

RESEARCH ARTICLE

# Correction of Excyclotropia by Surgery on the Inferior Rectus Muscle in Patients with Thyroid Eye Disease: A Retrospective, Observational Study

Yasuhiro Takahashi<sup>1</sup>, Yoshiyuki Kitaguchi<sup>1</sup>, Shunsuke Nakakura<sup>2</sup>, Hidenori Mito<sup>1,3</sup>, Akiko Kimura<sup>4</sup>, Hirohiko Kakizaki<sup>1\*</sup>

**1** Department of Oculoplastic, Orbital & Lacrimal Surgery, Aichi Medical University Hospital, Aichi, Japan, **2** Department of Ophthalmology, Saneikai Tsukazaki Hospital, Himeji, Japan, **3** Ide Eye Hospital, Yamagata, Japan, **4** Department of Ophthalmology, Hyogo College of Medicine, Hyogo, Japan

\* [cosme@d1.dion.ne.jp](mailto:cosme@d1.dion.ne.jp)



## Abstract

### Purpose

To examine the characteristics of excyclotropia correction through surgery on the inferior rectus muscle in patients with thyroid eye disease.

### Methods

This was a retrospective, observational study at a single institution. We reviewed 36 patients who had undergone unilateral inferior rectus muscle recession, with or without nasal inferior rectus muscle transposition. The following factors were investigated as possibly influencing excyclotropia correction: inferior rectus muscle thickness, degree of adipose change in the inferior rectus muscle, smoking status, history of orbital radiotherapy, and the amount of inferior rectus muscle recession. Using T1-weighted coronal magnetic resonance imaging, we measured the cross-sectional area of the inferior rectus muscle at its largest point, as well as the bright-signal area of the inferior rectus muscle, which reflects intermuscular adipose change. We then calculated the percentage internal bright-signal area at the point of the largest inferior rectus muscle cross-sectional area. The history of orbital radiotherapy was graded using a binary system. We evaluated correlations among excyclotropia correction, the amount of nasal inferior rectus muscle transposition, and the possible influencing factors listed, using stepwise multiple regression analyses.

### Results

The multiple regression model demonstrated a significant relationship among excyclotropia correction, amount of nasal inferior rectus muscle transposition, and the amount of inferior rectus muscle recession ( $Y_{\text{CORRECTION}} = 8.546X_{\text{TENDON WIDTH}} + 0.405X_{\text{RECESSION}} - 0.908$ ;  $r = 0.844$ ; adjusted  $r^2 = 0.695$ ;  $P < 0.001$ ).

## OPEN ACCESS

**Citation:** Takahashi Y, Kitaguchi Y, Nakakura S, Mito H, Kimura A, Kakizaki H (2016) Correction of Excyclotropia by Surgery on the Inferior Rectus Muscle in Patients with Thyroid Eye Disease: A Retrospective, Observational Study. PLoS ONE 11 (7): e0159562. doi:10.1371/journal.pone.0159562

**Editor:** Graham R. Wallace, University of Birmingham, UNITED KINGDOM

**Received:** March 15, 2016

**Accepted:** July 4, 2016

**Published:** July 19, 2016

**Copyright:** © 2016 Takahashi et al. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** All relevant data are within the paper and its Supporting Information files.

**Funding:** The authors have no support or funding to report.

**Competing Interests:** The authors have declared that no competing interests exist.

## Conclusions

Excyclotropia correction was correlated with the amount of nasal inferior rectus muscle transposition and the amount of inferior rectus muscle recession, but not with the other factors. The regression model presented in this study will enable us to determine more precisely the amount of nasal inferior rectus muscle transposition in patients with excyclotropia of various angles.

## Introduction

Excyclotropia impairs binocular single vision and has a strong negative impact on patients' daily activities [1]. This visual disorder is commonly accompanied by thyroid-associated inferior rectus (IR) myopathy with fibrotic contracture [2–5]. Patients can compensate for mild excyclotropia by head tilt [3–6], but severe forms of the disorder cannot be completely compensated in this manner; in addition, excyclotropia cannot be corrected using prisms [7].

Nasal transposition of the fibrous IR muscle is a reasonable treatment for excyclotropia in thyroid eye disease (TED) [8–10]. One previous study reported a 7° excyclotropia that was corrected using nasal transposition of one IR muscle tendon width [8]. However, the researchers who performed the study did not analyze the correlation between the angle of excyclotropia and the amount of nasal IR muscle transposition [8]. It is therefore unclear whether a dose-effect relationship can be extrapolated to patients with different degrees of excyclotropia.

The outcomes of strabismus surgery in patients with TED are less reproducible than those in patients without TED [11]. Therefore, to ensure a more tailored surgery, it is vital that clinicians understand the factors that influence strabismus in patients with TED. Presumptive influential factors for strabismus surgery in patients with TED include thickness of the target extraocular muscles, severity of adipose change in the transposed muscles, smoking status, histories of orbital radiotherapy and orbital decompression surgery, and the amount of concomitant muscle recession [11–20]. The thickness of the extraocular muscles and adipose changes reflect the severity of fibrous changes therein [18]. Smoking and orbital radiotherapy lead to excessive orbital fibrosis [3,19]. Orbital decompression surgery restricts extraocular muscle motility [20]. Muscle recession releases a fibrous contracture of the extraocular muscle [13]. However, no previous studies have shown the influences of these factors on excyclotropia correction in patients with TED.

In this study, we analyzed the correlations among excyclotropia correction, the amount of nasal IR muscle transposition, and the aforementioned influencing factors in patients with TED.

## Materials and Methods

### Patients

This study was a retrospective chart review of all patients with TED who underwent unilateral IR muscle recession with nasal IR muscle transposition, performed by one of the authors (H. K.), between March 2011 and December 2015. We also reviewed the medical records of all patients with TED who underwent unilateral simple IR muscle recession, carried out by the same surgeon, during the same period. Five patients underwent bilateral IR muscle recession during the study period, and a further seven patients underwent combination surgery of IR muscle recession on the affected side and superior rectus muscle recession on the unaffected

side. However, we excluded these data from the analyses, because they were influenced by the concomitant procedure, and we wished to assess the effect of isolated unilateral surgery.

This study was approved by the Institutional Review Board (IRB) of Aichi Medical University Hospital (no. 15–025), and followed the tenets of the Declaration of Helsinki. The IRB granted a waiver of informed consent for this study on the basis of the ethical guidelines for medical and health research involving human subjects established by the Japanese [Ministry of Education, Culture, Sports, Science and Technology](#), and by the [Ministry of Health, Labour, and Welfare](#). The waiver was granted because the study was a retrospective chart review, not an interventional study, and because it was difficult to obtain consent from patients who had been treated several years prior. Nevertheless, at the request of the IRB, we published an outline of the study, available for public viewing, on the Aichi Medical University website; this also gave patients the opportunity to decline participation. None of the patients declined participation. Personal identifiers were removed from the records prior to data analyses.

A diagnosis of TED was the presence of at least one of the characteristic eyelid signs (eyelid fullness, eyelid retraction, and/or eyelid lag) as well as the presence of thyroid autoimmunity [21]. The inferior rectus muscle enlarged without muscle tendon involvement in all patients, which also supported the diagnosis of TED [22]. All patients included in the study were controlled as euthyroid at the time of surgery, and were in the static or chronic “burnout” phase of TED. We judged the condition of each patient’s disease using the clinical activity score (CAS) [23], as well as by the presence or absence of inflammation in the extraocular muscles, as revealed by magnetic resonance imaging (MRI). The CAS was calculated using seven parameters: retrobulbar discomfort, pain on eye movement, eyelid erythema, eyelid swelling, conjunctival injection, chemosis, and swollen caruncle [23]. When the patient had a CAS of less than three points, their TED was defined as being in the static or chronic “burnout” phase [23].

The exclusion criteria were a history of strabismus surgery, temporal IR muscle transposition, missing clinical data, and a follow-up time of < 3 months. We also excluded patients who had an intracranial lesion revealed on MRI and those with concomitant neuro-ophthalmologic disorder(s). We could not statistically evaluate the influence of the history of orbital decompression surgery on excyclotropia correction, because only one patient had applicable data. For this reason, we excluded this patient from this study.

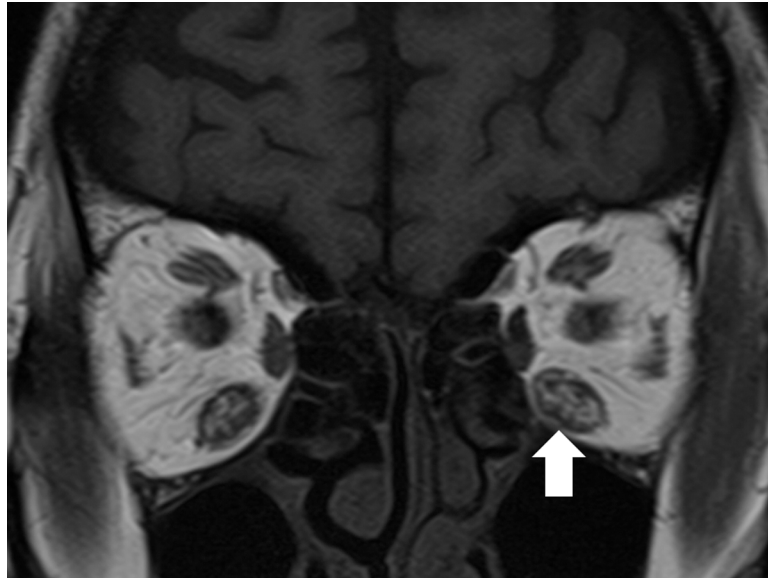
## Data Collection

The following data were collected: age, sex, CAS, surgical side, MRI findings, smoking status, history of orbital radiotherapy, amounts of nasal IR muscle transposition and IR muscle recession, preoperative and postoperative angles of ocular deviation, and preoperative and postoperative binocular single vision fields.

## Magnetic Resonance Imaging

MRI was performed using a 1.5-Tesla scanner (Magnetom Abant™; Siemens Healthcare, Erlangen, Germany), with the patients in the supine position. Coronal T1- and T2-weighted gradient-echo sequences were acquired (T1—repetition time: 500 ms, echo time: 10 ms, field of view: 140 × 140 mm, matrix: 256 × 220, section thickness: 3 mm with a 0.6 mm gap between slices; T2—repetition time: 4000 ms, echo time: 100 ms, all other parameters were the same as in T1). Patients were asked to look at a light source to ensure their eyes were fixed in the primary position.

The IR muscle cross-sectional area at the largest point was measured on a T1-weighted MRI image by one of the authors (Y.T.), using the measuring tool available in the MRI viewer (ShadeQuest/ViewR™; Yokogawa Medical Solutions Corporation, Tokyo, Japan). The same author



**Fig 1. Internal bright signal in the inferior rectus muscle.** A high intensity area in the inferior rectus muscle is measured on a T1-weighted coronal magnetic resonance image (arrow).

doi:10.1371/journal.pone.0159562.g001

also examined the internal bright-signal in the IR muscle, which reflects adipose change within the muscle. The high intensity area was measured on a T1-weighted MRI image at the largest IR cross-sectional area, using the aforementioned measuring tool (Fig 1). We calculated the percentage internal bright-signal area at the largest IR muscle thickness as follows: the internal bright-signal area/the largest IR muscle thickness  $\times$  100.

### Smoking Status

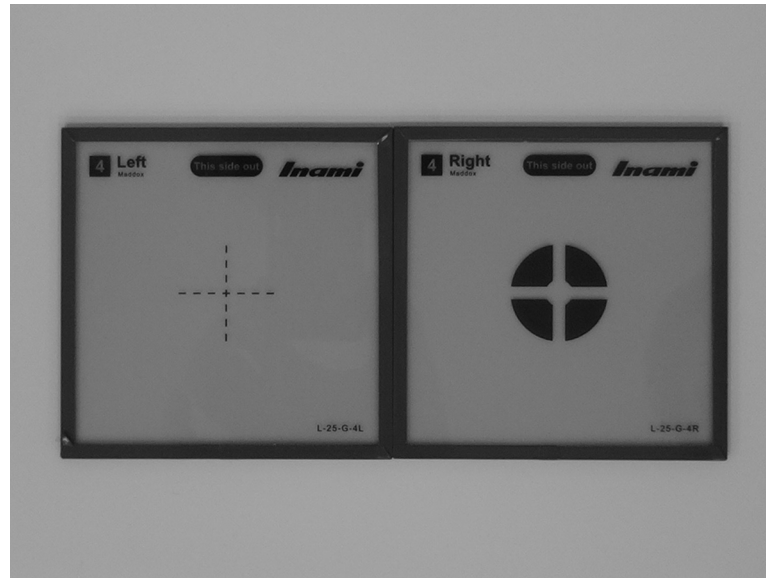
We asked all patients the number of cigarettes they smoked per day. All smokers were current smokers at the first examination, while all non-smokers had never smoked.

### History of Orbital Radiotherapy

The dose used for orbital radiotherapy was 20 Gy in all treated patients. Previous orbital radiotherapy was expressed using a binary system (a dummy variable; 0 = with no history, 1 = with a history) [24].

### Orthoptic Examination

The angle of ocular deviation was measured using a synoptophore (Clement Clarke International Ltd., Edinburgh, UK) 1 day before surgery and 3 months after surgery. The patient's head was positioned upright, and the instrument set such that the fixating eye was the eye on which surgery was planned. One of two arms of the synoptophore was fixed at 0°. We used two slides: a black circle with a cross-shaped blank and a black cross (L-25G; Inami, Tokyo, Japan) (Fig 2). The black circle slide was fixed in the arm of the fixating eye, and the patient was asked to move the black cross until it was positioned appropriately within the circle. We recorded the angle at which this was achieved.



**Fig 2. Slides for the synoptophore.** A black cross (left) and a black circle with a cross-shaped blank (right) were used.

doi:10.1371/journal.pone.0159562.g002

## Surgical Technique

Surgery was performed under either general or local anesthesia. A perilimbal conjunctival incision, with radial relaxing incisions, was made in the inferior quadrant. A muscle hook was used to secure the IR muscle at its insertion, and the Tenon's capsule around the IR muscle was thoroughly dissected using cotton swabs. As the tendon width varies between individuals [25], the width of the IR muscle tendon was measured at the scleral insertion using a caliper. The IR muscle tendon was secured using locking 8–0 polyglactin sutures at two points (Vicryl<sup>®</sup>; Johnson and Johnson Company, New Brunswick, NJ, USA) 1 mm posterior to the globe insertion, because the tip thickness of the muscle hook was 1 mm. Next, the IR muscle was detached from its insertion. In patients with simple IR muscle recession, the sutures were fixed to the sclera 1 mm posterior to the point that was estimated on the basis of the preoperative ocular deviation angle. Recession of the IR muscle was calculated as follows: 2° of ocular deviation per 1 mm IR muscle recession [8,26]. In patients with both IR muscle recession and nasal IR muscle transposition, we transposed the IR muscle nasally along the spiral of Tillaux; we did so concomitantly with IR muscle recession. The amount of nasal IR muscle transposition was preoperatively calculated based on the preoperative deviation angle and the measurement result of the tendon width as follows: 7° of ocular deviation per one IR muscle tendon width transposition, assuming that the previously reported dose–effect relationship correlated linearly [8]. The IR muscle tendon was additionally fixed to the sclera using 8–0 polyglactin sutures at two to four points to prevent slippage of the IR muscle. Finally, the conjunctiva was closed using 8–0 polyglactin sutures.

## Statistical Analyses

Patient age, IR muscle cross-sectional area, percentage internal bright-signal area at the point of largest IR muscle thickness, and number of cigarettes smoked per day were expressed as means  $\pm$  standard deviations. In patients with simple IR muscle recession, the angle of cyclotropia before surgery was compared with that after surgery using the paired *t*-test. The

correlations among excyclotopia correction, nasal IR muscle transposition, and the aforementioned hypothesized factors were analyzed using stepwise multiple regression analyses. All statistical analyses were performed using SPSS™ version 22 software (IBM Japan, Tokyo, Japan). A *P*-value of < 0.05 was considered statistically significant.

## Results

Thirty-six patients (13 men, 23 women; mean age,  $60.3 \pm 10.4$  years; range, 38–78 years; 17 right eyes, 19 left eyes) were included in this study.

The largest IR muscle cross-sectional area was  $79.8 \pm 21.4$  mm<sup>2</sup> (range, 41.9–136.4 mm<sup>2</sup>). The percentage internal bright-signal area at the point of largest IR muscle thickness was  $22.6\% \pm 22.2\%$  (range, 0%–81.4%). Twenty-five patients (6 men, 19 women) were non-smokers. The mean number of cigarettes smoked per day in smokers was  $3.8 \pm 6.7$  (range, 3–20 cigarettes per day). Orbital irradiation was performed in 14 patients (6 men, 8 women).

The IR muscle was nasally transposed in 25 patients (69.4%), while the remaining 11 patients (30.6%) underwent simple IR muscle recession. Based on clinical evidence, none of the patients developed a slipped IR muscle postoperatively. All patients obtained binocular single vision at the primary position after surgery. Of the 11 patients with simple IR muscle recession, excyclotopia was reduced in 8 patients (72.7%; mean, 2.4°; range, 1°–5°). This reduction was statistically significant (*P* = 0.003). The mean reduction in excyclotopia was 3.0° in three patients with a 1/4 IR muscle tendon width transposition (range, 3°–3°), 4.3° in nine patients with a 1/2 IR muscle tendon width transposition (range, 3°–8°), 8.0° in two patients with a 2/3 IR muscle tendon width transposition (range, 7°–9°), 5.2° in five patients with a 3/4 IR muscle tendon width transposition (range, 2°–8°), and 11.7° in six patients with a one IR muscle tendon width transposition (range, 8°–15°).

A multiple regression formula showed that excyclotopia, amount of nasal IR muscle transposition, and amount of concomitant IR muscle recession were significantly correlated ( $Y_{\text{CORRECTION}} = 8.546X_{\text{TENDON WIDTH}} + 0.405X_{\text{RECESSION}} - 0.908$ ;  $r = 0.844$ ; adjusted  $r^2 = 0.695$ ; *P* < 0.001). The coefficient of the 'X' variable indicated a positive correlation with excyclotopia correction. By a stepwise process, IR muscle thickness, the internal bright-signal area, smoking status, and a history of orbital radiotherapy were removed from the regression model.

## Discussion

In the current study, multiple regression analyses identified a significant relationship among excyclotopia correction, the amount of nasal IR muscle transposition, and the amount of concomitant IR muscle recession in patients with TED. IR muscle thickness, the internal bright-signal area, smoking status, and a history of orbital radiotherapy showed no such correlation.

Correction of the excyclotopia was positively correlated with the amount of the nasal IR muscle transposition. The formula presented in this study will enable clinicians to determine more precisely the amount of nasal IR muscle transposition in patients with excyclotopia of various angles.

Excyclotopia was significantly reduced after a simple IR muscle recession in 8 of 11 patients (72.7%; mean, 2.4°; range, 1°–5°). A previous study demonstrated a similar result; namely, that excyclotopia decreased after simple IR muscle recession in all five patients with TED (range, 4–8 prism diopters) [27]. Taken together, these results indicate that simple IR muscle recession can correct mild excyclotopia in patients with TED. Because fibrous contracture of the IR muscle causes excess excycloduction, IR muscle recession decreases excycloduction [13].

The thickness of the IR muscle, the internal bright-signal within the IR muscle, and smoking status did not correlate with excyclotopia correction, even though these factors are associated

with the severity of fibrotic contracture in the IR muscle [3,18,19]. This indicates that these factors are not predictors of excyclotropia correction.

A history of orbital radiotherapy did not significantly affect the correlation between nasal IR muscle transposition and excyclotropia correction. This was similar to our previous study, which demonstrated no correlation between the effect of IR muscle recession and a history of orbital radiotherapy [18]. Even though orbital radiotherapy leads to orbital fibrosis, it decreases thyroid-related orbital inflammation, which may offset the radiation-induced orbital fibrosis [18].

The coefficient of the tendon width in the regression model was 8.546, and the mean excyclotropia correction in the six patients with one IR muscle tendon width transposition was 11.7°. The excyclotropia correction in this study appeared to be larger than that in the previous study mentioned (7° of excyclotropia correction by nasal transposition per one IR muscle tendon width), although all patients in both studies obtained binocular single vision at the primary position [8]. Differences between the present (surgical eye) and previous studies (non-surgical eye) in terms of the position of the fixing eye during the synoptophore test may account for this discrepancy [8,28]. When the surgical eye is fixed during the synoptophore test, a larger deviation angle may be estimated by Hering's law than when the non-surgical eye is fixed [29].

Inferior oblique muscle weakening surgery can be used for excyclotropia correction [30]. However, nasal transposition of an affected IR muscle is a more reasonable, easier, and more quantitative procedure [30]. In addition, excyclotropia is commonly accompanied by thyroid-associated IR myopathy with fibrotic contracture [2–5], which also causes hypotropia. The combination of nasal transposition and recession of the IR muscle can simultaneously correct excyclotropia and hypotropia.

The main methodological limitation of the present study was its retrospective design. In addition, we included patients with TED who did not have a history of orbital decompression surgery. Orbital decompression surgery causes more restriction of extraocular muscle motility [20]. Therefore, the present regression model cannot be applied to patients with TED who have a history of orbital decompression surgery. Future studies are necessary to determine regression models for such patients.

In conclusion, excyclotropia correction in patients with TED was correlated with the amount of the nasal IR muscle transposition and the amount of concomitant IR muscle recession, but not with IR muscle thickness, internal bright-signal area, smoking status, and a history of orbital radiotherapy.

## Supporting Information

**S1 File. Data analyzed.**  
(XLSX)

## Author Contributions

Conceived and designed the experiments: YT HK. Performed the experiments: YT HK. Analyzed the data: YT YK SN HK. Contributed reagents/materials/analysis tools: YT. Wrote the paper: YT YK SN HM AK HK. Interpretation of data for the work: YT YK HM AK HK. Revising it critically for important intellectual content: YT YK SN HM AK HK. Final approval of the version to be published: YT YK SN HM AK HK. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: YT YK SN HM AK HK.

## References

1. Kimura A. Management of thyroid-associated ophthalmopathy: strabismus surgery: Part 2. *Rinsho Ganka* 2013; 67:1630–1636 (Japanese).
2. Nardi M. Eye muscle surgery. In: Wiersinga WM, Kahaly GJ, editors. *Graves' Orbitopathy: A Multidisciplinary Approach*. Basel: Karger; 2007. pp. 176–187.
3. Nardi M. Squint surgery in TED: Hints and fints, or why Graves' patients are difficult patients. *Orbit* 2009; 28:245–250. PMID: [19839883](#)
4. Trobe JD. Cyclodeviation in acquired vertical strabismus. *Arch Ophthalmol* 1984; 102:717–720. PMID: [6721761](#)
5. Caygill WM. Excyclotropia in dysthyroid ophthalmopathy. *Am J Ophthalmol* 1972; 73:437–441. PMID: [5013251](#)
6. Chen VM, Dagi LR. Ocular misalignment in Graves' disease may mimic that of superior oblique palsy. *J Neuro-Ophthalmol* 2008; 28:302–304.
7. Woo SJ, Seo JM, Hwang JM. Clinical characteristics of cyclodeviation. *Eye* 2005; 19:873–878. PMID: [15731772](#)
8. Kimura A. Management of thyroid associated ophthalmopathy: strabismus surgery: Part 1. *Rinsho Ganka* 2013; 67:1452–1457 (Japanese).
9. Kushner BJ. Torsion and pattern strabismus: Potential conflicts in treatment. *JAMA Ophthalmol* 2013; 131:190–193. doi: [10.1001/2013.jamaophthalmol.199](#) PMID: [23411884](#)
10. von Noorden GK, Chu MW. Surgical treatment options in cyclotropia. *J Pediatr Ophthalmol Strabismus* 1990; 27:291–293. PMID: [2086744](#)
11. Nassar MM, Dickinson AJ, Neoh C, Powell C, Buck D, Galal E, et al. Parameters predicting outcomes of strabismus surgery in the management of Graves' ophthalmopathy. *J AAPOS* 2009; 13:236–240. doi: [10.1016/j.jaapos.2008.11.007](#) PMID: [19395292](#)
12. Peragallo JH, Velez FG, Demer JL, Pineles SL. Postoperative drift in patients with thyroid ophthalmopathy undergoing unilateral inferior rectus muscle recession. *Strabismus* 2013; 21:23–28. doi: [10.3109/09273972.2012.762533](#) PMID: [23477773](#)
13. Jellema HM, Saeed P, Everhard-Halm Y, Prick L, Mourits M. Bilateral inferior rectus muscle recession in patients with Graves' orbitopathy: Is it effective? *Ophthalm Plast Reconstr Surg* 2012; 28:268–272. doi: [10.1097/IOP.0b013e3182565c26](#) PMID: [22689133](#)
14. De Hoog J, Stravers S, Kalmann R. Recession of the inferior rectus muscle in Graves' orbitopathy. *Eye* 2010; 24:1011–1017. doi: [10.1038/eye.2009.267](#) PMID: [19911020](#)
15. Pitz S, Esch A, Müller-Forell WS, Kahaly G, Mann W, Pfeiffer N. Is there a relationship between the degree of preoperative motility impairment of the muscle thickness and the outcome of strabismus surgery in patients with Graves' orbitopathy after decompression surgery? *Orbit* 2005; 24:173–176. PMID: [16169802](#)
16. Yoo SH, Pineles SL, Goldberg RA, Velez FG. Rectus muscle resection in Graves' ophthalmopathy. *J AAPOS* 2013; 17:9–15. doi: [10.1016/j.jaapos.2012.09.018](#) PMID: [23352720](#)
17. Mourits MP, Koorneef L, van Mourik-Noordenbos AM, van der Meulen-Schot HM, Prummel MF, Wiersinga WM, et al. Extraocular muscle surgery for Graves' ophthalmopathy: does prior treatment influence surgical outcome? *Br J Ophthalmol* 1990; 74:481–483. PMID: [2390524](#)
18. Takahashi Y, Kakizaki H. Predictors of the dose-effect relationship regarding unilateral inferior rectus muscle recession in patients with thyroid eye disease. *Int J Endocrinol* 2015; 2015:703671. doi: [10.1155/2015/703671](#) PMID: [26221140](#)
19. Prendiville P, Chopra M, Gauderman WJ, Feldon SE. The role of restricted motility in determining outcomes for vertical strabismus surgery in Graves' ophthalmopathy. *Ophthalmology* 2000; 107:545–549. PMID: [10711893](#)
20. Gilbert J, Dailey RA, Christensen LE. Characteristics and outcomes of strabismus surgery after orbital decompression surgery. *J AAPOS* 2005; 9:26–30. PMID: [15729277](#)
21. Mourits MP. Diagnosis and differential diagnosis of Grave's orbitopathy. In: Wiersinga MM, Kahaly GJ, editors. *Grave's Orbitopathy: A Multidisciplinary Approach*. Basel: Karger; 2007. pp. 66–77.
22. Kahaly GJ. Imaging in thyroid-associated orbitopathy. *Eur J Endocrinol* 2001; 145:107–118. PMID: [11454505](#)
23. Mourits MP, Koorneef L, Wiersinga WM, Prummel MF, Berghout A, van der Gaag R. Clinical criteria for the assessment of disease activity in Grave's ophthalmopathy: a novel approach. *Br J Ophthalmol* 1989; 73:639–644. PMID: [2765444](#)



24. Skrivaneck S. The use of dummy variables in regression analysis. Available: <https://www.moresteam.com/whitepapers/download/dummy-variables.pdf>.
25. Dutton JJ. Extraocular muscles. In: Dutton JJ, editor. Atlas of Clinical and Surgical Orbital Anatomy. 2nd edition. Philadelphia: Elsevier Saunders; 2011. pp. 29–49.
26. Schittkowski M, Fichter N, Guthoff R. Strabismus surgery in Graves' disease: dose-effect relationships and functional results. *Klin Monbl Augenheilkd* 2004; 221:941–947. PMID: [15562358](#)
27. Köse S, Üretmen Ö, Emre S, Pamukcu K. Recession of the inferior rectus muscle under topical anesthesia in thyroid ophthalmopathy. *J Pediatr Ophthalmol Strabismus* 2002; 39:331–335. PMID: [12458843](#)
28. Kubota M, Kimura A, Meguro C, Mahara C, Sano N, Tanaka M, et al. Examination of the measurements of vertical and cyclo deviations in the patients who have vertical or cyclo strabismus. *Japanese Orthoptic Journal* 2008; 37:91–94 (Japanese).
29. von Noorden GK, Campos EC. Physiology of the ocular movements. In: von Noorden GK, Campos EC, editors. *Binocular Vision and Ocular Motility: Theory and Management of Strabismus*. 6th edition. St. Louis: Mosby; 2002. pp. 52–84.
30. Okamoto M, Kimura A, Masuda A, Mimura O. Surgical effects of nasal transposition of inferior rectus muscle: 135 cases of acquired superior oblique palsy. *Clin Ophthalmol* 2015; 9:691–695. doi: [10.2147/OPHTH.S79482](#) PMID: [25945030](#)