

Observations about Objective and Subjective Ocular Torsion

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Objective: To investigate the relationship between objective and subjective torsion in patients with cyclovertical strabismus and determine whether objective torsion differs according to which eye is fixing.

Design: A prospective evaluation of tests of objective and subjective torsion.

Participants: Thirty-six patients with various types of cyclovertical strabismus.

Methods: Subjective torsion was assessed with the double Maddox rod, and objective torsion was graded in a masked manner from fundus photographs.

Main Outcome Measures: Quantification of objective or subjective torsion.

Results: Objective torsion was the same regardless of which eye was used for fixation. However, after prolonged occlusion of the nonaffected eye, there was often an increase in objective torsion in the nonaffected eye. Subjective torsion typically was absent in patients with objective torsion if they did not have bifoveal fusion but was similar to objective torsion in patients with bifoveal fusional potential.

Conclusions: Assessment of objective and subjective torsion are each important but play separate roles in the evaluation of cyclovertical strabismus. There is no immediate torsional motor shift when fixation switches from the nonaffected to the affected eye. However, prolonged fixation of the affected eye may possibly result in a motor torsional change in the nonaffected eye in some patients.

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The cyclovertical muscles have the 3-fold actions of vertical, horizontal, or torsional rotation of the eyes.¹ The oblique muscles have a greater torsional component than the rectus muscles; however, particularly when associated with restrictions as occurs in Graves' orbitopathy or orbital fractures, the rectus muscles can contribute substantially to torsion.^{2,3} Proper interpretation of the findings of ocular torsion can be helpful in understanding the mechanism responsible for complex vertical strabismus and can be essential to its management.^{2,4,5}

Ocular torsion can be measured objectively or subjectively, and the 2 methods often do not produce interchangeable results.⁴ Subjective torsion involves the patient's perception of tilting of an image and is classically tested with the double Maddox rod test.⁵ Objective torsion assessment involves determining whether the fundus is anatomically rotated from its normal position by using either indirect ophthalmoscopy or fundus photography.^{2,4–6} Although it can be clinically useful to assess both objective and subjective torsion, there are currently no studies that quantitatively compare the relative usefulness of one with the other in different clinical settings. Prior studies indicate that the results of the 2 assessments are often contradictory, which is consistent with our experience.^{4,5} For example, it is common for there to be objective torsion in a patient with childhood-onset horizontal strabismus associated with an A or V pattern and oblique muscle dysfunction, yet these patients typically have no subjective torsion. There have been reports of patients with unilateral superior oblique muscle palsy who consistently only localize the subjective torsion to the unaffected

eye, because they fixate with the paretic eye, yet they only have objective torsion in the paretic eye.^{4,7} We have observed similar patients, some of whom are described in this article. However, we have also less commonly observed patients who have unilateral superior oblique muscle palsy according to all of the usual diagnostic criteria^{8–10} and who fixate with the paretic eye because of uncorrected anisometropia or amblyopia in the fellow eye. They not only localize the subjective extorsion to the nonparetic eye but also have objective extorsion limited to that eye. This study investigates both objective and subjective ocular torsion in different clinical settings to determine how these 2 findings relate to one another and how they should be interpreted.

Subjects and Methods

This is a prospective study consisting of consecutive patients who met the criteria for at least 1 of 3 different investigations of ocular torsion, each of which had different inclusion criteria as described below. One study investigated if objective torsion was different depending on which eye was fixating, the second study compared the findings of objective and subjective torsion in patients with different strabismic conditions, and the third study looked at changes in objective and subjective torsion after strabismus surgery.

Dissociated vertical divergence was an exclusion criteria for all 3 investigations, because it is often associated with a rotary component that may change with occlusion, which would make torsional measurements variable.^{11–13} If a patient met the respective criteria, the only other causes for exclusion were lack of suffi-

cient cooperation for the measurements required or a refusal to participate.

Subjective testing with the double Maddox rod was performed using white and red Maddox rods that were scored to permit accurate determination of their position in the trial frame. The test was conducted in very dim room illumination. Past research demonstrates that approximately 83% of patients will subjectively localize torsion to the eye viewing through the red lens regardless of which eye is paretic.¹⁴ This artifact is thought to occur because horizontal room contours are more easily seen through the white Maddox rod, even in dim lighting. This is a different phenomenon than the adaptive psychologic phenomenon of righting images seen under monocular conditions. Consequently, we always placed the white lens over the nonparetic eye if only 1 eye was paretic and had the patient orient the white lens first so he or she perceived the white line as being horizontal. In cases of bilateral paresis or restriction, or cases of primary bilateral oblique muscle overaction, the white lens was placed before the habitually fixating eye. For each patient, a total of 6 measurements of subjective torsion were made, 3 in which the line made by the red Maddox rod was rotated slowly toward the orientation of the line made by the white Maddox rod from a counterclockwise direction and 3 coming from a clockwise direction under binocular conditions. The 6 readings were each read to the nearest degree and were averaged for data analysis. This technique has been described in detail and shown to be accurate and reproducible to within 2 degrees.¹⁵ Thus, if any of the 6 readings differed from the mean by more than 2 degrees, the subject was considered unreliable and was excluded.

Fundus photographs were obtained with a digital Topcon fundus camera using either internal or external fixation, depending on the particular study being conducted. For internal fixation, the subject fixated on the internal fixation device in the camera with the eye being photographed. For external fixation, the subject was asked to look at a fixation target with the eye that was not being studied held near the photographer's ear. Thus, fixation was always at or near the primary position. To prevent inadvertent head tilting, care was taken to ensure the subject's right and left lateral canthi were level with the alignment marks on the frame of the chin rest of the camera; a bite bar was not used. For the photographs that were taken with 1 eye patched as described below, the lateral canthus was identified with a skin-marking pen before occlusion, with the line extending far enough laterally that it was not completely covered by the patch. The digital images were exported to the principal investigator's computer for grading. For most photography sessions, both the right and left eyes were photographed. However, in a few instances, a postoperative photograph may have been taken of 1 eye only if the patient had undergone unilateral surgery.

Guyton^{4,16,17} reworked the data published by Bixenman and von Noorden⁶ and confirmed the simplification he had formulated from earlier experience, that in normal subjects the fovea is level within the lower one third of the optic disc. Thus, 2 imaginary lines, 1 tangent with the bottom of the optic nerve and the other parallel to that line but through the junction of the lower third and middle third of the optic nerve, would represent the boundaries for the position of the fovea with respect to torsion when viewed on a non-inverted anatomically correct photograph (e.g., 12 o'clock retina is at the top). If the fovea is above the normal range, the eye is objectively intorted; if the fovea is below that, the eye is objectively extorted (Fig 1). This classification allows for a normal torsional range of approximately 9 degrees in most eyes.⁴ Thus, if a patient initially had his/her fovea near the border for extorsion (level with the bottom of the optic nerve) and then developed up to 9 degrees of intorsion of that eye, the fovea would be just at the limit of normal for intorsion and could still be considered normal. Consequently, because the starting point for any particular patient

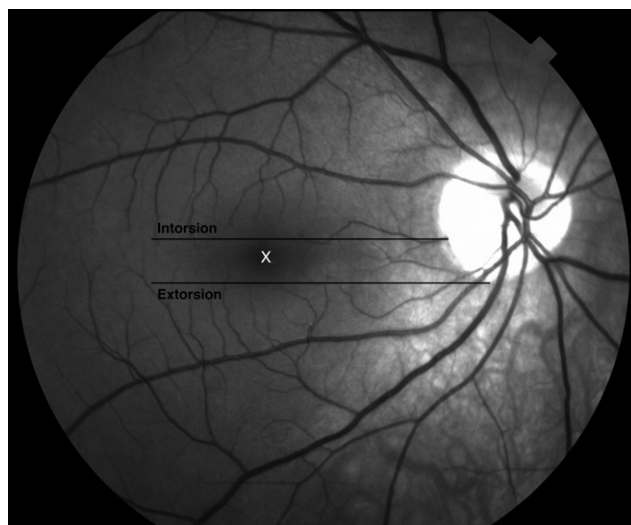


Figure 1. The normal position of the fovea lies level with the lower one third of the optic disc, as demarcated by these 2 lines. The eye is intorted if the fovea is above the upper line and extorted if it is below the lower line. This allows for a range of approximately 9 degrees for normal.

is typically not known, one would not expect there to be a 1-to-1 correlation between objective and subjective torsion with respect to degrees of rotation.

Photographs were graded by placing an acetate template over the computer screen (Fig 2A). The template had tic marks 1 degree apart on vertical and horizontal lines to help position it over the bottom of the optic disc with proper centration from right to left. It also had leveling lines to ensure it was not inadvertently rotated. Lines spaced 5 degrees apart radiated from the centration point, and between them shorter tic marks were spaced 1 degree apart. The fovea was identified, and the cursor of the computer was placed at its center to ensure accurate location. For photographs that are reproduced in the article, we digitally superimposed an "X" over the location of the fovea to facilitate interpretation. The position of the fovea was recorded both with respect to a +1 to +4 grading system and with respect to a specific number of degrees above or below the bottom of the disk. The fovea was graded as having a trace of extorsion if it lay on the border for extorsion, as +1 if it was below the border and up to or at 5 degrees, +2 if it was from 6 to 10 degrees, +3 if it was from 11 to 15 degrees, and +4 if it was more than 15 degrees. If the fovea was from 1 to 9 degrees or more above the bottom of the disk, it was graded as "no torsion"; however, the actual number of degrees of rotation from the horizontal was recorded. If it was more than 9 degrees above the bottom of the disk, the eye was considered intorted. In this situation, the template was repositioned so the centration point was at the junction of the lower and middle of the disk, and the grade of intorsion was measured using a 1 to 4-point scale that was a mirror image of that used for extorsion (Fig 2B). This grading system is a modification of that used clinically by Guyton.⁴ He based the difference between grades of torsion on clinical estimates of fractions of the disk diameter, whereas our system was based on accurately measuring degrees of rotation. Although Guyton's system may be more useful in a clinical setting, ours allows for more quantitative readings for research purposes. All fundus images in this study are presented in the normal upright position, contrary to the indirect ophthalmoscopic view (inverted and reversed) as preferred by Guyton.⁴ To assess interobserver reliability and reproducibility, all photographs were graded independently by both authors who were masked at the time to the patients' identi-

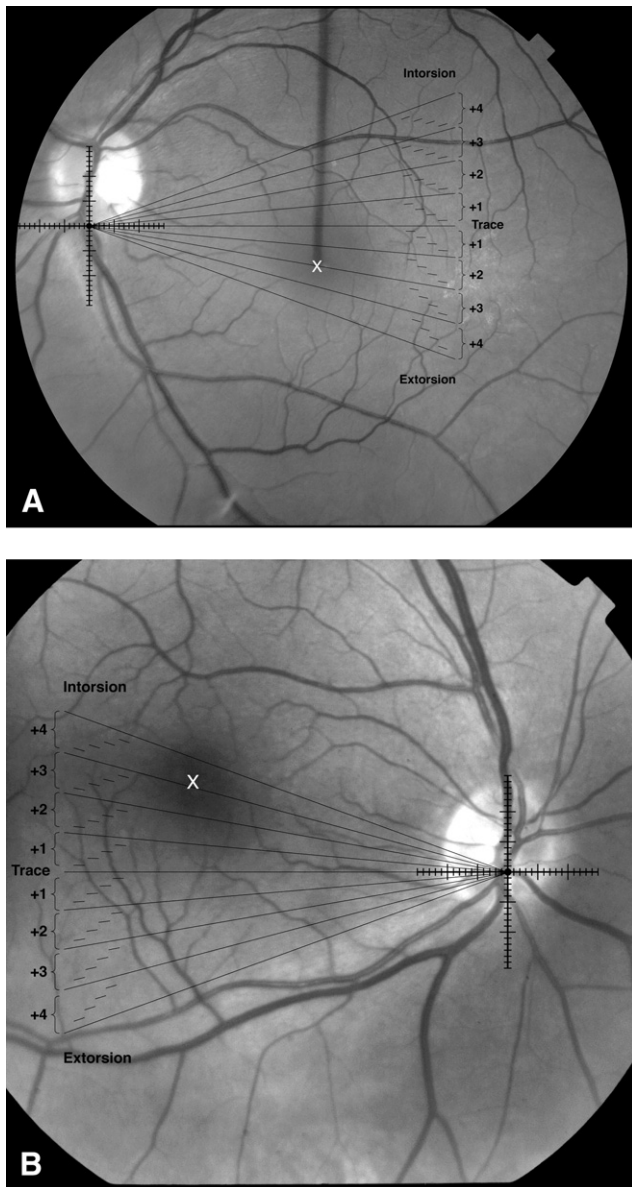


Figure 2. A, This left eye shows +2 extorsion photographed with internal fixation. The fovea is 10 degrees below the bottom of the optic disc. The template for measuring an eye with extorsion is “zeroed” at the bottom of the optic disc. B, This right eye shows +4 intorsion photographed with external fixation. The fovea is 16 degrees above the junction of the lower and middle third of the optic disc. Thus, the template for measuring intorsion is “zeroed” at the junction of the lower two thirds of the optic disc.

ties and clinical conditions. An average of the 2 readings were used for data analysis. In addition, 6 photographs (3 with intorsion and 3 with extorsion) were read on 2 different occasions by each of the 2 readers, who at the time were similarly masked.

Motility testing was done with the appropriate optical correction in place and consisted of the prism and alternating cover test measurements at 6 m in the 9 diagnostic fields of gaze, as well as with head tilt right and left. When appropriate, the diagnosis of unilateral superior oblique muscle palsy was made using the 3-step test but also included the absence of dissociated vertical divergence and of a reversal of the hypertropia in any of the oblique

fields or on head tilt.^{9,10} Recent studies have suggested that many patients thought to have superior oblique muscle palsy by the usual criteria may instead have either pulley heterotopia¹⁸ or a disorder of the vergence adaptation mechanism¹⁹ that may mimic superior oblique muscle palsy. For the purposes of this article, we will refer to patients as having a superior oblique muscle palsy if they meet the aforementioned diagnostic criteria. Similarly, if an apparent superior oblique muscle palsy was in fact caused by pulley heterotopia or a disorder of the vergence adaptation mechanism, then both eyes could be considered “affected,” even though common diagnostic criteria would suggest a unilateral problem. In this article, we will refer to the eye that has a hypertropia that increases in adduction and on ipsilateral head tilt, associated with an excyclotropia, as being the “paretic” or “affected” eye, even though those terms may represent a simplification. In the cases of restrictive strabismus, we refer to the eye with the restriction as the affected eye or the restricted eye. All patients diagnosed with unilateral superior oblique muscle palsy underwent surgery consisting of an ipsilateral inferior oblique recession or an ipsilateral inferior oblique recession combined with a contralateral inferior rectus recession, and none showed signs of having had a bilateral masked superior oblique muscle palsy by 6 months after surgery.

We realize that most patients with strabismus will have at least some limited degree of binocularity or peripheral fusion when tested with sufficiently dissociating methods; few actually have no fusion at all.²⁰ For simplicity we will use the term “no fusion” if a patient is not diplopic in free space, has suppression with the Worth 4-dot test at 6 and at 1/3 m, and has no stereopsis.

Investigation 1: Objective Torsion Fixating with the Affected versus Nonaffected Eye

Consecutive patients with an acquired vertical strabismus or decompensated presumed congenital superior oblique muscle palsy with vertical and torsional diplopia underwent fundus photography to assess if objective torsion was the same with either eye fixing. First, the right and left eyes (in random order) were photographed with the eye being studied used for fixation (internal camera fixation). Afterward the photographs were repeated with the camera’s internal fixation device removed from view, and the eye that was not being photographed fixated on an external target (external fixation). In select patients with unilateral torsional problems, the nonaffected eye was then patched for 45 minutes to 1 hour. Fundus photographs of the affected eye were then repeated before removal of the patch from the nonaffected eye. Afterward, the fellow eye was unpatched and similarly photographed.

Investigation 2: Comparison of Objective and Subjective Torsion in Patients with and without Fusion

This investigation consists of measuring objective and subjective torsion in the aforementioned manner in 3 different groups of patients. One consisted of patients with esotropia or exotropia associated with A or V patterns and appropriate oblique muscle dysfunction (superior oblique overaction for A patterns and inferior oblique overaction for V patterns), who did not have fusion. The second group consisted of patients with intermittent exotropia with either A or V patterns and appropriate oblique muscle dysfunction, who had intermittent bifoveal fusion and intermittent suppression. The third group had bifoveal fusion potential with intermittent vertical and torsional diplopia secondary to strabismus acquired in adulthood or from decompensation of presumed congenital superior oblique muscle palsy. For this investigation the internal fixation device was used generally for fundus photography.

Investigation 3: Comparison of Change in Objective and Subjective Torsion after Surgery

This investigation consists of measuring objective and subjective torsion in patients before and after surgery to correct for torsional diplopia or oblique muscle dysfunction without diplopia. Outcome testing for this subset of patients was approximately 6 weeks after surgery.

Some patients were included in more than 1 investigation. This study was approved by the institutional review board of the University of Wisconsin and was compliant with the Health Insurance Portability and Accountability Act.

Results

The study comprised 36 patients, the clinical characteristics of whom are in Table 1. Fourteen of the 36 patients were studied before and after surgery for a total of 50 measurement sessions. In all cases, the measurements made by the 2 different graders were within 2 degrees of agreement, and in 86% they were within 1 degree. Similarly, the 2 separate readings of each of the 6 photos that were read twice by each examiner were always within 2 degrees of agreement. With respect to the 4-point grading system of torsion, 82% of the time the 2 readers agreed exactly. The remaining 18% were instances in which the fovea was within 1 degree of the border between grades, and in those cases the examiners disagreed by only 1 point on the grading scale. Of the patients with A or V patterns with oblique dysfunction, the majority had the fundus torsion of the expected type. A patterns with superior oblique overaction typically had fundus intorsion, and V patterns with inferior oblique overaction typically had fundus extorsion. A few in each of these 2 groups, however, were graded as having no fundus torsion. In all cases, the fovea was within a few degrees of the border for the type of torsion expected with the pattern manifested. Similarly, 1 patient with a superior oblique

muscle palsy had a 5-degree subjective excyclotropia. Although the fovea was in the normal range, it was only 2 degrees from the border for extorsion. One patient had a superior oblique muscle palsy with an ipsilateral superior rectus muscle contracture.^{21,22} She had no torsion either objectively or subjectively. Presumably the tight superior rectus muscle negated the excyclotropia that would have occurred if the superior oblique muscle palsy had been in isolation.

Results for Investigation 1: Objective Torsion Fixating with the Affected versus Nonaffected Eye

This investigation consists of 14 patients. Eight patients had symptomatic extorsion, 5 secondary to superior oblique muscle palsy and 3 secondary to restriction. Two of the patients with restriction had Graves' orbitopathy, and 1 patient had muscle entrapment after orbital fracture. All 14 patients were found to have 40 seconds of stereopsis when tested with their eyes aligned, usually requiring the use of a compensatory head posture. In some cases, this determination was made after extraocular muscle surgery. Two patients had symptomatic intorsion, 1 secondary to the superior oblique tendon incarceration syndrome²³ and 1 secondary to Graves' orbitopathy. An additional 4 patients did not have fusion, 2 of whom had V pattern esotropia with bilateral inferior oblique overaction and 2 of whom had A pattern exotropia with bilateral superior oblique overaction. These 4 patients had no stereopsis. For this investigation and those reported below, we considered a change of 2 degrees as being the smallest necessary to consider torsion to be clinically significantly different, on the basis of our data regarding the accuracy of our grading system. None of the eyes tested showed a clinically significant difference in objective torsion between the photographs taken when either eye being photographed or the contralateral eye was used for fixation (internal vs. external fixation; Fig 3). Thus there does not appear to be an immediate motor torsional change when fixation changes from the eye being evaluated to the fellow eye. In the 9 patients with symptomatic torsion secondary to a unilateral paretic or restrictive strabismus (all 8 with symptomatic extorsion and the 1 with intorsion secondary to the superior oblique tendon incarceration syndrome), fundus photographs were repeated after the nonaffected eye was occluded for 45 to 60 minutes. Four of the patients showed no change in the fundus torsion of the affected eye after occlusion. However, in 5 patients (4 with superior oblique muscle palsy and 1 with the superior oblique tendon incarceration syndrome) there was a torsional correction movement in the affected eye in the form of an incyclorotation if the eye had been excyclotorted, or an excyclorotation if the eye had been incyclotorted, after monocular occlusion of the fellow eye. This correctional rotation ranged from 4 to 11 degrees (Fig 3). The behavior of the occluded, nonaffected eye was inconsistent in these patients. In 1 of the patients with superior oblique muscle palsy, there was no change in the fundus torsion in the nonparetic eye despite there being a 5-degree correctional incyclorotation of the paretic eye. In 2 of the patients with superior oblique muscle palsy, the eyes showed a cyclovergence movement. The paretic eye showed an incyclorotation when the nonparetic eye excyclorotated, and in both cases the cyclorotation of the nonparetic eye was of a smaller amount than that seen in the paretic eye. In the remaining patient with superior oblique muscle palsy and the 1 patient with the superior oblique tendon incarceration syndrome, the eyes made a cyclovergence movement. Both eyes incyclorotated in the patient with a superior oblique muscle palsy and both eyes excyclorotated in the patient with the superior oblique tendon incarceration syndrome. Why some patients made a cyclovergence and others made a cyclovergence movement cannot be determined from this small subset of patients. Of the 5 patients, 4 had bifoveal fusion when

Table 1. Patient Characteristics

Motility	Studied	
	N	Preoperatively and Postoperatively, N
No fusion		
V pattern with inferior oblique overaction	6	2
A pattern with superior oblique overaction	5	2
Intermittent bifoveal fusion (intermittent exotropia)		
V pattern with inferior oblique overaction	4	1
A pattern with superior oblique overaction	2	1
Bifoveal fusion potential with excyclotropia		
Fourth nerve palsy	9	4
Graves' orbitopathy	2	1
Orbital fracture	1	
Bifoveal fusion potential with incyclotropia		
Partial third nerve palsy	1	
Graves' orbitopathy	2	1
Superior oblique tendon incarceration syndrome	2	1
Orbital fracture	1	1
Fourth nerve palsy plus ipsilateral superior rectus Contracture resulting in no torsion	1	
Total	36	14



aligned; only the patient with superior oblique tendon incarceration syndrome was constantly tropic and diplopic at the time of testing. He had been tested, however, before his first extraocular muscle surgical procedure and had 40 seconds of stereopsis. In the 4 patients with intermittent bifoveal fusion, unilateral occlusion could theoretically have caused a decay of fusional vergence tonus resulting in a change in horizontal, vertical, or torsional alignment, as has been reported by Hwang and Guyton.²⁴ However, in all 4 patients, the change in the vertical and horizontal deviation after occlusion was only trivial (always < 2 PD vertically or 4 PD horizontally). Thus, it is unlikely that a loss of fusional vergences tonus accounted for the torsional change. This issue could perhaps have been answered had we repeated the experiment after occlusion of the paretic eye. Unfortunately, that was not done.

This investigation suggests that prolonged fixation with a paretic or restricted eye, alternate occlusion, or perhaps even spontaneous alternating fixation may possibly result in an anatomic motor change with respect to torsion shifting the torsion misalignment to the nonparetic or nonrestricted eye. It is outside the scope of this article to investigate the mechanism responsible for this finding, as we are primarily documenting that it can occur.

Results for Investigation 2: Comparison of Objective and Subjective Torsion in Patients with and without Fusion

For this investigation, 36 patients were studied. Of them, 11 had no stereopsis, 6 had intermittent fusion with 40 seconds of stereopsis when aligned but were not diplopic when tropic, and 19 had bifoveal fusion potential as characterized by 40 seconds of stereopsis when aligned and diplopia when tropic.

Eleven patients, 6 with V patterns and 5 with A patterns, comprise the subset in this investigation of patients without fusion. By history, all had a constant esotropia or exotropia acquired in childhood, all had the expected pattern of oblique overaction, and none had stereopsis. Nine patients had objective fundus torsion in the expected direction, and the remaining 2 patients were within 2 degrees of the border for the expected type of torsion. Two patients could not be tested for subjective torsion because of an inability to see the white and red Maddox rod simultaneously because of suppression. The remaining 8 patients reported no subjective torsion with the double Maddox rod test. The eleventh patient reported a small excyclotopia of 3 to 4 degrees (total for both eyes). He had +3 inferior oblique overaction bilaterally and grade +2 fundus extorsion bilaterally. It appears that subjective torsion by itself is not useful in evaluating patients without fusion; however, comparing it with objective torsion may be useful in establishing the onset of a cyclovertebral motility problem.

Four patients with V patterns and 2 patients with A patterns comprise the subset in this investigation of patients with intermittent exotropia and intermittent fusion, and all 6 patients had 40 seconds of stereopsis. In all cases, the history suggested an onset in childhood. Five of the 6 patients showed fundus torsion of the expected type, and the sixth patient was borderline for torsion in

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Figure 3. A, This patient has 15 degrees of subjective intorsion and grade +1 fundus torsion secondary to the superior oblique tendon incarceration syndrome.¹⁶ The fovea lies 12 degrees above the bottom of the optic disc when photographed with internal fixation. B, With external fixation, the fovea is also 12 degrees above the bottom of the optic disc indicating no change in torsion. C, After 60 minutes of occlusion of his left eye, the fovea in the right eye is 1 degree above the bottom of the optic disc, indicating a decrease in the intorsion by 11 degrees.

both eyes. One of the patients with an A pattern exotropia and superior oblique overaction had 4 degrees of subjective intorsion (total for both eyes), and the rest showed no subjective torsion. It appears that subjective torsion by itself is also not useful in evaluating patients with intermittent exotropia and intermittent fusion.

Fourteen patients with excyclotropia and 6 patients with incyclotropia comprise the subset of this investigation of patients with bifoveal fusion and diplopia. When tested in their preferred compensatory head posture, all patients fused, did not have diplopia in free space, and had 40 seconds of stereopsis, but reported subjective torsion with the double Maddox rod test. When tested in the head erect position and after dissociation with a cover test if needed to suspend fusion, they all had vertical and torsional diplopia, with the exception of the previously described patient with superior oblique muscle palsy and ipsilateral superior rectus contracture in whom the 2 problems counteracted one another with respect to torsion. The remaining 13 patients had fundus torsion that was of a similar magnitude and direction as their subjective torsion. Because there is a range of approximately 9 degrees that can still qualify as normal with respect to fundus torsion, no attempt was made to rigorously quantify the comparison of the objective and subjective torsion in these patients. It is impractical to do so because one does not know the starting point for any given patient with respect to fundus torsion.

Results for Investigation 3: Comparison of Change in Objective and Subjective Torsion after Surgery

The 8 eyes in patients without bifoveal fusion who underwent bilateral oblique weakening (4 inferior oblique and 4 superior oblique) had a mean decrease in their respective fundus torsion of 6.5 ± 9 degrees per eye after surgery. They had negligible subjective torsion preoperatively and only had a change in subjective torsion by a mean of 0.8 ± 0.8 degrees in the expected direction after surgery. The difference in the change of objective torsion and subjective torsion was statistically significant ($P < 0.001$; paired t test). This suggests poor correlation between the change in objective and subjective torsion in this patient group. The 4 eyes in patients with intermittent exotropia and intermittent bifoveal fusion who were studied before and after surgery showed a mean decrease in objective fundus torsion by 8.5 ± 1.3 degrees per eye after surgery but only had a change in subjective torsion by a mean of 2.5 ± 0.6 degrees after surgery; they both had no subjective torsion preoperatively. This difference was statistically significant ($P = 0.0023$; paired t test). This also suggests poor correlation between the change in objective and subjective torsion in this patient group.

However, the 8 patients with fusion and diplopia who were studied after surgery showed a strong correlation between the change in objective and subjective torsion after surgery. Some of these patients had bilateral torsional problems and underwent bilateral surgery; however, some with unilateral torsional problems also underwent bilateral surgery. This was most common in patients with unilateral superior oblique muscle palsy, in whom the ipsilateral inferior oblique and contralateral inferior rectus were recessed. Thus, for data analysis in this subset, we used the total amount of subjective torsion (right and left eyes combined) before and after surgery, and used the total change in fundus torsion (right and left eyes combined). We found a mean decrease in subjective torsion of 9.6 ± 2.7 degrees after surgery and a mean decrease in objective torsion of 6.6 ± 1.6 degrees. In each case, the decrease in fundus torsion was somewhat less than the decrease in subjective torsion, and this difference was significant ($P = 0.0201$, paired t test). Nevertheless, the change in objective and subjective torsion in patients with fusion does appear to more closely match than in

patients without fusion or intermittent fusion. This suggests that the surgical correction of symptomatic torsion is partly due to an anatomic realignment with respect to torsion, but also in part to sensory adaptation.

Discussion

The study shows that measuring both objective and subjective torsion can be useful, but the 2 measurements play different roles in assessing patients with complex motility. In some types of patients, there is good correlation between the findings of the 2 tests, and in others there is not. Assessing objective torsion can be helpful in determining whether a motility pattern is caused by oblique muscle dysfunction or vertical rectus muscle restriction or overaction. For example, it has been shown that the V or Y pattern associated with pseudo-inferior oblique overaction or Duane syndrome is in fact not caused by the inferior oblique muscles or associated with fundus extorsion.^{25,26} However, in patients with alphabet patterns who do not have fusion, or have intermittent fusion, testing subjective torsion may not be meaningful. This is similar to Guyton's⁴ observation that patients do not report subjective torsion if their torsional problem developed in childhood. We did have some patients with superior oblique muscle palsy in whom there was documentation that the palsy began early in childhood, yet they had subjective torsion. Perhaps it is the absence of fusion potential that is more important than the age of onset of the torsion that dictates if subjective torsion is present. It is important to keep in mind, however, that assessing fundus torsion may also give misleading information in this setting. In a previous study, Morton and colleagues² found that many patients with A or V pattern did not have the expected finding of fundus torsion. As pointed out by Guyton,¹⁷ many of these can be explained by the 9-degree range that exists for normal individuals, as has been previously discussed. However, this mechanism does not appear to account for all the inconsistencies.

However, the measurement of subjective torsion may indicate if a given patient's torsion needs to be addressed as part of the treatment plan. If a patient has objective torsion, but does not have subjective torsion, one perhaps need not specifically address the torsion if other treatment approaches will correct the motility pattern. For example, an A pattern exotropia with mild superior oblique overaction might be treated with lateral rectus recessions and infraplacement. Even if there is fundus intorsion, as long as there is no subjective intorsion and an absence of fusion, the treatment will likely be successful. This is despite the fact that the rectus muscle infraplacement would, if anything, worsen the intorsion.

We found that there is no immediate motor correction for torsional misalignment when fixation shifts from the normal eye to the contralateral torqued eye, and consequently objective torsion can be studied with either eye fixing. Over time, however, there may be at least a partial motor correction of torsion in some patients when fixation occurs with the affected eye for at least 45 minutes because of occlusion of the nonaffected eye. Why this occurred in some patients

and not others is not clear. Perhaps with a longer period of fixation with the torqued eye, the finding may have occurred in more patients. Our methodology and data do not permit us to determine with certainty that the same partial correction of motor torsion would occur in the fixing eye of a patient with parietic or restricted strabismus if they spontaneously fixated with the affected eye. Our methodology involved complete occlusion of the nonaffected eye that disrupts fusion and is not the same as an idiopathic shift in fixation under binocular conditions. This is of theoretic concern because it has been suggested that prolonged occlusion of the deviating eye in patients with superior oblique muscle palsy can result in an increase in extorsion.²⁷ Our observation, however, that some patients with torsional diplopia may not only localize the torsion subjectively to the normal or less affected contralateral eye but also have most or all of the objective torsion in that eye if they fixate with the more affected eye suggests that a similar response occurs. For example, 1 of the patients in this study presented to us 3 days after closed head trauma due to a motor vehicle accident. She had mild residual amblyopia after prior treatment with a best-corrected visual acuity of 20/30 in her right eye and fixated consistently with her left eye. She had been our patient before her accident and was found to have 40 seconds of stereopsis. She had a small right hypotropia that increased on right gaze and left head tilt. A small V pattern was present, and she had a reversal of the hypertropia in the field of the right superior oblique and on right head tilt. Subjectively she had a total of 18 degrees of excyclotopia, localizing 12 degrees to her right eye and 6 degrees to her left eye. Although we did not photograph her fundi at the initial examination, we noted +2 fundus extorsion in her left eye and a trace of extorsion in her right eye. We diagnosed bilateral asymmetric superior oblique muscle palsies. When we reexamined her 10 weeks later, her prism and cover measurements had not changed substantially. She still had approximately 12 degrees of subjective extorsion in her right eye and 6 degrees in her left eye and trace fundus extorsion in her right eye, but now had no fundus torsion in her more parietic left eye and had borderline objective extorsion of her left eye (Fig 4). By 4 months after her injury, her prism and cover measurements remained unchanged. However, she now showed grade +4 extorsion in her non-fixing, less-parietic right eye and further intorsional rotation of her more parietic fixing left eye (Fig 5). The fact that over this time period there was essentially no change in her prism and cover test measurements in all fields of gaze, and her versions did not change, suggests the change in her torsion was not a function of recovery of the her left superior oblique muscle function or an evolving additional problem, such as an ocular tilt reaction²⁸ or right inferior rectus contracture. We have seen other similar patients who we observed over time after the onset of an acute superior oblique muscle palsy who spontaneously fixated with the palsied eye. We observed that objective and subjective torsion was switched to the nonpalsied eye over an observation period of approximately 6 months. These observations were subsequent to my earlier report on objective torsion.² Consequently, the localization of objective torsion to 1 eye or the other may not be as useful as was previously

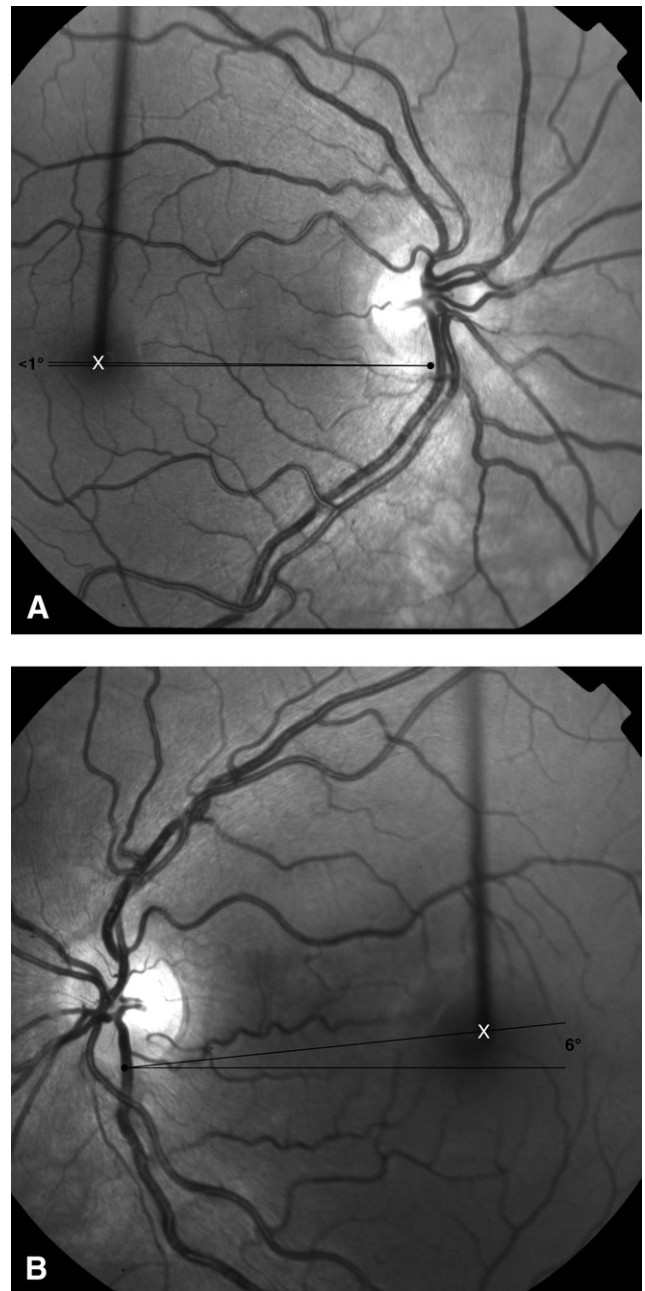


Figure 4. This woman was diagnosed 3 days after closed head trauma as having a bilateral asymmetric fourth nerve palsy, with the left eye more affected. At that time, she was observed to have trace extorsion of the right fundus and +2 extorsion of the left fundus; however, her fundi were not photographed that day. She consistently fixated with her left eye because of mild amblyopia in her right eye. Seen 10 weeks after diagnosis, she still shows borderline extorsion in the right eye (A) and no torsion in her more parietic fixing left eye (B).

thought in sorting out which eye has abnormal muscles. One of the authors (BJK)¹⁰ previously reported that the presence of bilateral fundus torsion was an important sign in diagnosing bilateral masked superior oblique muscle palsy. Although this may be one of several helpful signs, it can be misleading in patients who either alternate fixation or fixate

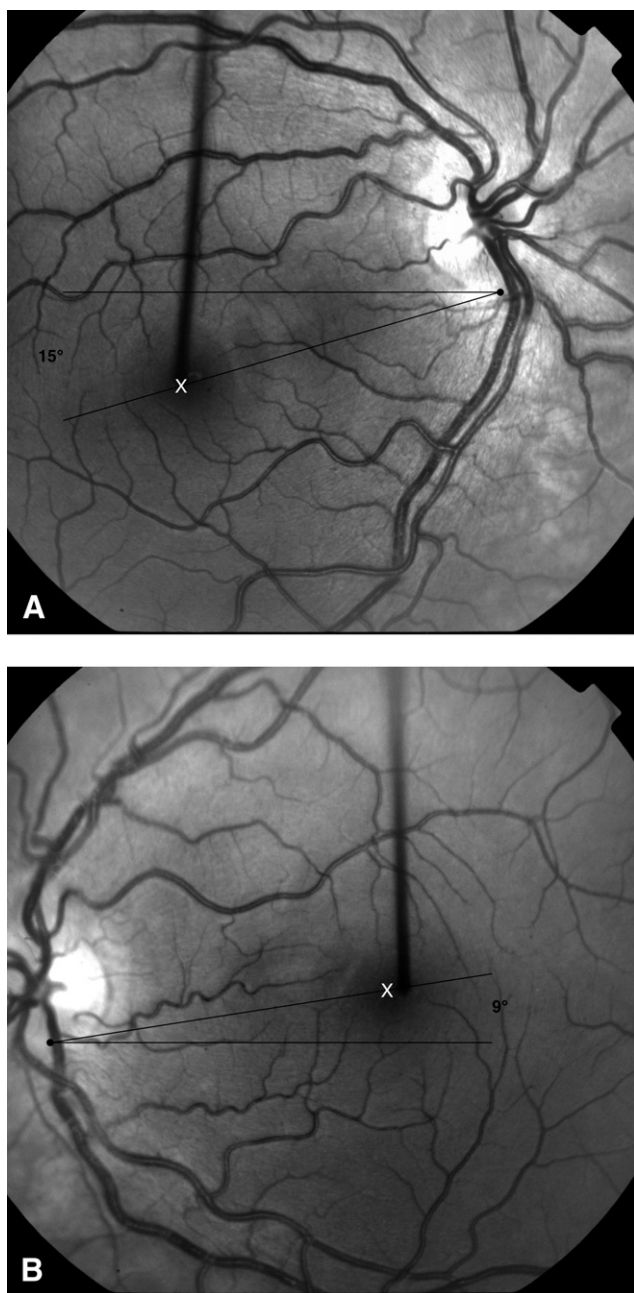


Figure 5. The patient in Figure 4 is shown 4 months after diagnosis. A, There has been an increase in the extorsion of the right fundus, which now measures Grade +4. The total increase in fundus extorsion 10 weeks after diagnosis is approximately 15 degrees. B, There has been further intorsional rotation of 3 degrees of the left fundus, which now shows borderline intorsion. The fovea is now 9 degrees above the bottom of the optic disc compared with 6 degrees, as seen in Figure 4B. Her motility pattern still shows a greater paresis in the left eye with a right hypotropia in most fields of gaze.

with the paretic eye. One possible explanation for this change in objective torsion can be understood from Guyton's¹⁹ theories of muscle length adaptation resulting from vergence adaptation combined with Mudgil and colleagues'²⁹ collaborative investigation of vertical fusional mechanisms.

For example, if a patient with a superior oblique muscle paresis is still able to fuse, and uses the cyclovertical fusion strategy that includes a cyclovergence, the objective extorsion that originally existed in the paretic eye may shift partially or even fully to the nonparetic eye over time. This clearly does not occur in all such individuals, but some may be more susceptible to these mechanisms than others.

When objective fundus torsion is present, it is actually the optic disc that is torsionally rotated with respect to the fovea, which is in its normal anatomic position. We chose to grade fundus torsion according to whether the fovea was above or below its expected normal position with respect to the optic disc for several reasons. Prior studies of fundus torsion have also been based on apparent rotation of the fovea with respect to the optic disc, and we wanted our study to be consistent with established grading systems.^{2,4-6} In addition, when we look for fundus torsion with the indirect ophthalmoscope, it subjectively appears to us as though it is the fovea that is rotated, even though that is not the case. We wanted our grading system to be congruent with this clinical impression. Also, our grid allowed precise location of the junction of the upper two thirds and lower one third of the optic disc because of the tic marks around the centration point. This is an important landmark for grading patients with intorsion. If we used the fovea for centration, the identification of this point on the optic disc would have been less accurate. In reality, the angle measured would be identical regardless of whether we used a point on the optic disc or the fovea as our point of centration.

Study Limitations

Some limitations of this study deserve mention. Although we measured subjective torsion in the manner that is typically used clinically, there are some potential artifacts with this method. Using a white and red Maddox rod, and having the white lens over the nonparetic or less paretic eye will typically indicate no torsion in the eye behind the white lens.¹⁴ This can be misleading in patients with bilateral torsional problems. However, having a patient orient either a red or white lens over a torqued eye under monocular conditions will often indicate no torsion, because patients sensorially right a torqued image in this setting. We considered 2 red Maddox rods, as has been suggested by Simons and coauthors.¹⁴ Although they found this decreased the color dissociation artifact, they found it still occurred, albeit less frequently. This is not surprising. With the Lancaster red-green test,³⁰ whichever eye sees the streak first will tend to perceive it as vertically straight, even if it is the eye with torsion. Our own unpublished experience with using 2 red Maddox rods for testing subjective torsion also found some inaccuracy with lateralization. Although this technique may be preferable to using a white and red Maddox rod, it does not appear to be in widespread use. We believe the technique we used replicates what is done clinically, and thus is useful for our purposes. No specific compensation was made for orbital asymmetry when photographing patients with superior oblique muscle palsy³¹ or

orbital fracture. In theory, this could have introduced some artifact in head positioning during fundus photography. Although we did not quantitatively measure facial asymmetry in our patients, none of them had obvious asymmetry that we noted clinically. However, if facial asymmetry was present in any patients, the identical artifact would have been introduced in all fundus photographs taken of a given patient. Thus, it would have had no impact on changes in torsion that occurred from 1 examination to the next. Finally, we quantified objective torsion with fundus photographs, which breaks up fusion and will not allow for any theoretic effect of cyclovergence. However, in clinical practice we look for fundus torsion with ophthalmoscopy, which also breaks up fusion, and we wanted our study to parallel what is seen clinically.

In conclusion, this study supports prior investigations on the usefulness of assessing torsion both objectively and subjectively, and the concept that each has their role in the motility examination.^{2,4,5} It confirms prior claims that there is better correlation of objective and subjective torsion in patients with bifoveal fusion than those without and that a comparison of objective and subjective torsion can be helpful in determining the onset of a cyclovertical deviation.^{4,5} Subjective torsion is more likely to approximate objective torsion if the deviation developed after visual maturity. If there is objective torsion but no subjective torsion, the deviation probably developed before visual maturity. We have shown that there is no motor correction of torsion because fixation switches between the torqued and non-torqued eye and suggested that in some patients a motor correction may possibly occur in the torqued eye if there is prolonged fixation with that eye. Whether this occurs because of vergence adaptation or other mechanisms is not clear. This phenomenon may make the clinical assessment of objective torsion misleading in patients with torsion if they alternate fixation or habitually fixate with the affected eye.

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