



How to Better Treat Patients with Intermittent Exotropia: A Review of Surgical Treatment of Intermittent Exotropia

Jeong-Min Hwang

Department of Ophthalmology, Seoul National University Bundang Hospital, Seoul National University College of Medicine, Seongnam, Korea

Intermittent exotropia (X(T)) is the most common form of strabismus, especially in Asians. Treatment of X(T) includes occlusion, overminus lens, and surgery, of which, surgery is the mainstay of treatment. Commonly performed surgical procedures for X(T) are bilateral lateral rectus muscle recession or unilateral lateral rectus recession with medial rectus resection; however, it is unclear which of the two surgeries is more effective. The purpose of this review is to provide an insight on the surgical treatment of X(T). Randomized controlled trials, comparative observational studies, and case series with a large number of patients as well as a long follow-up period of over a year were included.

Key Words: Bilateral lateral rectus muscle recession, Exotropia, Medial rectus resection, Surgery, Unilateral lateral rectus recession

Introduction

Intermittent exotropia (X(T)) is characterized by an intermittent outward deviation of one eye, and is the most common form of strabismus, affecting approximately two out of 100 children before the age of 3 years [1]. Treatment of X(T) includes occlusion, use of overminus lens, and surgery [2]. Spectacle correction of myopia, astigmatism, and anisometropia as well as occlusion therapy for amblyopia should precede the surgery. Spontaneous resolution of X(T) is rare [3]; therefore, surgery is the mainstay of treat-

ment [2]. Commonly performed surgical procedures for X(T) are bilateral lateral rectus muscle recession (BLR) or unilateral lateral rectus recession with medial rectus resection (RR) [2]. However, the most effective surgical treatment for X(T) is still unclear. The purpose of this review is to provide an insight into the surgical treatment of X(T); this review included randomized controlled trials (RCTs), comparative observational studies, and case series with a large number of patients and long follow-up period of over a year.

There are a few limitations to compare the surgical outcomes between BLR and RR because of significant differences among the studies, including ethnicity, number of patients, variable classifications of X(T), control of X(T), deviation angles, types of surgical procedure, surgical doses, and definitions of surgical success (esodeviation/exodeviation of 5 to 10 prism diopters [PD]), as well as duration of follow-up. For example, surgical outcome is affected by the follow-up period, as seen in the recurrence rate in-

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Corresponding Author: Jeong-Min Hwang, MD. Department of Ophthalmology, Seoul National University Bundang Hospital, Seoul National University College of Medicine, 82 Gumi-ro 173beon-gil, Bundang-gu, Seongnam 13620, Korea. Tel: 82-31-787-7379, Fax: 82-31-787-4057, E-mail: hjm@snu.ac.kr

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creasing with the follow-up time. [4-40]. Lim et al. [25] reported a success rate (5 PD esotropia to 10 PD exotropia) of 58% at 1 year postoperatively, which decreased to 47% at 2 years postoperatively in 489 patients after RR, while the recurrence rate of 28% at 6 months increased to 78% at 5 years postoperatively [25].

Determination of Target Angles for Surgery

Recurrence of X(T) is common after surgery, and the recurrence rates increase over time [23]. Failure to discover the maximum angle of deviation may contribute to the recurrence [16] and identifying the maximum angle of deviation may help decrease the recurrence rate. Kushner [41] found that the 1-hour occlusion test increased the distance deviation angle and suggested performing a diagnostic preoperative occlusion test. Niederecker and Scott [42] also reported that the 5-day occlusion test increased the angle of exotropia. However, Arnoldi and Reynolds [43] suggested that diagnostic occlusion did not increase the angle of X(T) in cases with poor fusional capacities. Han et al. [44] found that 1-day occlusion test increased distance deviation angle in 14% (26 of 185), and near deviation angle in 31% (57 of 185) of the cases, especially with hyperopia. Interestingly, 39% (9 of 23) of the divergence excess type and 20% (3 of 15) of the convergence insufficiency type cases were converted to other types after the 1-day occlusion test [44]. Therefore, 1-day occlusion tests may be useful in patients with divergence excess or convergence insufficiency type X(T), as well as in hyperopes. In addition, they compared the occlusion test to multiple preoperative examinations to identify the maximum deviation angle and found that multiple preoperative examinations had greater potential in revealing the maximum angle of deviation [44].

Some patients with X(T) may show a variable target angle before surgery [45]. Pritchard [46] pointed out that variability in the preoperative measurement of X(T) may explain the high rate of recurrence. Furthermore, it should be determined whether the surgical dose could be performed based on the largest angle ever measured or the most common or final angle measured, when preoperative angles of X(T) were inconsistent. Kim and Hwang [16] evaluated the safety of BLR based on the largest angle ever measured. At the last follow-up, the average angle of exo-

tropia (esotropia 2 PD to exotropia 30 PD) was 6.8 PD at distance, and 6.2 PD (esotropia 9 PD to exotropia 30 PD) at near. Moreover, there was no overcorrection of over 2 PD of esophoria at distance and 9 PD of intermittent esotropia and esophoria at near in two patients, respectively. They suggested that the largest angle ever measured should be the target angle for surgery [16].

Classification of X(T) Based on Near-Distance Difference

Surgical treatment of X(T) may vary according to the type of X(T). Burian [47] classified X(T) into four different types: basic, divergence excess, simulated divergence excess, and convergence insufficiency. The basic type is the X(T) with less than 10 PD difference between the deviation angles at distance and at near [47]. Divergence excess type X(T) is defined when the deviation angle is greater at distance than at nearby ≥ 10 PD [47]. Simulated divergence excess type X(T) is designated when the near deviation angle increases with occlusion or on adding +3.00 lens [47]. Burian and Franceschetti [48] reported that 30 to 45 minutes of monocular occlusion was sufficient to increase the near deviation angle. Gurlu and Erda [49] found that the distance deviation angle stabilized after 1-hour occlusion test and the near deviation angle after 3-hour occlusion. Convergence insufficiency type X(T) is defined when the deviation angle is greater at near than at distance by ≥ 10 PD [47].

Kushner and Morton [50] classified divergence excess type X(T) as a high ratio of accommodative convergence (AC) to accommodation (A) ratio and proximal convergence. He substituted simulated divergence excess to tenacious proximal fusion, and divided convergence insufficiency type to low AC/A ratio, fusional convergence insufficiency, and pseudoconvergence insufficiency [50].

Kushner [51] reported that the surgical result after BLR is known to be better in simulated divergence excess type than in basic type X(T). Kim et al. [32] also found higher cumulative success rates with divergence excess type compared to the basic type after augmented BLR. Chia et al. [17] reported better results in the simulated divergence excess type than the basic type X(T) both after BLR and RR. However, Hardesty et al. [52] found similar results in the divergence excess type and basic type X(T).

Near-distance difference may change after surgery. Hardesty et al. [52] reported that BLR corrected the distant angle more than the near angle only in the divergence excess type X(T); however, Cho et al. [53] found that basic type X(T) converted into convergence insufficiency type more often after BLR than after RR.

Surgical Treatment in Basic Type X(T)

BLR and RR are the two most common surgical procedures performed to treat basic type X(T). Several studies have compared the relative efficacy of the two surgeries; however, there is no consensus regarding the more effective surgery. Most of the studies are retrospective. Four RCTs have previously compared BLR and RR [18,51,54,55], and three of them [18,51,54] demonstrated that RR could be more effective than BLR, especially with unequal accommodation or with a dominant eye. However, RR has the risk of inducing lateral incomitance [56]. Graeber and Hunter [56] reported that asymmetric surgery including RR resulted in larger incomitance than symmetric surgery, while preoperative incomitance more likely resolved with asymmetric than symmetric surgery. However, Tibrewal et al. [57] reported that RR with lateral rectus recession ≤ 9 mm and medial RR ≤ 6.5 mm in X(T) of 40 PD at an average did not induce lateral incomitance over 5 PD or postoperative diplopia.

Comparison of BLR and RR in basic type X(T)

1) Randomized controlled trials

Kushner [51] randomized patients with basic type X(T) into either the RR (17 patients) or BLR groups (19 patients) and observed them for a year. Exophoria ≤ 10 PD to esophoria ≤ 5 PD were considered satisfactory, and intermittent/manifest tropia, unsatisfactory. He found that RR was more effective than BLR (82% vs. 52%, $p < 0.05$).

Additionally, Jeoung et al. [18] reported better results with RR (55 of 66, 83%) than with BLR (28 of 58, 48%) in exotropes with a dominant eye; however, the overcorrection rate was significantly higher with RR (7.6% vs. 0%), especially with poor preoperative stereopsis.

Somer et al. [54] evaluated the accommodative response with dynamic retinoscopy and found better results with RR (13 of 18, 72%) than with BLR (5 of 14, 36%) in 32 pa-

tients with unequal accommodation. There was no significant difference between RR (7 of 8, 87%) and BLR (5 of 7, 71%) in 15 patients with an equal accommodation. Yang and Hwang [58] found a significant asymmetry in the accommodative response in exotropes with a dominant eye during binocular viewing, such as decreased accommodative response in the nondominant eye. Considering the findings of Jeoung et al. [18] and Somer et al. [54], RR may be considered more beneficial than BLR, especially in patients with unequal accommodation.

Pediatric Eye Disease Investigator Group [55] reported a multicenter RCT, including 197 children aged 3 to 11 years of age, with 15 to 40 PD of basic type X(T), and near stereoacuity ≤ 400 arcsecond. They defined the suboptimal surgical outcome as exotropia ≥ 10 PD to constant esotropia ≥ 6 PD at distance or near with simultaneous prism cover test, loss of two octaves or more of stereoacuity from the baseline, or reoperation without meeting any of these criteria. Cumulative probability of suboptimal surgical outcome was 46% (43 of 101) after BLR versus 37% (33 of 96) after RR. Reoperation rates at 3 years were 10% after BLR and 5% after RR. The final result at postoperative 3 years showed similar suboptimal surgical outcomes with BLR (29%) and RR (17%).

2) Meta-analyses

A meta-analysis, including 454 patients of three RCTs and three retrospective studies found a higher success rate and lower recurrence with RR within a year postoperatively in basic type X(T) [59]. No significant difference in terms of overcorrection rates was observed between BLR and RR [59]. Another meta-analysis, including nine studies found that the success rate of RR was better than that of BLR for up to 2 years; however, after 2 years, the success rate of BLR became higher than that of RR with a lower undercorrection rate [60]. The overcorrection rate was not different regardless of the follow-up period [60]. Another meta-analysis involving 967 patients from 10 studies found no differences in the success rates and overcorrection and/or undercorrection rates between BLR and RR [61].

3) Retrospective studies

Retrospective studies favoring BLR in basic type X(T)

Maruo et al. [62] reported that BLR was more effective in achieving an alignment of $\leq \pm 4$ PD (140 of 210, 67%)

than RR (59 of 180, 33%) after 4 years postoperatively. Exotropia was present in 31% (65 of 210) of the patients after BLR, and 67% (121 of 180) after RR at postoperative 4 years. They also found that the alignment measuring $\leq \pm 4$ PD was more common with patients aged <3 and >11 years of age at surgery. Choi et al. [27] found no significant difference until postoperative 2 years; however, a higher success rate with BLR (58%) than RR (27%, $p < 0.01$) was observed 3.8 years later. Cumulative probability of survival from recurrence was higher with BLR than with RR [27]. They also found that recurrences were most common within postoperative 6 months, and continued to increase with RR, but not with BLR. The study concluded that BLR was beneficial 2 years postoperatively with a lower recurrence rate after 6 months postoperatively [27]. Yang et al. [63] observed better motor outcomes with RR at postoperative 6 months (83% vs. 82%), which were similar to the outcomes with BLR at 12 and 24 months postoperatively, followed by better outcomes with BLR at 36 months postoperatively (61% vs. 43%). However, they did not designate the X(T) types in their study.

Retrospective studies favoring RR in basic type X(T)

Chia et al. [17] found better surgical outcomes with RR at postoperative 1 year (75% vs. 42%, $p < 0.001$), along with more residual X(T) with BLR (56% vs. 13%) and more consecutive esotropia with RR (13% vs. 2%). Wang et al. [64] also reported better surgical outcomes (85% vs. 66%, $p = 0.037$) and less undercorrection (6% vs. 24%, $p = 0.023$) without any difference in overcorrection (11% vs. 9%, $p = 1.000$) with RR compared to BLR after a mean follow-up of 14.8 ± 9.5 months (range, 6–42 months with BLR and 6–48 months with RR). Kim et al. [38] reported better results with lower recurrence with RR than with BLR in the largest series of 560 patients with basic type X(T) with an average follow-up of 9.5 years. BLR is more likely to result in relapse within postoperative 1 year than RR (29.3% vs. 7.0%, $p < 0.001$). The overcorrection rate was higher with RR until 4 years postoperatively, and subsequently decreased in a continuous manner over time; there was no significant difference in the overcorrection rate between BLR versus RR beyond 5 years postoperatively [38]. Cho et al. [53] found that the basic type X(T) changed to the convergence insufficiency type more frequently after BLR than after RR. They suggested that the high rate of development of the convergence insufficiency

type X(T) after BLR should be considered to select a surgical procedure. In contrast, Bae et al. [65] reported that the type of X(T) changed mostly to the basic type after BLR, RR, or unilateral lateral rectus recession (ULR) after the 1-hour monocular occlusion.

Retrospective studies with comparable results between BLR and RR in basic type X(T)

In 99 patients with basic type X(T), Bang et al. [66] reported a higher success rate and lower recurrence rate 6 months and 1 year after BLR (92% with BLR vs. 74% with RR, $p = 0.040$), but no difference at postoperative 5 years (54% with BLR vs. 42% with RR). Moreover, the recurrence occurred until 2 to 3 years after BLR, while RR caused a greater exodrift for postoperative 1 year. Five years later, the success rate (54% with BLR vs. 42% with RR) as well as the reoperation rate (24% with BLR vs. 34% with RR) was observed to be comparable.

Surgical Treatment in Divergence Excess and Simulated Divergence Excess Type X(T)

Burian [47] recommended BLR for divergence excess type as well as simulated divergence excess type X(T). Chia et al. [17] favored BLR rather than RR because of the higher overcorrection rate after RR in true divergence excess type X(T). They found better surgical outcomes in true divergence excess type X(T) than in basic type X(T). Kushner [51] reported a satisfactory outcome after BLR in 80% (55 of 68) of patients with simulated divergence excess type X(T). Kim et al. [32] found higher success rates with the divergence excess type X(T) compared to the basic type X(T) after BLR.

Surgical Treatment in Convergence Insufficiency Type X(T)

Surgical treatment of the convergence insufficiency type X(T) includes RR, modified RR, slanted or non-slanted BLR (upper horn based on distance deviation angle and lower horn based on near deviation angle), slanted or non-slanted unilateral (UMR) and bilateral medial rectus (BMR) resection with or without an adjustable suture, and

medial rectus plication [20,21,24,67-81]. The corresponding success rates ranged from 18% to 92%, and most studies concluded that the duration of consecutive esotropia or diplopia was shorter than 4 weeks, with a tendency to exodrift with time following any of the surgical methods.

Modified RR (LR recession based on distance deviation angle and MR resection based on near deviation angle) could result in satisfactory surgical outcomes in the convergence insufficiency type X(T) [21,24,79]. Kraft et al. [79] reported the results of modified RR in 14 patients with a near-distance difference ≥ 8 PD. At postoperative follow-up ≥ 6 months, the mean angle of X(T) was 0.1 PD at distance and 1.8 PD at near, and the near-distance difference was 1.7 PD. Choi et al. [21] reported the surgical result of modified RR from 23 to 9 PD at distance and from 34 to 14 PD at near with mean near-distance difference from 11 to 5 PD, 1 year later (mean, 27 months; range, 12–68 months). Yang and Hwang [24] divided 65 patients with convergence insufficiency type X(T) into three groups according to the response to monocular occlusion for 1 day: true convergence insufficiency as near-distance differences ≥ 10 PD before and after occlusion (24 children), masked convergence insufficiency as near-distance differences < 10 PD before occlusion and ≥ 10 PD after occlusion (19 children), and pseudoconvergence insufficiency as near-distance differences ≥ 10 PD before occlusion and < 10 PD after occlusion (22 children). They compared the surgical results of modified RR with augmented BLR based on the near measurements in addition to adding 1 mm more. The cumulative probabilities of success 2 years after augmented BLR versus modified RR were 61% versus 100% in the true convergence insufficiency, 58% versus 100% in the masked convergence insufficiency, and 77% versus 71% in the pseudoconvergence insufficiency type X(T). The modified RR was significantly more successful than the augmented BLR in the management of the true/masked convergence insufficiency type X(T).

Hermann [78] performed BMR resection of 3.5 to 4.5 mm in 14 patients; the postoperative overcorrection in all the patients was managed with Fresnel prisms. Diplopia with consecutive esotropia at distance resolved after an average of 2.7 months. von Noorden [80] reported the surgical results of BMR resection in six patients with convergence insufficiency type X(T). Fresnel prisms were necessary to manage diplopia at distance for 5 weeks to 5 months. Five months after immediate overcorrection,

five out of six patients showed exophoria, and one showed exodeviation of 23 PD at near. Choi and Rosenbaum [69] performed UMR or BMR resection with targeted angles of 10 to 20 PD esotropia at distance and 5 to 10 PD esotropia at near using adjustable sutures. Postoperatively, 16 of 21 patients (76%) showed exodeviation at distance or at near. Averaged esodeviation of 2 PD (esodeviation of 12 PD to exodeviation of 6 PD) at distance, and exodeviation of 3 PD (esodeviation of 10 PD to exodeviation of 16 PD) at near were present at the last follow-up (range, 6–66 months) [69]. Fresnel prisms were necessary in 14 of 21 patients for 3 to 6 months or over. All of them showed undercorrections after UMR resection [69]. Considering the relatively short follow-up period of 6 months in 62% of the cases, the undercorrection may increase with time.

Surgical results of slanted BMR resection (upper horn based on distance deviation and lower horn based on near deviation) was variable. Biedner [68] reported an alignment of < 10 PD after single slanted MR resection in three patients. The small number of patients as well as the small preoperative X(T) < 10 PD at distance should be considered with the study by Biedner [68]. In contrast, Choi and Hwang [20] reported an exodrift with time, such as undercorrection of exodeviation of ≥ 10 PD at distance and at near in all of the 10 patients after the slanted BMR resection. They demonstrated that postoperative esotropia or diplopia lasted for less than postoperative 4 weeks [20]. Nemet and Stolovitch [81] also reported a final undercorrection in all of the three patients after slanted BMR resection. They described that esotropia at distance tended to diminish and disappear with time, and that it ultimately resulted in recurrence of convergence insufficiency type X(T) [81]. In conclusion, although slanted BMR resection has little risk of consecutive esotropia at distance, it was associated with a long-term unsatisfactory chance of recurrence.

Snir et al. [75] reported that 1-mm different slanted BLR was superior to the standard BLR in reducing X(T) at distance and at near as well as distance-near differences in the 11 of 12 patients. Farid and Abdelbaset [71] prospectively compared three procedures of slanted BLR (upper horn based on distance deviation angle and lower horn based on near deviation angle in 22 patients), modified RR (LR recession based on distance deviation angle and MR resection based on near deviation angle in 23 patients), and augmented BLR based on near deviation in 22 patients.

After 1 year, they found similar improvements in near deviation, while, at distance, the slanted BLR showed slightly better outcomes compared with the other two procedures. Distance-near disparity reduced more with augmented BLR and slanted BLR than with modified RR. There was no overcorrection at near after all three procedures, and an overcorrection (27%) was observed at distance only in augmented BLR based on near deviation angle. The undercorrection rate at distance was 23% with augmented BLR and slanted BLR, and 57% after modified RR. The undercorrection rate at near was 50% after slanted BLR, 70% after modified RR, and 73% with augmented BLR. They found the best results with slanted BLR revealing the lowest rates of overcorrection and/or undercorrection, however, still with 50% of undercorrection. Their results were quite contrary to those of the study by Yang and Hwang [24], in which modified RR provided better results than augmented BLR based on the near deviation angle with additional 1 mm. The follow-up period was longer (2 years) in the study by Yang and Hwang [24] than in the study by Farid and Abdelbaset [71] (1 year).

Surgical Treatment in X(T) with High AC/A Ratio

Kushner [82] reported that among the 154 patients with distance-near differences ≥ 10 PD, 14% had a high AC/A ratio. He recommended that near measurements in exotropes must be performed after prolonged monocular occlusion. Six of the 22 patients with a high AC/A ratio showed esotropia at near after surgery. Overcorrecting minus lens or bifocal glasses were attempted in the remaining 16 patients, and most of them showed normal AC/A ratio after 18 years of age.

Cases of X(T) with a high AC/A ratio can be managed with BLR and posterior fixation sutures on BMR to prevent the postoperative overcorrection at near. Additional bifocal glasses might be necessary. Brodsky and Fray [83] reported that BLR and posterior fixation sutures on BMR achieved a stable alignment at distance and near without bifocal glasses in five of the six patients with X(T) and a high AC/A ratio, and with bifocal glasses for intermittent esotropia at near in one remaining patient. In contrast, Khawam et al. [84] reported that all 14 patients with X(T) and a high AC/A ratio did not develop esotropia after BLR.

Instead, 50% of them showed a successful alignment with $< \pm 8$ PD and 50% showed a recurrence with ≥ 8 PD after BLR. Choi and Jung [85] reported that BLR and posterior fixation sutures on BMR achieved exodeviation of ≤ 8 PD at distance and at near, and a distance-near difference of ≤ 10 PD without bifocal glasses in five of the seven patients with X(T) and a high AC/A ratio, and esotropia at near managed with bifocal glasses in one patient.

Surgical Treatment of X(T) with Dissociated Horizontal Deviation

Wilson et al. [86] reported that ULR could control most of the manifest dissociated horizontal deviation (DHD). BLR may be necessary for bilateral DHD with alternate fixation, especially with coexisting X(T) and DHD [86]. Gamio [87] reported surgical results in nine patients with X(T) and DHD after an average of 35 months. In contrast to the findings of the study by Wilson et al. [86], Gamio [87] concluded that BLR rather than ULR was almost always needed, even with a strong fixation preference.

Surgical Treatment of X(T) with All Oblique Muscle Overaction

Overaction of all oblique muscles may disappear following the surgical procedures on horizontal rectus muscles [88]. Therefore, weakening of oblique muscles should be considered with caution.

Surgical Treatment in Small-Angle X(T)

Small-angle X(T) could be treated with ULR, BLR, or RR. Operating on one muscle could spare other muscles for reoperation and could reduce the surgery time as well as the risks of scleral perforation or endophthalmitis. A meta-analysis concluded that RR showed a higher success rate and lower undercorrection than ULR for X(T) ≤ 20 PD. In contrast, RR and ULR showed similar results for X(T) of 20 to 25 PD [60].

Feretic et al. [89] performed a ULR of 11.5 to 12.0 mm on the nondominant eye in 10 patients with X(T) of 14 to 16 PD. They found that an immediate postoperative over-

correction of 4 to 6 PD was functionally desirable. Abduction limitation was minimal for ULR of up to 12 mm. Nelson et al. [90] reported orthophoria in 51%, undercorrection in 44%, and overcorrection in 5% of 55 patients after 7 to 8 mm of ULR with a minimum follow-up of 6 months. Spierer and Spierer [91] reported a success (<10 PD) rate of 84% after ULR in 25 patients with X(T) \leq 25 PD, 0.5 to 5 years (mean, 3.2 ± 1.3 years) after treatment. Wang and Nelson [92] reported a success rate (\leq 5 PD) of 76% after ULR in 100 patients with X(T) of 15 to 35 PD, 0.5 to 7.4 years (mean, 2.9 ± 1.8 years) after treatment. They found a decreased success rate with time and the amount of initial X(T) was significantly correlated with the final success rate. In contrast, Olitsky [93] reported no significant alignment difference at postoperative 1 week versus 6 months after ULR and suggested that an acceptable alignment in the 1st week might be promising unlike the surgical outcomes after BLR.

Kim et al. [94] compared surgical outcomes of ULR (82 patients) to RR (98 patients) for X(T) of 20 to 25 PD with a follow-up of \geq 2 years. A successful alignment \leq 10 PD was achieved in 61% of the patients after ULR and 56% after RR. ULR resulted in a greater recurrence until 3 months later, and then showed similar results at postoperative 6 months. Kim et al. [31] compared the surgical outcomes of ULR of 10 mm (69 patients) and RR (61 patients) for X(T) \leq 20 PD with a follow-up \geq 2 years. The success rate was significantly higher with ULR at postoperative 6 months, but became comparable at postoperative 2 years. Finally, after a mean duration of 3 years, the recurrence rates were lower with RR, and the overcorrection rates were comparable. They concluded that RR resulted in a more successful alignment and lower recurrence than ULR for X(T) \leq 20 PD.

Lyu et al. [95] reported a success rate of 93% at postoperative 2 years and 83% at the final examination (average, postoperative 3.9 years) in 214 patients with basic type X(T) of 15 to 24 PD. They found a worse outcome with X(T) of 20 to 25 PD than with X(T) less than 20 PD, and no overcorrection. Oh et al. [96] compared the surgical results according to the amount of ULR in 163 patients with X(T) of 20 PD. They found different rates of recurrence, such as 26% with 8.0 mm, 19% with 8.5 mm, and 9% with 9.0 mm within postoperative 2 years. The possibility of recurrence varied significantly according to the age at the time of surgery. For example, recurrence was noted at

6.5 years of age versus no recurrence at 8 years of age at the time of surgery. They concluded that a younger age at the time of surgery and ULR of 8.0 mm were significant risk factors for recurrence after ULR in X(T) of 20 PD. They suggested a surgical dose of 9.0 mm with ULR for X(T) of 20 PD. In contrast, Weakley and Stager [97] found a lesser effect in patients $>$ 4 years of age and \leq 20 PD of X(T), while Wang and Nelson [92] found no relationship with the age at surgery and surgical outcome. Kim and Choi [98] reported the mean effect per millimeter of ULR in 37 patients with basic type X(T) of 16 to 25 PD was 2.98 ± 0.42 PD/mm (range, 2.4–4.1 PD/mm), with the effect of ULR greater with a narrower LR tendon width.

Surgical Outcomes of Augmented Surgeries

Augmented BLR

Kushner [51] suggested that increasing the dose of BLR might be beneficial for patients with basic type X(T). Since Lee et al. [99] first reported better surgical results with augmented BLR by 1.5 to 2.5 mm, BLR augmentation by 1.0 to 2.5 mm or increasing the target angle by 5 PD [100] have been shown to improve the long-term surgical results without a significant difference in the overcorrection rate [32,99,100]. Kim et al. [32] found that patients with divergence excess type showed better results than those with the basic type after augmented BLR. They suggested that augmentation should be considered when planning BLR, especially for the divergence excess type X(T). Awadein et al. [101] demonstrated that augmented BLR by 1.5 mm significantly increased the success rate only in older patients above 12 years of age. They suggested that augmentation according to age could improve the surgical outcome of X(T).

Augmented RR

Increasing the surgical dosage of MR resection by 1 mm improved the long-term surgical results compared to the original dosage without significant differences in overcorrection [34]. With an increased surgical dosage, the recurrence rate (7.0 %) at postoperative 2 years was remarkably lower compared to the recurrence rate (range, 38%–61%) reported in the previous studies [25,27,62,63].

Factors Affecting Surgical Outcomes

Age

The relationship between age and surgical results is controversial. Early surgery may help develop better binocular vision [102-104], but may also pose a risk of developing amblyopia to children with immature visual system because of the postoperative overcorrection [105]. The fact that the surgery was performed at a young age could imply that X(T) may be present from an early age consequently disturbing the binocular vision, and that X(T) was severe enough for the caretakers to notice. Late surgery can provide benefits of more accurate measurements and lesser chances of developing amblyopia, but can impose lesser chances of developing binocular vision [102].

Maruo et al. [62] reported that an alignment $\leq \pm 4$ PD was achieved with surgeries that were performed at < 3 years or > 11 years of age. Abroms et al. [102] reported better sensory and motor outcomes with surgeries performed at < 7 years of age, X(T) duration < 5 years, or with intermittency rather than constancy. Asjes-Tydemans et al. [103] reported that surgeries performed at < 7 years of age could result in better motor (exodeviation of < 10 PD) and sensory outcomes as well as fewer instances of reoperations. Tibrewal et al. [104] found an older age at surgery and a larger preoperative deviation to impose greater chances of failure. Recently, a meta-analysis, including 11 retrospective studies revealed that earlier surgery at < 4 years of age led to better results after BLR [40]. Awadein et al. [101] reported a negative correlation between age at surgery and response to surgery for all angles. Reduction of the surgical dose in patients younger than 7 years of age resulted in no significant surgical outcomes; however, increasing the surgical dose in older patients > 12 years of age significantly increased the success rate [101]. They concluded that modifying the surgical dose according to age can improve the surgical outcome of X(T).

In contrast, Kim et al. [38] reported that a younger age at onset and at surgery were risk factors for recurrence in the largest case series of basic type X(T). Lim et al. [25] found lesser recurrence with older age at onset and at surgery after RR. Lim et al. [26] also found lesser recurrence with older age at surgery after BLR.

Jeon et al. [106] reported no difference in terms of surgical success before versus after 4 years of age at surgery.

Chia et al. [17] found no difference in surgical outcome among the different age groups.

Refractive errors

Although most studies reported that refractive errors do not affect the final surgical outcomes [15,16,18-22], Gezer et al. [107] found a relationship with a shift toward myopia and less favorable surgical outcomes, such as higher myopia with larger postoperative deviation. In contrast, Zou et al. [108] found that a greater degree of myopia and smaller deviations contributed to higher success rates, and that hyperopia and larger deviations resulted in lower success rates. Kim et al. [38] reported that preoperative hyperopia $> +2.00$ diopters was one of the risk factors of recurrence. Han et al. [44] revealed that preoperative monocular occlusion increased near deviation angle, especially in hyperopes. Pineles et al. [23] found that anisometropia was associated with a poor surgical outcome.

Anatomic factors

Kim and Choi [98] reported a larger effect of ULR with a narrower tendon width of LR. Lee et al. [109] revealed that the limbus-insertion distance of LR was significantly correlated with dose-response effects. The greater distance of the LR insertion to limbus, the greater is the BLR/ULR effect; for example, 0.2 PD/mm in ULR caused 0.4 PD/mm in BLR at postoperative 6 months. They suggested that the limbus-insertion distance of LR could be a predictor of the recession effect [109].

Preoperative angle of deviation

Differing surgical results have been associated with the changes in the preoperative deviation angle. A larger preoperative deviation angle may be associated with poor surgical outcomes [29,104,107]. Gezer et al. [107] found that the preoperative deviation angle was the most important factor for determining the surgical outcome. Patients with larger preoperative deviations had a poorer successful outcome after a single surgical intervention, while those with smaller preoperative deviation angle had more favorable surgical outcomes. Yam et al. [29] also reported that a smaller angle of deviation correlated with a smaller postoperative drift after BLR. Yang et al. [110] reported that a

larger preoperative near deviation angle >16 PD and a larger initial postoperative exodeviation of >5 PD at distance were predictors of recurrence in 92 patients with X(T) ≤ 25 PD after ULR of 10 mm at more than postoperative 2 years. Kim et al. [38] found that a larger exodeviation of >5 PD at near than at distance was one of the risk factors of recurrence in 560 children with basic type X(T) with an average follow-up of 9.5 years. In contrast, Lim et al. [25,26] found no relationship between the preoperative deviation angle and surgical outcome in both RR and BLR. Chia et al. [17] found no difference in the surgical outcome according to the preoperative degree of control or deviation angle of X(T) at distance. Kim and Kim [45] found better surgical outcomes with variable preoperative measurements than with consistent preoperative measurements.

Early postoperative angle

Postoperative exodrift is common; therefore, an initial overcorrection could be desirable. The desirable initial overcorrection varies in values and has been reported as: 0–9 PD [13], 0–10 PD [9], 5–7 PD [11], 6–10 PD [10], 10 PD [12], 4–14 PD [5], >10 PD [19], 10–15 PD [6,7], 11–20 PD [4,8], and 1–20 PD [14]. In contrast, Leow et al. [111] reported that the exodrift was greater with an initial esotropia and orthophoria compared to that with exotropia. They found that success was unaffected by initial ocular alignment and suggested that deliberate initial overcorrection may be unnecessary.

An initial overcorrection of 17 to 20 PD might be acceptable [4,7,14]; however, risks of consecutive esotropia and monofixation syndrome exist, which can lead to loss of stereopsis and amblyopia especially in young children [13,23]. Kim et al. [15] reported their findings in 68 consecutive patients with initial overcorrection of ≥ 20 PD at distance or at near. The patients were managed with an alternate full-time occlusion, echthiophate iodide, or prism glasses for the period of overcorrection. An initial overcorrection ≥ 20 PD decreased to ≤ 10 PD at distance and at near within postoperative 4 weeks in 72% (49 of 68) of the patients. Four patients (5.9%) needed a reoperation for consecutive esotropia. Finally, orthotropia to exodeviation and/or esodeviation ≤ 10 PD was achieved in 71% (48 of 68), and exodeviations >10 PD in 16% (11 of 68) of the patients at distance or at near. They concluded that an initial over-

correction ≥ 20 PD mostly reduced to ≤ 10 PD within 4 weeks, and reoperations for consecutive esotropia were necessary in 6% of the patients.

Residual exotropia at postoperative 1 week and 1 month led to recurrence [25,26,104]. However, few patients may manifest delayed consecutive esotropia after showing orthotropia to exotropia at postoperative 1 month, especially after BLR [112,113]. Therefore, surgeons should recognize the possibility of delayed development of consecutive esotropia.

Follow-up period

Recurrences increase with a longer follow-up period. Ekdawi et al. [114] reported that a misalignment of ≥ 10 PD increased from 54% at 5 years to 76% at 10 years, and further increased to 86%, 15 years later. Lim et al. [25] reported that the recurrence rate after RR continuously increased from 5.3% at 1 month, 16.0% at 3 months, 27.6% at 6 months, 41.9% at 12 months, 60.7% at 2 years, 70.8% at 3 years, 74.5% at 4 years, and 77.9% at 5 years.

Management of Postoperative Strabismus

Management of recurrent exotropia

Yang and Hwang [22] compared the efficacy of BMR to UMR for the treatment of recurrent exotropia ≤ 25 PD after BLR. After BMR resection, 54% (13 of 44) of the patients showed successful outcomes (exodeviation of <10 PD to esodeviation of <5 PD), 42% (10 of 44) showed overcorrection, and 4% (1 of 44) showed an undercorrection at 22.8 ± 10.9 months (range, 8–43 months). After UMR resection, 80% (16 of 20) of the patients showed successful outcomes, 10% (2 of 20) showed overcorrection, and 10% (2 of 20) showed an undercorrection at 21.6 ± 8.8 months (range, 9–43 months). The success rates and incidence of recurrence were not significantly different between BMR and UMR resection; however, the incidence of overcorrection was significantly higher with BMR resection. They concluded that large UMR resections could be safe and effective in treating recurrent exotropia ≤ 25 PD after BLR with significantly lower overcorrection rate than that with BMR resection. Later, Sung et al. [36] compared the long-term effects of BMR to UMR resection for recurrent exo-

tropia of 20 to 30 PD with a minimum follow-up of 5 years. At 5 years after surgery, the success rates were not significantly different between the BMR and UMR resection (57% vs. 62%); similar findings were observed in the recurrence rates. The overcorrection rate was still significantly higher with BMR resection (35% vs. 15%, $p = 0.039$). The effect of UMR resection was significantly greater with a larger amount of BLR. Multivariate analysis showed that a large BLR and an initial overcorrection >10 PD were significant risk factors for overcorrection. They concluded that a large UMR resection is still safe and efficient for recurrent exotropia of 20 to 30 PD; however, reduction in surgical dosage for UMR resection in cases with the previous large BLR is necessary considering the high risk of long-term overcorrection.

Management of consecutive esotropia

Initial overcorrections were managed conservatively with monocular patching, full hyperopic correction, bifocal glasses, topical anticholinesterase, botulinum toxin, or base-out prisms [28,115-118]. Kim and Choi [119] reported that the divergence excess type X(T), amblyopia, BLR, esodeviation of ≥ 20 PD at postoperative day 1, younger age at diagnosis and surgery, and shorter duration from onset to surgery were risk factors for consecutive esotropia. Baik et al. [112] found that 79% of consecutive esotropia were patients who underwent BLR that were orthotropic after 1 month, then later developed esodeviation within 7.4 ± 6.0 months (range, 2–29 months). Lee and Kim [113] also found that 5% (13 of 284) of the patients developed consecutive esotropia after showing orthotropia or exodeviation at postoperative 1 month. They presented a larger preoperative angle of exodeviation, poorer stereopsis, younger age at the time of surgery, and mostly after BLR rather than RR. Chougule et al. [120] found that constant exotropia and larger lateral rectus recession were associated with abduction limitation in consecutive esotropia. Notably, lateral rectus advancement was effective irrespective of abduction limitation.

Lee and Hwang [28] administered prism glasses in 110 patients with consecutive esodeviation of ≥ 5 PD from 4 weeks after RR. An average period of prism wearing was 21 months, and the esodeviation decreased at the rate of 2.9 PD in 6 months. Thirty-four patients (32%) were weaned off the prism glasses within 1 year. The prism-weaned

group showed a larger preoperative constant deviation and anisometropia, and higher exodrift. No patient demonstrated new-onset amblyopia; however, one patient (0.95%) demonstrated loss of stereoacuity because of overcorrection. Finally, successful motor outcomes (exodeviation of ≤ 10 PD to esodeviation of ≤ 5 PD) were achieved in 71% of the patients, and the stereoacuity improved or was maintained in 92% of the patients. They concluded that the prismatic correction could lead to good motor outcomes while maintaining favorable sensory status in consecutive esotropia.

Lee et al. [117] administered prism glasses in 39 patients with esodeviation of ≥ 5 PD from 4 weeks after BLR. Successful motor outcome (exodeviation of ≤ 10 PD to esodeviation of ≤ 5 PD) was achieved in 67% of the patients, and stereoacuity was improved or maintained in 79% of the patients. Notably, no patient lost stereopsis because of overcorrection. Prism glasses were necessary for an average of 24 months, and the esodeviation decreased at the rate of 4.2 ± 6.7 PD/yr. At the last visit, 82% of the patients were weaned off prism glasses. They concluded that after BLR, consecutive esodeviation continuously decreased, and 82% of the patients were weaned off prism glasses after 3 years. Prismatic correction could lead to good motor and sensory status in most patients with consecutive esotropia after BLR.

Another option for managing the persistent consecutive esotropia could be botulinum toxin injection with or without electromyographic guidance. Yang et al. [118] reported successful alignment in 69% of the patients with 1.3 ± 0.7 botulinum injections without electromyographic guidance in patients with consecutive esotropia of 21.8 ± 9.1 PD at distance and 21.3 ± 8.3 PD at near. Multivariate analysis revealed that initial postoperative esodeviation of ≤ 18 PD at 1 month after exotropia surgery was a predictor for success. Vertical deviation and/or ptosis occurred in 8% of the patients and resolved within 3 months. There was no recurrence of exotropia. They concluded that botulinum toxin injection without electromyographic guidance could be safe and effective in the treatment of consecutive esotropia without causing recurrent exotropia, especially with esodeviation ≤ 18 PD at 1 month after exotropia surgery.

Long-standing consecutive esotropia could be managed with MR recession or LR advancement. Adamopoulou and Rao [121] reported that UMR recession was successful in 63% (10 of 16) of patients with consecutive esotropia af-

ter BLR, RR, or BMR resection. X(T) recurred in 31% (5 of 16) of the patients with RR as the initial surgery, and one patient showed undercorrection.

Kim et al. [122] calculated the ratio of the change in muscle position to the change in visual angle deviation, and the surgical dose-effect relationship of lateral rectus advancement in 11 patients with consecutive esotropia. One week postoperatively, the success rate was 82% and the average correction ratio was 4.31 ± 0.96 PD/mm. Multiple regression analysis showed that the amount of muscle advancement and preoperative deviation angle were positively correlated with the correction ratio. Surgical dose-effect relationship increased with the preoperative deviation angle and amount of muscle advancement; therefore, reducing the amount of muscle advancement with larger angle deviations should be considered. Kim and Lee [123] evaluated the efficacy of ULR advancement based on one-fourth of the angle for consecutive esotropia within 25 PD after BLR. Orthotropia and/or exodeviation of ≤ 8 PD was achieved in 91% (10 of 11) of the patients. The surgical effects of ULR advancement were 3.3 ± 0.7 PD/mm after 1 day, 3.7 ± 0.6 PD/mm after 1 week, and 3.8 ± 0.7 PD/mm after 6 months.

Park et al. [124] compared ULR advancement with MR recession (AR) to BMR recession for consecutive esotropia after BLR. One year later, the success rates were almost similar (86% after AR vs. 73% after BMR recession). Recurrence of X(T) occurred in 14% of the patients after AR versus 27% after BMR recession.

Conclusion

Although RR achieved better surgical outcomes in three of the four RCTs, several retrospective studies reported better or comparable surgical outcomes of BLR versus RR. The debate over the better surgical procedure for X(T) may continue and differ according to the experience of each surgeon. Various preoperative and postoperative factors can influence the surgical outcome. An augmented dose of BLR and RR could be helpful in reducing the recurrence of X(T); however, overcorrection should be carefully managed with the use of Fresnel prism or ground-in prism glasses. Future RCTs comparing BLR and RR as well as studies evaluating the prognostic factors for surgical outcome are needed.

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