A Modified Method for Measuring Uniocular Fields of Fixation

Reliability in Healthy Subjects and in Patients With Graves Orbitopathy

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Objective: To assess the intraobserver and interobserver reliability of recording uniocular fields of fixation using a modified perimeter technique in healthy subjects and patients with Graves orbitopathy (GO). Patients with restrictive myopathies, particularly GO, require accurate measurement of monocular excursions. These ductions are recorded in 4 to 12 directions of gaze using a perimeter, producing a plot known as a uniocular field of fixation. While 4 direction plots give limited information on vertical muscles, recording 12 directions is time consuming and uncomfortable. This modified technique uses the 6 directions of gaze corresponding to the primary field of action of each muscle.

Methods: A single observer measured modified uniocular fields of fixation in 35 healthy subjects aged 20 to 60 years to establish normal and age-related ranges for all ductions. Fifteen subjects underwent measurement on 5 separate occasions by the same observer to establish intraobserver reproducibility. A second observer independently performed measurements in 10 of the subjects to determine interobserver reproducibility. Reliability was compared with that measured in 29 patients with GO.

Results: The technique was reproducible to within 4° for healthy subjects undergoing assessment by a single observer. When results of 2 observers were compared, the coefficient of repeatability was 7.9°. For subjects with GO, however, maximal variability was 7.8°. For clinical purposes, only a change of 8° or more can be assumed to be significant.

Conclusions: This technique offers advantages for assessing any restrictive myopathy, including GO to within 8°. This level of accuracy is likely to be similar in other centers, and has implications for interpreting GO outcome measures, where 5° was previously taken to represent significant change.


In assessing restricted eye movements in patients, the measurement of monocular excursions (ductions) remains essential. In the clinical setting, ductions are commonly graded using simple scales, eg, −4 to 0 to +4. Such methods are, however, prone to standardization errors and are less suitable for accurate quantification. This is particularly true in Graves orbitopathy (GO), in which quantified motility change is an important outcome measure.1,2 The most common techniques for measuring monocular excursions use an arc or a Goldmann perimeter. Excursions are measured along 4 to 12 directions of gaze to produce a uniocular field of fixation (UFOF).1-3 6 Measuring in all meridians on a perimeter3 is time consuming and tiring and uncomfortable for the patient, and hence potentially inaccurate. Conversely, assessment limited to 4 directions of gaze (0°, 90°, 180°, and 270°)1,6 can be performed rapidly, but interpretation of individual vertical muscles is limited. In particular, small but significant changes in inferior rectus restriction commonly seen in GO may be less apparent if upgaze in abduction is not assessed.

A compromise is to measure in 6 cardinal directions, improving on assessment of individual vertical muscles with little extra time. However, gaze directions chosen previously,3 ie, 0°, 45°, 135°, 180°, 225°, and 315°, still reflect function of more than 1 muscle for 4 of the 6 directions. A more logical approach would therefore be the measurement of UFOF in the 6 directions of gaze that reflect the primary field of action of each of the extraocular muscles. This allows direct association between each measurement and 1 particular muscle in conditions where the action of that particular...
The local ethical committee of the United Newcastle Hospitals Trust, Newcastle upon Tyne, United Kingdom, approved this study. All healthy volunteers and subjects with GO freely gave written informed consent before recruitment, and the authors declare that this research followed the tenets of the Declaration of Helsinki.

TECHNIQUE

Standard Goldmann perimeter charts were premarked with 6 axes (Figure 1). These cardinal axes corresponded to the primary field of action of each muscle as follows: in the right eye, the lateral rectus corresponded to 0°; superior rectus, 67°; inferior oblique, 141°; medial rectus, 180°; superior oblique, 216°; and inferior rectus, 293°. Measurement axes and charts in the left eye mirrored those in the right. The head position on the chin rest was eliminated, and head rotation was minimized. Before testing, foveal light threshold was established by selecting the dimmest, smallest light discernible at the fovea. Commencing with 01e at the dimmest setting, target size was increased before brightness until threshold was established, and this target was then used to measure the whole UFOF. The difference between central and peripheral fixation was clarified to maximize the accuracy of subjective measurements. To plot the UFOF, the patient followed the illuminated target along each of the 6 axes and indicated when central fixation was lost. The observer verified this loss of fixation via the central telescope; if subjective responses were unreliable, the objective measurements of maximal excursions could be taken. In practice, all of the measurements were recorded subjectively in both parts of the study, emphasizing the easiness of the technique.

The excursion of each muscle was measured, based on 12 mm on the Goldmann perimeter charts being equivalent to 10° of excursion. Individual muscle scores were recorded in degrees, as were summed scores from antagonist muscle pairs and scores from all 6 muscles, giving a total movement score per eye. Muscles were always tested in the same order, and each horizontal rectus was checked twice to assess consistency (within 5°). Hence, 7 measurements per eye were recorded for each UFOF. A single observer (H.H.) performed all assessments apart from those used to calculate interobserver reliability.

STUDY A

Normal Excursions

To establish normal ranges for each muscle, the UFOF of the right eye was plotted for 35 healthy volunteers aged 20 to 60 years with no ocular pathology. All measurements were subjective. By calculating the mean and standard deviation for each muscle excursions the foveal light threshold was established by selecting the dimmest, smallest light discernible at the fovea. Commencing with 01e at the dimmest setting, target size was increased before brightness until threshold was established, and this target was then used to measure the whole UFOF. The difference between central and peripheral fixation was clarified to maximize the accuracy of subjective measurements. To plot the UFOF, the patient followed the illuminated target along each of the 6 axes and indicated when central fixation was lost. The observer verified this loss of fixation via the central telescope; if subjective responses were unreliable, the objective measurements of maximal excursions could be taken. In practice, all of the measurements were recorded subjectively in both parts of the study, emphasizing the easiness of the technique.

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Reproducibility

To establish intraobserver reproducibility, 15 healthy subjects underwent testing on 5 different occasions a minimum of 3 hours apart by the same observer (H.H.), who was masked to the previous results. From these data, the mean intertest variation for...
the 5 measurements was calculated. To try to ensure that head position was not a significant source of inaccuracy, the calculations were repeated for antagonist muscle pairs (medial and lateral rectus, superior and inferior rectus, and inferior and superior oblique) and compared with the reproducibility measurements for individual muscles.

To ensure validity in a clinical environment, 2 independent observers (H.H. and S.R.) assessed the right UFOF in a group of 10 healthy subjects on separate occasions. The measurements were analyzed independently (K.W.M.) using the strategy of Bland and Altman.11

### Age-Related Variability

For analysis of age-related variation, these subjects were divided into 10-year age cohorts.

#### STUDY B

In study B, 29 patients with GO were recruited from the combined thyroid eye clinic of a tertiary care referral center. This aspect of the study was not concerned with the influence of the disease and any previous treatments on the UFOF, but rather with ensuring that the method was suitable for all patients with GO regardless of severity or activity. Sequential recruitment ensured that a wide range of severity and activity was indeed represented.

Each subject underwent assessment twice on the same day (a minimum of 1 hour apart) to minimize the chance of any real change in motility, and all measurements were performed subjectively. To reduce the risk of observer bias toward an identical score, several subjects underwent assessment randomly at each session, and no numerical scores were calculated until the second measurements had been taken. The standard deviation was calculated for each muscle in each subject and averaged to establish the mean standard deviation. To compare these data with those of healthy subjects, 2 measurements were randomly chosen from the 5 available for each healthy subject. The analyses of these 2 measurements from healthy subjects were then compared with those from the patients with GO.

#### RESULTS

### STUDY A

#### Normal Excursions

The 35 healthy subjects included 15 men and 20 women (age range, 21-60 years; mean age, 37.7 years). When the UFOF of the right eye was plotted for each subject, there were no significant differences between the men and women, and data were therefore amalgamated. The mean excursion and 95% CI for each muscle are shown in Table 1, together with the mean excursions in different age groups. The mean total motility score per eye was 301.5° (95% CI, 279°-324°).

#### Reproducibility

Fifteen healthy subjects, including 3 men and 12 women (age range, 23-50 years; mean, 32.1 years) underwent measurement on 5 occasions. The mean standard deviation was similar for all individual muscles (Table 2). Based on the greatest degree of variability (mean SD, 1.9°) the intrasubject (single-observer) variability was calculated as 3.7° for a single muscle with 95% confidence. For paired muscle analysis (Table 2), maximum intra-subject variability was 4.5°. Hence for clinical purposes, a change in excursion of 4° in a single muscle or 5° in paired muscles is necessary before it can be deemed to be a significant change.

Ten healthy subjects, including 2 men and 8 women (age range, 23-50 years; mean age, 33.1 years) underwent assessment to analyze interobserver variation. The Bland-Altman strategy was applied, comparing the differences between 2 independent measurements with the average of both. All muscles were analyzed, typified by the example shown in Figure 2 pertaining to the right medial rectus. The mean difference between observers was 0.67°, with 95% confidence limits of −2.22° and 3.56°. The zero difference line lies within these confidence levels, confirming that mean interobserver differences were not significant. There was no evidence of a systematic bias between observers; however, there was considerable variability, the coefficient of repeatability (calculated as 2×SD of the differences) being 7.9°.

#### Age-Related Variability

The number of subjects assessed in each age cohort is shown in Table 1, together with the mean excursion of each muscle. Individual muscle and total (per eye) muscle scores were similar for each age group. No age-related decline was apparent for any muscle. Scattergram analy-

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### Table 1. Mean Excursion of Each Individual Muscle and Total Eye Muscle Score for Healthy Subjects

<table>
<thead>
<tr>
<th>Muscle</th>
<th>20-29 (n = 13)</th>
<th>30-39 (n = 7)</th>
<th>40-49 (n = 8)</th>
<th>50-59 (n = 7)</th>
<th>All Ages, Mean (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superior oblique</td>
<td>47.4</td>
<td>49.7</td>
<td>50.0</td>
<td>47.9</td>
<td>48.5 (41.8-55.2)</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>61.1</td>
<td>62.3</td>
<td>63.4</td>
<td>61.4</td>
<td>61.9 (54.4-69.4)</td>
</tr>
<tr>
<td>Inferior oblique</td>
<td>46.8</td>
<td>43.7</td>
<td>45.1</td>
<td>46.3</td>
<td>45.7 (39.1-52.3)</td>
</tr>
<tr>
<td>Superior rectus</td>
<td>44.6</td>
<td>41.1</td>
<td>40.6</td>
<td>42.9</td>
<td>42.7 (36.1-49.3)</td>
</tr>
<tr>
<td>Lateral rectus</td>
<td>53.0</td>
<td>52.4</td>
<td>51.9</td>
<td>50.3</td>
<td>52.1 (44.7-59.5)</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>50.5</td>
<td>51.0</td>
<td>51.4</td>
<td>49.4</td>
<td>50.6 (45.2-56.1)</td>
</tr>
<tr>
<td>Total Muscle Excursion</td>
<td>303.4</td>
<td>300.2</td>
<td>302.4</td>
<td>298.2</td>
<td>301.5 (279.0-324.0)</td>
</tr>
</tbody>
</table>

Abbreviation: CI, confidence interval.

*Data are given as degrees.
sis of superior rectus excursion vs age suggested a slight trend toward age-related decline (Figure 3), but with one-way analysis of variance, this was not significant ($P = .11$).

**STUDY B**

The 29 patients with GO were aged 31 to 74 years (mean age, 54.0 years). Table 3 summarizes the age, sex, GO severity (maximum category for classification of eye changes), and GO activity (CAS) for each patient. All patients with class V disease also had muscle restriction. There was a wide range of disease activity at the time of assessment; however, most were judged to have active disease, and 17 (59%) had a CAS of at least 3. The disease severity also varied considerably over the group, but 23 (79%) had evidence of restricted motility, and 15 of these (65%) complained of gaze-evoked pain.

Figure 4 and Table 4 compare reproducibility data for healthy subjects with those for patients with GO. As only 2 measurements were available for each patient with GO, only 2 of the 5 available measurements for healthy subjects were randomly chosen to compare these 2 groups (this explains why the standard deviations and CIs that relate to the healthy subjects in Table 4 are not identical to those of the same healthy subjects in Table 2).

The spread of data in the GO group appears to have a wider distribution than in healthy subjects, particularly for 3 of the 6 muscles, although the difference in variance does not achieve significance for any muscle. Analysis of the CI shows that normal variation of measured excursions is larger in patients with GO than in healthy subjects. Therefore, a change of 8° is required to detect statistically significant change in a single muscle in patients with GO.

To ensure that this difference in reproducibility was not age-related variability and was indeed related to GO, the data were further analyzed by dividing the GO group into 2 cohorts with the respective age ranges of 31 to 55 years (14 patients) and 56 to 74 years (15 patients). The mean difference between these cohorts was tested for significance (2-tailed $t$ test) for each muscle and was found to be insignificant in each one (eg, for the medial rectus, mean difference in the cohort aged 31–55 years, $−1.50°$ [SD, $3.52°$]; mean difference in the cohort aged 56–74 years, $−1.27°$ [SD, $3.65°$]; $P = .86$; $df$, 28).

**COMMENT**

We herein present data on the reliability of measuring ocular excursions using a modified method for plotting UFOF. In contrast to previously described techniques, this can give information on all individual muscles, while taking less than 5 minutes per eye to perform. This has allowed us to establish normal ranges for all extraocular muscle excursions, establish the reproducibility of such measurements, and compare the reproducibility of measurements between healthy subjects and patients with GO.
When muscle restriction within the ipsilateral antagonist(s) is the main cause of motility limitation, as for example in GO, then no measurement axis can ever reliably show the action of a single vertical muscle. All axes will be a compromise. This does not, however, invalidate the method for useful sequential assessment. For other patients whose limitation derives solely from the muscle being assessed rather than its antagonist, the axes reflect a single muscle, and it is more logical to use this method than one using 45° axes. Hence this modified technique is suitable for all patients regardless of the origin of their motility restriction and now forms part of routine motility assessment, including that in patients with blowout fractures, mitochondrial cytopathies, and GO.

Ocular excursions may be assessed subjectively or objectively, depending on whether the subject or the observer, respectively, defines the limit of excursion.1,2,3,4,6,8,9,12-15 Objective methods are of the following 2 basic types: those that measure the movement of the limbus or corneal light reflex on maximal excursion using a handheld or a slitlamp-mounted ruler,1,2,9,12 and those that use a handheld or fixed perimeter.1,3,6,8 The former are subject to significant parallax errors and standardization difficulties. Although useful in the clinical setting, they have limitations for accurate assessment of excursions as an outcome measure. Fixed perimeters used objectively are much easier to standardize, but difficulties can still arise when the eyelid obscures the end point of downgaze. Subjective methods eliminate most of these variables, but accuracy depends on foveal fixation being reliably maintained by the subject. This is not always realistic, particularly with discomfort and fatigue; hence a rapid test with few axes is more likely to be reliable. This is particularly pertinent in GO, where gaze-evoked discomfort is common. Excellent reproducibility has been reported.

Table 3. Characteristics of the GO Patient Group (Study B)

<table>
<thead>
<tr>
<th>CAS</th>
<th>I</th>
<th>Ila</th>
<th>IIb</th>
<th>IIc</th>
<th>IIIa</th>
<th>IIIb</th>
<th>IIIc</th>
<th>IVa</th>
<th>IVb</th>
<th>IVc</th>
<th>Va</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>43/F, 74/F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>31/F</td>
<td></td>
<td></td>
<td></td>
<td>70/M</td>
<td>56/F</td>
<td>39/M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>50/M</td>
<td>68/F</td>
<td>58/F</td>
<td></td>
<td>55/F</td>
<td>64/M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>34/F, 40/F</td>
<td>59/F, 73/M</td>
<td>55/F, 73/M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>54/F</td>
<td>31/F, 49/F, 63/M, 56/M, 58/M</td>
<td>45/M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47/M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47/M</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>48/F</td>
</tr>
</tbody>
</table>

Abbreviations: CAS, Clinical Activity Score; F, female; GO, Graves orbitopathy; M, male; NOSPECS, category for classification of eye changes in GO (no signs or symptoms, only signs, soft tissue involvement with symptoms and signs, proptosis, extraocular muscle involvement, corneal involvement, and sight [visual acuity] loss).

*Data are given as years of age/sex.

Figure 4. Scattergram of differences between observers in measurement of muscle excursions for healthy subjects and patients with Graves orbitopathy (GO). Abbreviations of muscles are explained in the legend to Figure 1.
for objective assessment of 4 axes using a perimeter,⁶ and although it seems likely that subjective methods are more accurate in reliable subjects, published comparisons are scarce.¹⁵ The results reported by Mourits et al¹ and Gerling et al⁶ are similar to those reported herein and confirm that perimeter methods are an appropriate way of assessing muscle function for normal clinical assessment and research. Although only subjective results are reported herein, patient inconsistency is readily observed via the central telescope, and the test can then easily be performed objectively.

Minor differences in head position between assessments will reduce the accuracy of any technique, and summed scores from antagonist muscle pairs in healthy subjects were analyzed to assess this. Reproducibility of paired scores was slightly better than summed reproducibility of 2 individual muscle scores, suggesting that head rotation and misalignment are potential sources of inaccuracy, albeit of low magnitude. These findings are similar to those reported by Gerling et al,⁶ who compared total vertical and horizontal ranges with single-muscle ductions. Such errors are minimized by careful positioning of the head, use of a headband, and sequential comparison of the muscle excursion least likely to be affected by pathology before moving on to assess other muscles, eg, repeating medial rectus excursion in GO, where lateral rectus restriction is least common. These errors due to head position are obviated by the total movement score, which offsets the gains and losses of rotation. This is rapidly calculated from the sum of the 6 ductions. Alternatively, the 6 points on the UFOF plot could be used to determine an area score, which would have the same advantages in negating the effects of head misalignment. This study did not, however, evaluate this.

The effect of interobserver variation on results was also analyzed in this study. There was no overall effect, as the mean difference between observers was not significantly different from zero. Nevertheless, there was substantially more interobserver than intraobserver variation. Gerling et al⁶ found no significant difference between interobserver and intraobserver reproducibility and stated that “it is not necessary to insist on the same examiner in follow-up studies.” Our findings do not support this, and in practice we attempt to use the same observer for sequential assessment whenever possible.

The mean horizontal muscle excursions reported herein are similar to those reported previously using objective perimeter techniques.¹⁶ Although no vertical muscle comparisons can be made with other studies, we were unable to demonstrate a significant age-related decline in superior rectus excursion. Chamberlain⁷ examined subjects 94 years and younger and reported progressive decline in elevation throughout life, whereas Clark and Isenberg⁸ examined subjects 84 years and older and noted 0.5% to 1% per year decline in all versions beginning in the third decade, with upgaze the most affected. Similar results have been noted in subjects aged 60 and 70 years or younger, using objective perimeter methods.¹⁶ This phenomenon has been attributed to disuse, a theory supported by the finding that grossly kyphotic elderly patients can show remarkable preservation of elevation.⁶ It is not clear why age-related decline was not noted in this study. The number of older subjects was small; hence, small differences could have been missed, and had a group of subjects much older than 60 years been examined, a decline in versions might have been observed.

The most important result from this study, however, concerns the reliability of the technique in patients with GO, and this was not due to the older age of the subjects with GO. Gerling et al⁶ found the reliability of patients with GO to be marginally better than that of healthy subjects. Using the coefficient of variation, they concluded that for GO, the mean coefficient of variation was 2.3%. Therefore, in 95% of patients, the repeated measurement would be ±4.6% of the original, a total variation of 9.2%. From those data, this equated to a change of 2° to 4.6° for patients with GO depending on the muscle assessed, whereas for healthy subjects it equated to a change of 3.6° to 5.2°. They therefore concluded that for patients with GO, the passive resistance of the orbital tissues had a greater effect on the maximal excursion than the voluntary effort of the patient. The data presented herein are remarkably similar to those reported by Mourits et al¹; who also reported a maximum coefficient of repeatability of 8° between observers. It is difficult to know whether the results of Gerling et al⁶ differ significantly, but a possible explanation lies in the disease phase of the patients studied. Patients with active disease commonly experience significant pain on excursions, and this was true of 15 (52%) of the patients described herein. Pain likely influenced voluntary effort and affected reliability; however, to investigate this effect with adequate statistical power would require in excess of 200 patients, and

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**Table 4. Comparison of Reproducibility of Individual Muscle Measurements Between Healthy Subjects and Patients With GO (Study B)**

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Mean (SD) Difference*</th>
<th>P Value</th>
<th>95% CI Difference*</th>
<th>F Test of Variance, P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Subjects</td>
<td>Patients With GO</td>
<td></td>
<td>Healthy Subjects</td>
<td>Patients With GO</td>
</tr>
<tr>
<td>Medial rectus</td>
<td>2.00 (2.39)</td>
<td>.21</td>
<td>4.68 (3.52)</td>
<td>6.90 (3.99)</td>
</tr>
<tr>
<td>Lateral rectus</td>
<td>1.27 (2.69)</td>
<td>.29</td>
<td>5.27 (2.39)</td>
<td>7.82 (3.89)</td>
</tr>
<tr>
<td>Superior rectus</td>
<td>0.13 (2.10)</td>
<td>.08</td>
<td>4.12 (2.64)</td>
<td>5.17 (3.78)</td>
</tr>
<tr>
<td>Inferior rectus</td>
<td>1.40 (1.84)</td>
<td>.06</td>
<td>3.61 (2.02)</td>
<td>4.47 (2.58)</td>
</tr>
<tr>
<td>Inferior oblique</td>
<td>0.53 (2.61)</td>
<td>.42</td>
<td>5.12 (3.76)</td>
<td>7.37 (4.08)</td>
</tr>
<tr>
<td>Superior oblique</td>
<td>1.00 (2.73)</td>
<td>.29</td>
<td>5.34 (3.41)</td>
<td>6.68 (4.19)</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; GO, Graves orbitopathy.

*Data are given as degrees.
CORRECTION

In the article titled “Sunlight and the 10-Year Incidence of Age-Related Maculopathy: The Beaver Dam Eye Study,” published in the May issue of the ARCHIVES (2004;122:750-757), the “Results” section of the abstract contained some errors. These sentences should have read as follows: “While controlling for age and sex, we found that participants exposed to the summer sun for more than 5 hours a day during their teens, in their 30s, and at the baseline examination were at a higher risk of developing increased retinal pigment (risk ratio [RR], 2.99; 95% confidence interval [CI], 1.18-7.60; P = .02) and early ARM (RR, 2.20; 95% CI, 1.02-4.73; P = .04) by 10 years than those exposed less than 2 hours per day during the same periods. . . . Participants who experienced more than 10 severe sunburns during their youth were more likely than those who experienced 1 or no burn to develop drusen with a 230-μm diameter or larger (RR, 2.52; 95% CI, 1.29-4.94; P = .01) by the 10-year examination.” The ARCHIVES regrets the error.

REFERENCES

2. Gorman CA. The measurement of change in Graves’ ophthalmopathy. Thyroid. 1998;8:539-543.