained by the observation that convergence fusional amplitudes are less likely to be affected by small exophorias.[1] This is the first study to report reoperation rates in esophoria after PAT, nor have these rates been addressed in esotropia.[4,7,9,12–14]

We found only a few studies on prism adaptation and esophoria in the literature.[4,9] In our study, duration of prism adaptation ranged from one-half to 2 h. Pichler et al. found that the postoperative results in patients with esophoria were independent of the duration and amount of preoperative PAT, whether utilizing partial or full prism correction.[9] Equivalent effects were found with shorter periods of one to 5 h compared with longer periods,[9] which is comparable with our results. We observed a significant increase in AODn and AODd from baseline after PAT in the PAT group. This concurs with results of others where a significant increase in AOD in decompensated esophoria was noted following PAT.[4,9] Gietzelt et al. found a significant increase in AOD after at least 1 h of PAT (AODn 2.7PD/AODd 4.9PD), but this increase is much smaller than found by Pichler et al. (short PAT of 1–5 h: AODn 16PD/AODd 15.4PD) and in our study (AODn 14PD/AODd 16PD). This may be due to the fact that 76% ($n = 76/100$) of the patients in the Gietzelt study wore prism glasses or Fresnel prisms for days to weeks before PAT was performed,[4] making them less susceptible to the full effect of PAT. In our study, one-quarter of patients in the PAT group wore prisms, but we deem the small prism correction (6PD [IQR 5–9]) unlikely to affect the deviation after PAT. The amount of prisms in the non-PAT group was significantly higher than in the PAT group. This might be attributed to the fact that patients with smaller deviations of esophoria, especially before we were introduced to PAT, were primarily treated with prisms. As observed after the introduction of PAT, the deviation increases significantly, nearly doubling. Thus, providing some amount of prism initially may help patients compensate for a while, but over time this ability may decrease, and they become symptomatic, requiring a larger amount of prisms.

Residual esodeviation after surgery was significantly lower and closer to orthophoria in the PAT group compared to the non-PAT group. Our results are comparable to the one-year follow-up outcomes in the 1–5-h group from the study by Pichler et al. (AODn 2PD/AODd 1PD).[9] A significant improvement in stereoacuity, as measured by TNO, was observed only in the PAT group.

This study is subject to limitations inherent in a retrospective design, including selection bias and the lack of long-term follow-up clinical evaluations in both groups, particularly in the PAT group. This limitation is partly due to the fact that most patients who experience a successful surgical outcome have their outpatient care discontinued after 3–6 months, leaving mainly patients with suboptimal results for longer follow-up visits.

For patients who underwent reoperation or discontinued follow-up due to a favorable outcome or loss to follow-up, further control data were not recorded, which may contribute to selection bias. The median time from surgery to the last follow-up visit or from surgery to reoperation was longer in the non-PAT group than in the PAT group, possibly creating an impression of shorter follow-up in the PAT group. This could be explained by the significantly longer waiting times for clinical consultations and surgeries at our department before February 2021, when most of the non-PAT patients were seen. After February 2021, there was no difference in the time from surgery to the last follow-up visit or from surgery to reoperation between the groups. Another limitation is that patients who underwent reoperation elsewhere were not accounted for in this study. However, considering that over 90% of the patients resided in the same administrative region at the end of the study, most requiring further surgery would likely have been evaluated at our department. A strength of our study is the standardized evaluation and follow-up of patients with esophoria at our department. This is the largest study to date comparing reoperation rates and surgical outcomes between conventional orthoptic measurements and PAT. Larger studies, preferably randomized controlled trials, are needed.

In conclusion, surgical decisions based on PAT may reduce the likelihood of repeat surgical interventions, and PAT significantly increases baseline AOD compared to conventional orthoptic measurement. However, the optimal duration of PAT and the ideal surgical approach remain unknown.

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References

1. Pratt-Johnson JA, Geraldine T. *Management of Strabismus and Amblyopia; a practical guide*. 2nd ed. Thieme Medical Pub; 2001.
2. Ali MH, Berry S, Qureshi A, Rattanalert N, Demer JL. Decompensated esophoria as a benign cause of acquired esotropia. *Am J Ophthalmol*. 2018;194:95–100. doi:10.1016/j.ajo.2018.07.007.
3. Lavrich JB, Nelson LB. Diagnosis and treatment of strabismus disorders. *Pediatr Clin North Am*. 1993;40 (4):737–752. doi:10.1016/S0031-3955(16)38584-4.
4. Gietzelt C, Fricke J, Neugebauer A, Hedergott A. Prism adaptation test before strabismus surgery in patients with decompensated esophoria and decompensated microesotropia. *Int Ophthalmol*. 2022;42 (7):2195–2204. doi:10.1007/s10792-022-02219-3.
5. McBain HB, Au CK, Hancox J, et al. The impact of strabismus on quality of life in adults with and without diplopia: a systematic review. *Surv Ophthalmol*. 2014;59 (2):185–191. doi:10.1016/j.survophthal.2013.04.001.
6. Jampolsky A. A simplified approach to strabismus. In: *Symposium on Strabismus; Transactions of the New Orleans Academy of Ophthalmology*. St Louis, MO: C. V. Mosby Company; 1971:30–34.
7. Prism Adaptation Study Research Group. Efficacy of prism adaptation in the surgical management of acquired esotropia. *Arch Ophthalmol*. 1990;108(9):1248–1256. doi:10.1001/archopht.1990.01070110064026.
8. Brodsky MC. Phoria adaptation: the ghost in the machine. *J Binocul Vis Ocul Motil*. 2020;70(1):1–10. doi:10.1080/2576117X.2019.1706699.
9. Pichler U, Schmidbauer E, Hermann P, Wagner H, Bolz M, Mursch-Edlmayr AS. A comparative study of various prism adaptation forms in the surgical management of esophoria. *Acta Ophthalmol*. 2022;100(4): e1010–e1014. doi:10.1111/aos.15004.
10. Folk ER, Miller MT, Chapman L. Consecutive exotropia following surgery. *Br J Ophthalmol*. 1983;67 (8):546–548. doi:10.1136/bjo.67.8.546.
11. Yurdakul NS, Ugurlu S. Analysis of risk factors for consecutive exotropia and review of the literature. *J Pediatr Ophthalmol Strabismus*. 2013;50(5):268–273. doi:10.3928/01913913-20130430-01.
12. Ela-Dalman N, Velez G, Thacker N, Britt MT, Velez FG. Maximum motor fusion combined with one-hour preoperative prism adaptation test in patients with acquired esotropia. *J Aapos*. 2006;10(6):561–564. doi:10.1016/j.jaapos.2006.09.011.
13. Velez FG, Rosenbaum AL. Preoperative prism adaptation for acquired esotropia: long-term results. *J Aapos*. 2002;6(3):168–173. doi:10.1067/mpa.2002.123397.
14. Altman M, Baker JD, Petrunak J, Schweers M. Can prism adaptation for acquired esotropia be accomplished in a shorter time frame? *J Am Assoc For Pediatr Ophthalmol And Strabismus*. 1999;3 (5):259–262. doi:10.1016/S1091-8531(99)70019-4.