• Clinical Research •

Comparison of the outcome of complete abducens nerve palsy treated with Nishida procedure or augmented Hummelsheim procedure

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Received: 2026-06-12 Accepted: 2026-08-31

Abstract

● **AIM:** To compare the outcome of complete abducens nerve palsy (cANP) treated with Nishida procedure or augmented Hummelsheim procedure.

● **METHODS:** The medical records of 37 patients with cANP who underwent surgery between May 2019 and November 2024 were retrospectively reviewed. Patients were grouped according to surgical technique: Group A underwent the augmented Hummelsheim procedure, while Group B underwent the Nishida procedure. The primary deviation angle, abduction function, adduction function, degree of antagonist muscle recession, and improvement in diplopia pre- and post-operatively were examined and compared.

● **RESULTS:** A total of 37 patients with cANP were included in this study, comprising 9 cases subsequent to cranial tumour surgery and 28 cases following cranial trauma. The mean age in Groups A (n=21, 11 males) and B (n=16, 10 males) was 40.05±12.11y and 37.31±12.98y, respectively. The average angle of deviation reduced from 123.33±15.52 prism diopters (PD) before surgery to 2.52±5.83 PD in Group A, and from 123.13±16.21 to 4.75±3.67 PD in Group B at 6mo post-operation. No statistically significant difference was observed between the two groups post-operatively (P>0.05). The extent of medial rectus recession was smaller in Group A than in Group B (U=269.00, P=0.001). There was no statistically significant difference in the adduction function between the two groups at 6mo post-operatively (U=132.50, P>0.05). The operative time in Group B was significantly shorter than that in Group A (t=10.332, P<0.001). At the final follow-up, no cases of complications or recurrence were observed in either group.

● **CONCLUSION:** The results show equivalent efficacy between the two procedures for cANP. Both procedures are comparable in correcting deviation angle and adduction function in cANP. However, the Nishida procedure holds advantages with less surgical manipulation and shorter operative time.

● **KEYWORDS:** complete abducens nerve palsy; Nishida procedure; augmented Hummelsheim procedure; abduction function

DOI:10.18240/ijo.2026.12.16

Citation: Li NM, Zhang L, Hui YN, Zhang GO, Sun JX. Comparison of the outcome of complete abducens nerve palsy treated with Nishida procedure or augmented Hummelsheim procedure. *Int J Ophthalmol* 2026;19(12):2445-2452

INTRODUCTION

Abducens nerve palsy (ANP, sixth nerve palsy) is the most common extraocular muscle palsy and is categorized as congenital or acquired. Congenital ANP often results from neuromuscular hypoplasia, agenesis, or birth trauma. Acquired ANP is attributed to the abducens nerve's lengthy intracranial course and the short lateral orbital wall, making it susceptible to injury, inflammation, tumors, hemorrhage, and other causes, with an incidence of approximately 11.3 per 100 000[1-4]. A Korean study reported an overall annual incidence of 4.66 per 100 000[5]. The symptoms typically include horizontal diplopia and compensatory head posture. Congenital ANP is managed surgically, whereas acquired cases may exhibit spontaneous recovery in early stages, with reported recovery rates between 44.1% and 80%[6-8].

Initial intervention is supportive, neurotrophic agents, circulatory, and botulinum toxin type A injection[9]. When the symptoms do not disappear, and the misalignment remains stable beyond 6mo, surgical intervention may be considered, with reported success rates ranging from 25% to 91%[10-12]. In cases of paralytic esotropia, vertical muscle transposition

combined with antagonist muscle recession will have a greater effect, including tendon transposition, Jensen procedure, partial rectus transposition, augmented Hummelsheim procedure, and the Nishida procedure. Due to the risks of anterior segment ischemia and variable long-term efficacy associated with the Jensen procedure, alternative techniques have been developed. The augmented Hummelsheim procedure, which augments abduction while sparing ciliary vessels, is a common choice. In contrast, the Nishida procedure offers a lower-risk option by enhancing abduction through scleral fixation of the vertical muscle belly without its disinsertion.

Recent studies[13] have shown that while the Nishida procedure significantly reduces the risk of anterior segment ischemia caused by rectus muscle disinsertion, the postoperative scleral remodeling involves a self-adjusting effect that may lead to under-correction or over-correction. It increases uncertainty in surgical outcomes and complicates both the postoperative evaluation and the design of surgical plans for the operating surgeon. However, studies usually include patients with both complete and incomplete ANP, which may confound the evaluation. Furthermore, due to the relative rarity of complete ANP (cANP), most research evaluates a single surgical technique. This lack of comparative data leaves surgeons with limited evidence when selecting among different vertical muscle transposition procedures for cANP. To address this gap, the present study specifically enrolled patients with cANP, aiming to compare the short-term efficacy and safety of the augmented Hummelsheim procedure and the Nishida procedure.

PARTICIPANTS AND METHODS

Ethical Approval This study adheres to the Declaration of Helsinki, with informed consent obtained from all participants, and has been certified by the Ethics Committee of the institution (Approval Number: XJLL-KY-20252239).

Participants This retrospective study reviewed the medical records of consecutive patients with cANP who underwent surgery intervention between May 2019 and November 2024 in a single eye center. cANP is defined by the presence of abduction limitation of grade -4 or greater, characterized by the eye's inability to move past the midline during attempted lateral gaze, accompanied by a positive forced duction test[14]. Magnetic resonance imaging (MRI) or computed tomography (CT) of the brain was performed to identify the possible causes for cANP. The inclusion criteria were as follows: 1) age of 18y or older; 2) the identified etiologies include trauma, tumor (or related surgical procedures), inflammation, and hemorrhage; 3) cANP with stable deviation angle and over 6mo after conservative treatment; 4) capacity to cooperate with comprehensive ophthalmic examinations and adherence to scheduled follow-up protocols; 5) no history of botulinum toxin type A injection; 6) surgical intervention with either the Nishida procedure or augmented Hummelsheim procedure. Exclusion criteria included: 1) intracranial mass lesions, active neurological pathology, or restrictive strabismus; 2) vertical deviation of ≥6 prism diopters (PD); 3) significant systemic diseases; 4) coexisting ocular pathologies or other types of strabismus; 5) history of previous extraocular muscle surgery.

Examinations Data collected included age, sex, laterality, etiology of ANP, pre- and post-operative deviation degree in the primary position, pre- and post-operative abduction and binocular function. Deviation degree was measured with the Krimsky and prism test: the prism was positioned before the deviating eye. The prism was systematically adjusted while observing the relative displacement of the corneal light reflex, until the reflex was precisely centered within the pupil of the deviating eye. The abduction limitation was quantified using the Scott and Kraft[15] grading system for lateral rectus paralysis[16]. The grades, ranging from 0 to -8, were defined as follows: grade 0 (normal abduction); grade -1 (abduction to 75% of the temporal field); grade -2 (abduction to 50%); grade -3 (abduction to 25%); grade -4 (abduction just reaching the midline); grade -5 (unable to abduct past 75% of the nasal half); grade -6 (unable to abduct past 50%); grade -7 (unable to abduct past 25%); grade -8 (eye essentially fixed, with no abduction). Diplopia was assessed using the red filter and prism cover test, as well as binocular vision function testing *via* synoptophore (Clement Clarke Ltd., London, UK) and a four-point light test. A complete eye examination and forced duction test were also conducted.

Groups and Surgical Techniques Patients were divided into two groups based on the surgical procedure performed: the augmented Hummelsheim procedure (Group A) and the Nishida procedure (Group B). All surgeries were performed under general anesthesia by a single surgeon. Forced duction test was performed to identify medial rectus muscle limitation, preoperatively. All patients underwent medial rectus recession (MRc), the amounts of MRc were determined by the surgeon based on deviation angle in the primary position, and medial rectus tightness assessed by forced duction test. Operative time was measured as the interval commencing with the first conjunctiva incision and concluding with the completion of wound closure.

Augmented Hummelsheim procedure: the lateral half of the superior and inferior rectus muscles were isolated through superior-temporal and inferior-temporal incisions, respectively. The lateral half of the superior and inferior rectus muscle were transposed and sutured to the corresponding border of the lateral rectus insertion. A Foster suture was concurrently placed to secure a portion of the lateral rectus muscle belly to the temporal superior and inferior rectus insertions, 8 mm posterior to their original insertions.

The Nishida procedure: the temporal third of the superior rectus muscle was sutured to the superficial sclera 8 mm posterior to its original insertion, corresponding to the 1–2 o'clock position at 12 mm from the limbus. Similarly, the temporal third of the inferior rectus muscle was sutured to the superficial sclera 8 mm posterior to its insertion at the 4–5 o'clock position, also 12 mm from the limbus (Figure 1).

Follow-up All patients were followed postoperatively at 1wk, and 6mo. An ocular motility, deviation angle test, and diplopia at binocular viewing were evaluated. Surgical outcomes were evaluated based on the following parameters: deviative degree, ocular motility, the amount of MRc, operative time, stereopsis, and diplopia. Under-correction or over-correction was defined as a postoperative horizontal deviation in the primary position exceeding 10 PD. The safety of the procedure was assessed by the occurrence of anterior segment ischemia and other adverse events. The complications and recurrence were assessed and recorded until final follow-up.

Statistical Analysis All statistical data analyses were conducted using SPSS 26.0 statistical software (SPSS Inc., Chicago, USA). Data with normal distribution were expressed as mean±standard deviation (SD) and analysed using an independent samples *t*-test. Quantitative data and ordinal data not normal distribution were expressed as median (interquartile range) [M (IQR)] and analysed using the Mann-Whitney *U* test. All categorical data were expressed as frequency [percentile; *n* (%)]. The Chi-square test was employed. Repeated measures analysis of variance was used to compare the degree of strabismus between groups. A P value<0.05 was considered statistically significant.

RESULTS

Demographic and Clinical Features A total of 37 patients (21 males and 16 females) were enrolled in this study. The cohort consisted of 19 right eyes and 18 left eyes affected. The causes for cANP were categorized as 9 intracranial neoplasms cases (including 3 meningioma, 3 pituitary adenoma, 2 epidermoid cysts 1 Schwannoma) and 28 intracranial trauma cases (including 12 falls, 10 traffic accidents, 5 blunt force injury by heavy objects, 1 blast injury). Preoperatively, 3 patients maintained grade I binocular vision, 24 patients lacked grade III fusion, and 10 patients reported persistent diplopia. All patients exhibited a positive forced duction test. Patients were divided into two surgical groups: Group A (n=21) underwent augmented Hummelsheim, and Group B (n=16) underwent the Nishida. There was no statistically significant difference in the baseline data between the two groups (Table 1).

Surgical Outcomes In Group A, the deviation degree in primary position was reduced from 123.33±15.52 PD preoperatively to -3.29±7.31 PD at 1wk postoperatively, with a regression to 2.52±5.83 PD observed at the 6mo follow-up. In Group B, the preoperative deviation degree of 123.13±16.21 PD decreased to -0.50±4.94 PD 1wk after surgery and regressed to 4.75±3.67 PD at 6mo. There was no statistically significant difference in the angle of deviation between the two surgical techniques (F=0.369, P=0.547, η^2=0.966). There were statistically significant differences in the degree of deviation between preoperative and postoperative (both 1wk and 6mo) examinations in both groups (F=2854.170, P<0.001, η^2=0.988), reflecting substantial changes in the angle of deviation. The group-by-time interaction was not significant (F=0.362, P=0.698, η^2=0.010), suggesting that the temporal pattern of degree change was similar in both groups (Figure 2). Simple effect analysis confirmed that the deviation degree did not differ significantly between groups at any individual time point (preoperative: P=0.969; 1wk postoperative: P=0.199; 6mo postoperative: P=0.190). Within each group, however, the degree changed significantly over time (both P<0.001).

In Group A, the abduction function deficit improved from a preoperative grade of -6.00 (-5.00, -7.00) to -2.00 (-1.50, -3.00) at the 6mo postoperation. Similarly, in Group B, it improved from -6.00 (-5.00, -7.00) preoperatively to -2.00

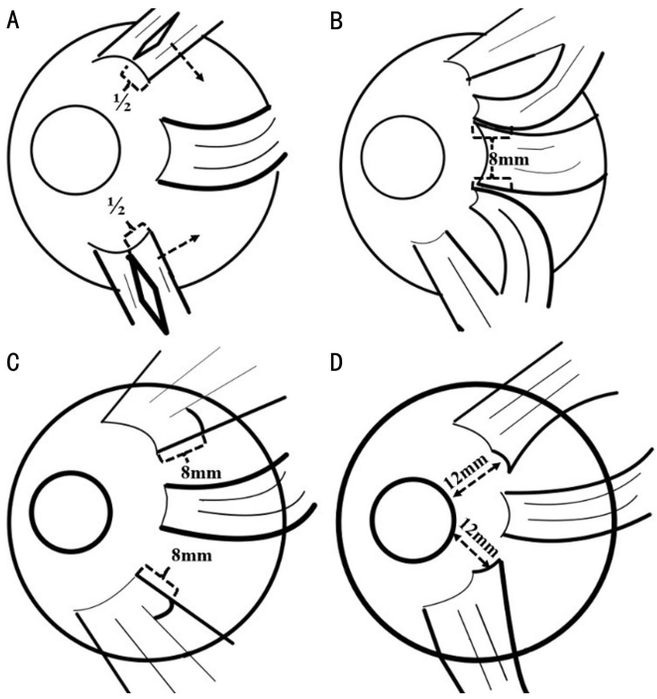


Figure 1 Surgical procedures A, B: Augmented Hummelsheim procedure. The lateral halves of the superior and inferior rectus muscles were isolated (A). Transposed and sutured to the corresponding border of the lateral rectus insertion (B). Foster suture was concurrently placed 8 mm posterior to the original insertions (B). C, D: The Nishida procedure. The temporal third of the superior and inferior rectus muscle was sutured to the superficial sclera 8 mm posterior to its original insertion (C). The anchored muscle was corresponding to the 1–2 o'clock and 4-5 o'clock position at 12 mm from the limbus (D).

Table 1 Baseline characteristics between the two groups

Parameters	Group A (*n*=21)	Group B (*n*=16)	χ^2/F	*P*
Age (y)	40.05±12.11	37.31±12.98	0.660	0.513
Gender, *n* (%)			0.379	0.538
Male	11 (52.4)	10 (62.5)		
Female	10 (47.6)	6 (37.5)		
Eye, *n* (%)			0.021	0.886
OD	11 (52.4)	8 (50.0)		
OS	10 (47.6)	8 (50.0)		
Duration (mo)	37.00 (8.00, 85.50)	42.50 (12.25, 72.50)	183.500	0.634
Preoperative deviation degree at near (PD)	123.33±15.52	123.13±16.21	0.040	0.969
Preoperative abduction function	-6.00 (-5.00, -7.00)	-6.00 (-5.00, -7.00)	172.500	0.884
Operative time (min)	68.33±7.47	47.56±3.37	10.332	<0.001

Data were expressed as means±standard deviations, median (interquartile range), or *n* (percentage). OD: *Oculus dexter*; OS: *Oculus sinister*; PD: Prism diopter.

Table 2 The abduction function in two groups before and after surgery

Parameters	Group A	Group B	*U*	*P*
Preoperative	-6.00 (5.00, 7.00)	-6.00 (5.00, 7.00)	172.500	0.884
6mo	-2.00 (1.50, 3.00)	-2.00 (2.00, 2.75)	184.500	0.570
U	-4.167	-3.596		
P	<0.001	<0.001		

Data were expressed as median (interquartile range). Significant difference in the angle of deviation in the two groups in preoperative and 1wk, 6mo after surgery.

(-2.00, -2.75) at 6mo post-surgery. Preoperative abduction function did not differ significantly between the two groups (*P*>0.05). Postoperatively, abduction improved significantly in both groups at the 6mo follow-up compared with preoperative levels (both *P*<0.001). However, there was no statistically significant difference in the abduction function between the two groups at the final assessment (*P*>0.05; Table 2).

The amount of MRc was 5.50 (5.00, 6.00) mm in Group A and 6.00 (6.00, 6.88) mm in Group B. The amount of MRc performed was significantly smaller in Group A than in Group B (*U*=269.000, *P*=0.001). Postoperative induced adduction limitation was graded at -2.00 (-2.50, -1.00) in Group A and -2.00 (-3.00, -2.00) in Group B (*P*=0.250).

In Group A, two cases of overcorrection (-20 PD, -15 PD) and one case of undercorrection (+15 PD) were noted at 1wk after surgery. One overcorrected patient underwent medial rectus advancement, and the deviation degree was -2 PD at the 6mo follow-up. The other overcorrected patient regressed to -8 PD by 6mo and was managed with prism glasses. The undercorrected patient, who had poor visual acuity, declined further intervention.

Postoperative distance stereopsis recovered in 28 of the 37 patients (75.7%), constituting a significant improvement from the preoperative baseline. Near stereopsis was recovered in 20 patients postoperatively. Two patients who had maintained preoperative near stereopsis *via* a compensatory head position were excluded from this comparison. Three patients reported mild, persistent distance diplopia, which was successfully corrected with prism glasses. No patient developed torsional strabismus or new vertical deviation, as assessed by the Maddox rod test. At the final follow-up, no cases of anterior segment ischemia or other postoperative complications were observed in either group. During the follow-up period, no recurrence of deviation was observed in any patient.

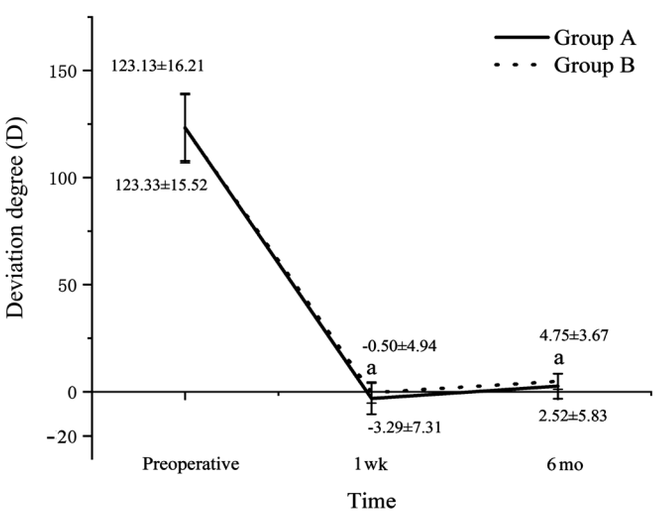


Figure 2 Deviation degree before and after surgery in two groups
[a]Significant differences were noted between preoperative and 1wk, and between preoperative and 6mo postoperatively.

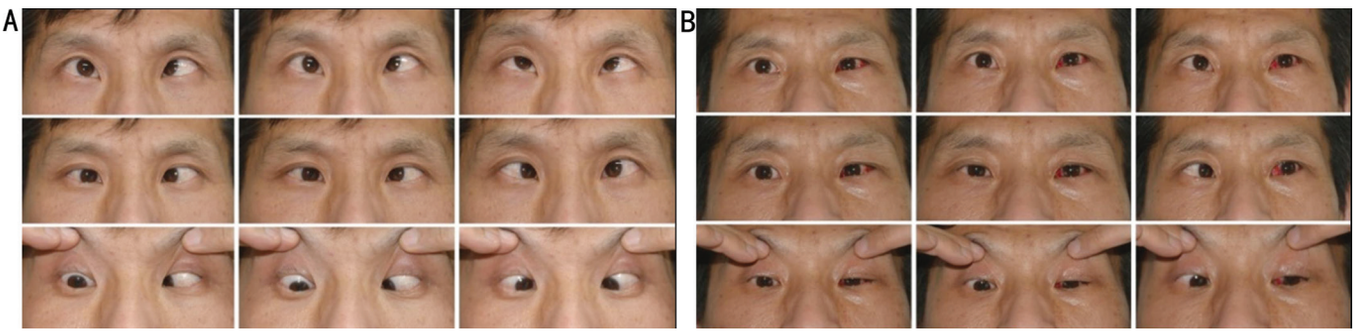


Figure 3 Preoperative photos of a patient with 145 PD esotropia and abduction deficit of -8 (A), displayed improvement of abduction of -4 and orthotropia in primary position after augmented Hummelsheim procedure on the left eye combined with botulinum toxin injection on the right eye (B) PD: Prism diopters.

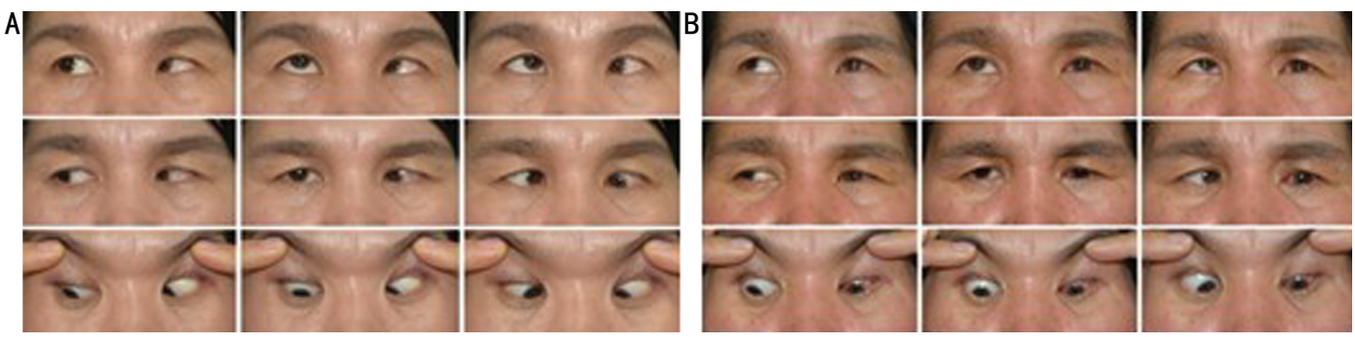


Figure 4 Preoperative photos of a patient with 160 PD esotropia and abduction deficit of -8 (A), displayed improvement of abduction of -4 and orthotropia in primary position after the left Nishida procedure (B) PD: Prism diopters.

Preoperatively, the patient, who had esotropia of 145 PD and bilateral abduction deficits (-8 of the left and -7 of the right), underwent augmented Hummelsheim procedure on the left eye combined with botulinum toxin injection on the right eye (Figure 3). After surgery, satisfactory orthotropia was achieved in the primary position ,with an induced adduction limitation grade of -4.

The other patient with preoperative esotropia of 160 PD and hypertropia of 5 PD, accompanied by severely limited left abduction of -8, achieved orthotropia in primary position and improved abduction deficit of -4, following the left Nishida procedure (Figure 4).

DISCUSSION

Patients with cANP typically present with large-angle paralytic esotropia and marked limitation of abduction. Strengthening the antagonist medial rectus is often insufficient to correct the deviation degree in primary position; therefore, vertical muscle transposition to the lateral rectus is commonly performed. In recent years, the augmented Hummelsheim procedure has been performed in patients with ANP due to its favorable efficacy and safety. However, the relative rarity of cANP and the limited comparative data on different transposition techniques have resulted in insufficient evidence regarding their respective outcomes. This study compared the efficacy and safety of the Nishida procedure and the augmented Hummelsheim procedure. The results demonstrated that both procedures were equally effective in correcting large-angle esotropia and improving abduction function, with no incidence of anterior segment ischemia or other postoperative complications. Furthermore, while the Nishida procedure required less operative time, it necessitated a greater amount of MRc.

In patients with severe abductive function deficit, traditional large recession of the medial rectus combined with lateral rectus resection frequently leads to undercorrection. Consequently, vertical rectus transposition has become the preferred surgical approach, including full vertical rectus transposition, partial vertical rectus transposition, and the Jensen procedure. Compared with the Jensen procedure, which relies primarily on mechanical redirection[17-18], vertical transposition changes the transposed muscle closer to the lateral rectus insertion. However, the Jensen procedure may be associated with greater long-term ocular position variability. Although full vertical rectus transposition has demonstrated clinical efficacy, it carries risks of anterior segment ischemia[19-20] and new-onset vertical strabismus[21]. Partial vertical rectus transposition transposes the lateral halves of the superior and inferior rectus muscles to the lateral rectus insertion. The procedure preserves vertical balance while augmenting abduction through synergistic action and reduces ischemia risk by sparing ciliary circulation. In recent years, partial vertical rectus transposition combined with Foster suture fixation and simultaneous medial rectus recession has

gained popularity, with favorable outcomes reported[22]. The technique improves predictability by aligning the transposed muscle's force vector closer to the lateral rectus physiological axis through the semi-quantitative nature of combined recession[22]. Nevertheless, no technique eliminates the risk of anterior segment ischemia[23].

In 2003, Nishida *et al*[24] introduced a new technique involving suturing the temporal vertical rectus muscle belly to the sclera between the lateral rectus and the superior or inferior rectus, without detaching the tendon. This method achieved correction comparable to the Hummelsheim and Jensen procedures without inducing anterior segment ischemia or vertical strabismus and has since been widely adopted. In 2005, Nishida *et al*[25] proposed that operative damage might be caused by muscle splitting and introduced modification of the original procedure that eliminated the need for muscle splitting, with the aim of minimizing the risk of anterior segment ischemia. This modified technique was subsequently designated as the modified Nishida procedure. In 2013, Muraki *et al*[26] applied and validated the superiority of this technique. The vertical muscle transposition procedure without tenotomy or splitting of the transposed muscles was performed in patients as in our study. Subsequent studies[27] have demonstrated that the modified Nishida procedure, when combined with MRc, can achieve more favorable clinical outcomes.

Similarly, the Hummelsheim has been shown to be effective in correcting large-angle strabismus. Moreover, it has demonstrated a significant corrective effect of binocular single vision[28]. The modified Hummelsheim combined with MRc has been shown to achieve favorable outcomes in improving paralytic esotropia, compensatory head posture, and ocular motility restriction. Moreover, it has also been applied in the management of Duane retraction syndrome, as reported in previous studies[29].

All patients in this study presented with acquired complete abducens nerve palsy and significant residual esotropia despite at least six months of conservative treatment. Forced ductions confirmed medial rectus restriction, indicating surgical intervention. Both augmented Hummelsheim and the Nishida combined with MRc resulted in significant improvement in esotropia and abduction function postoperatively. No statistically significant difference in the last postoperative deviation was observed between the two groups, supporting the clinical applicability of both.

The MRc was significantly smaller in the augmented Hummelsheim than in the Nishida. This suggests that augmented Hummelsheim provides greater corrective force for abduction deficit, consistent with earlier studies[22]. This enhanced effect may be attributed to greater horizontal force generation from the transposed muscle halves, reducing the need for antagonist weakening. However, this mechanical advantage may also impose some limitation on postoperative adduction. In contrast, the Nishida required larger medial rectus recessions to achieve comparable alignment, which could explain the observed trend toward weaker adduction. Nonetheless, no significant difference in final adduction function was found between groups.

The difference in deviation between the one-week and six-month follow-ups in both groups may reflect underlying extraocular muscle abnormalities in paralytic strabismus. Following denervation, paralysis of the lateral rectus and contracture of the mesial rectus increases the likelihood of esotropia recurrence. The postoperative regression rates were 38.09% in Group A and 62.5% in Group B. Therefore, aiming for modest surgical overcorrection is advised, which aligns with conclusions from prior studies[30].

All surgeries were performed under microscopy. In the augmented Hummelsheim group, ciliary vessels of the medial rectus were preserved, and postoperative steroid eye drops and oral neurotrophic agents were administered. No cases of anterior segment ischemia occurred, contrasting with previous reports[19-31]. Meticulous surgical technique to avoid vascular injury remains essential, and staged surgery or preoperative botulinum toxin injection may be considered in high-risk cases[32]. Operative time was longer in the augmented Hummelsheim, likely due to greater technical complexity. Surgical planning should therefore consider not only the angle of deviation and degree of paralysis, but also the surgeon experience.

Overcorrection occurred in two patients in the augmented Hummelsheim group and one in the Nishida group. Under general anaesthesia, the surgical plan was based on experience and published recommendations for mild overcorrection, which may introduce bias. Additionally, progressive strengthening of abductive function may occur postoperatively as adhesions form between the transposed vertical rectus edges and the lateral rectus. These observations suggest that medial rectus recession should be moderated in augmented Hummelsheim, whereas the Nishida may require larger recessions. Further studies with larger samples are needed to confirm these findings.

Both augmented Hummelsheim and the Nishida achieved satisfactory postoperative alignment and stereopsis recovery. Augmented Hummelsheim required less MRc, provided greater correction, and may be preferable in severe abduction deficit. The Nishida offered shorter operative time and high safety, making it suitable for mild to moderate cases. A growing number of modified Nishida procedures have been increasingly utilized in clinical practice[33]. A modified Nishida technique has been introduced, reportedly offering greater correction with less demand on abduction and smaller MRc.

This study did not compare outcomes with different Nishida procedure which warrants future investigation. Additionally, this study did not evaluate outcomes in patients with prior botulinum toxin injection, an area requiring further research with expanded sample sizes.

ACKNOWLEDGEMENTS

Authors' Contributions: Li NM: designed the study, performed the surgeries, collected and analyzed the data, drafted the manuscript. Zhang L: participated in patient examination, follow-up, data collection, prepared the figures and tables. Hui YN: reviewed the surgical protocol, critically revised the manuscript. Zhang GO: assisted with data acquisition, statistical analysis. Sun JX: provided clinical resources and final approval of the manuscript.

Data Availability Statement: The de-identified datasets generated and analyzed during this study are available from the corresponding author on reasonable requests.

AI-Generated Content Disclosure: Doubao (ByteDance) was used solely for language polishing, grammar correction.

Foundation: Supported by Science and Technology Program of Xi'an (No.2025JH-YXYJZD-0057).

Conflicts of Interest: Li NM, None; **Zhang L,** None; **Hui YN,** None; **Zhang GO,** None; **Sun JX,** None.

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