Effects of Scleral Search Coil Wear on Visual Function

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Purpose. The scleral search coil is widely regarded as the gold standard measurement technique for eye movements. The effect of wearing scleral search coils on human vision has not been systematically studied. However, there are anecdotal reports of degraded visual acuity, mild eye irritation, and an increase rise in intraocular pressure (IOP). The current study was conducted to investigate the effect of scleral search coil use on visual acuity and ocular integrity.

Methods. Six subjects were examined; all had previously worn search coils. Two drops of topical anesthetic were administered before insertion of the coils. Coils were inserted by hand and secured by applying mild pressure. The coils were removed after 45 minutes or on request of either the subject or the clinician. Before, during (at 15-minutes intervals), and after the coil was worn, the following measurements were taken for both eyes: tonometry (noncontact), corneal topography, biomicroscopic examination, visual acuity (monocular Snellen), and an eye-discomfort rating.

Results. Scleral coils produced a variety of effects, including ocular discomfort, hyperemia of the bulbar conjunctiva, increased IOP, buckling of the iris, grade 2 and 3 corneal staining, and reduction in visual acuity. Effects appeared as early as 15 minutes after insertion of the coils. All observed effects seemed to be transient and dissipated after coils were removed.

Conclusions. Scleral coils may not be appropriate for all subjects. The findings suggest that there is a need for thorough subject prescreening and that clinicians should consider the risk/benefit ratio. Acute reduction in visual acuity may confound search coil findings. More research is needed to determine the maximum wearing time for properly screened subjects. (*Invest Ophthalmol Vis Sci.* 2003;44:1933–1938) DOI:10.1167/iovs.01-0926

Physiologists, psychologists, and clinicians depend on precise, accurate, reliable, robust, and safe measurement of the movements of the eyes. Eye-movement monitoring is obviously important for the study of normal and pathologic oculomotor function[1] but has also been informative in behavioral studies of attention, learning, and reading, among others.[2] In this study, we looked at the effects of the use of a particular method of eye-movement monitoring, the scleral search coil technique, on visual function and considered the implications of our findings for studies of visual or visuomotor performance.

Eye-movement monitoring techniques[3] can generally be classified as those that require direct contact with the globe or as noncontact techniques (such as electrooculography, infrared, and video techniques). Noncontact techniques were generally of poor quality before the development of modern electro-optical and video technology and, though much improved, remain susceptible to a range of artifacts. One of the most important contact methods was introduced by Robinson[4] who adapted the search coil magnometer to eye-movement monitoring. A "scleral" search coil mounted on the globe can detect changes in its orientation in relation to the surrounding alternating-current magnetic field generated by the external field coils. Because the system essentially measures the movement of the coil, it is vital that the coil adhere to the globe and that there be no slippage of the coil in relation to the eye. In the original design, the coil was mounted on a special contact lens and was held firmly to the globe by a vacuum that was supplied by an external line. Although precise and flexible, the vacuum sometimes resulted in deformation of the cornea, temporary curvature myopia, discomfort, an increase in intraocular pressure (IOP),[4] or potential damage to the ciliary body[3] that restricted wearing time and precluded widespread usage.

Collewijn et al.[5] introduced a new carrier for the search coil that enables more general use. The coil is embedded in a molded silicone rubber annulus that is worn concentric to the cornea, resting on the limbic area. On the side that contacts the globe, the annulus has a radius of curvature that is steeper than the globe itself. When pressed onto the globe, the flexible lens deforms and partly evacuates the space under the annulus, causing the annulus to stick firmly to the globe like a suction cup. This intrinsic negative pressure[6] eliminated the need for an external vacuum, and the annular design eliminated contact with the corneal surface. These changes were considerable improvements, and the technique has become the gold standard for eye-movement monitoring in the laboratory and, increasingly, in the clinic.[7,8]

When used to study nonvisually guided eye movements, such as the vestibular ocular reflex, the suitability of the monitoring technique can be evaluated on the ability to measure the eye movements themselves. However, when the task is visual or visuomotor we must take into account the effects, if any, of the eye-movement monitoring technique on visual function. Performance on many visual tasks varies with visual acuity. If a subject's visual acuity has been compromised by coil wear then this must be taken into account. In visuomotor or attentive tasks, whether a target is visible or salient may determine whether a voluntary or reflexive eye movement is executed. For example, Näsänen et al.[9] reported that reducing stimulus contrast necessitates an increase in the number and duration of fixations required to perform a serial search task.

Important magnetic search coil studies of retinal image stability under quasinatural viewing have challenged the belief that ultraprecise oculomotor control and gaze stability are required for normal visual function.[10–13] In contrast, demand for acuity imposed by a task can have significant effect on fixational movements. For example, subjects suppress microsaccades when performing visual or visuomotor tasks requiring high visual acuity.[14,15] Size, spatial-frequency content, and clarity of the target can affect the precision of oculomotor control, and the sustained vergence system is reportedly more sensitive to high-spatial-frequency detail than low-spatial-frequency detail.[16] In studies of the precision of visually stabilized gaze, the

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precision of the fixation target is of obvious importance, and degradation of acuity should be prevented.

There has been no systematic study of the effects of search coil wear on visual function. The commercial manufacturer of scleral search coil annuli, Skalar Medical (Delft, The Netherlands) mentions the possibility of degraded visual acuity, particularly during long recording sessions in their printed and online documentation.[17,18] Anecdotally, Duwaer et al.[19] reported perceived deformation of the visual field and significant degradation of visual acuity to the extent that subjects sometimes could not perform their tasks due to blurring of the stimulus. Furthermore, they reported that blurring caused by the annuli interfered with the ability of the subjects to maintain binocular alignment and that performance on a subjective nonius line, alignment task was worse when the coils were worn than without them. Arend and Skavenski[20] reported that two subjects experienced drastically blurred vision while wearing scleral search coil annuli. Vision was impaired to the point that the subjects could not participate in the study. de Bie[21] also described in subjects wearing search coil annuli occasional blurred or diplopic vision that was sometimes alleviated by blinking. In summary, there are anecdotal reports of degraded visual acuity, mild eye irritation, and an increase in IOP with the use of scleral search coils. Experienced investigators are aware of and guard against the potential complications but there are no data on which to attempt to estimate the magnitude or likelihood of these effects. In this study, we systematically measured parameters related to visual function over the time course of a typical experimental session with a small group of subjects.

METHODS

We examined six subjects recruited from the oculomotor laboratories of the authors and their colleagues. Subjects were between 24 and 37 years of age (mean age, 29.5 ± 5.2 years). Two were male and four female. All subjects had previously worn search coils and gave their informed consent. Three of the subjects regularly wore contact lenses. The study was approved by the Office of Research Ethics at the University of Waterloo and conformed to the tenets of the Declaration of Helsinki.

In each session, for each subject, a coil was inserted into one eye, with the other eye serving as an untreated control. Whether the left or right eye was chosen as the test eye was randomly determined. The various visual and ocular measures were taken on both eyes. A complete series of measurements could be taken in less than 10 minutes unless photodocumentation of significant findings was required. Subjects were instructed to blink normally, and no visual tasks were performed between measurements. These instructions were effective, and there was no excessive blinking, tearing, or fluid build up. Two subjects (subjects 2 and 6) repeated the procedure on another day with the treated and control eyes swapped.

The search coils were visually inspected for any defects or abnormalities before use in the experiment. Coils were disinfected before and after each trial by immersing them in 3% hydrogen peroxide solution for 20 to 30 minutes. The coils were then placed in a preserved saline solution for at least 15 minutes and were stored in the manufacturer's containers between trials. Before coil insertion, 2 drops of topical anesthetic (0.5% proparacaine hydrochloride) were administered. Coils were inserted by hand and secured by applying the minimum amount of pressure necessary to prevent slippage of the coil, by an individual with many years of coil insertion experience. The procedures used were those recommended by the manufacturer, with the exception that the coils were inserted by hand rather than with the insertion tool. After insertion of the coils, they were not manipulated until removal. The coils were removed with a specially designed surgical spatula after 45 minutes or on request of either the subject or the clinician. Before, during (at 15 minutes intervals), and after the coils were worn, the following measurements were taken for both eyes.

Visual Acuity

Monocular Snellen acuity was measured with habitual correction. Although this does not necessarily represent the best corrected visual acuity, we were most interested in changes compared with baseline than in the baseline itself. Projector charts with multiple lines of the same size were used to minimize the effects of memorization of the chart with repeated measures. The test distance was 6 m, and constant illumination providing good chart contrast was achieved in the room by having the overhead fluorescent lights nearest the chart off and those above the subject at half-maximum setting.[22]

Tonometry

A noncontact tonometer (Xpert NCT Advanced Logic Tonometer, model 1243; Reichert Ophthalmic Instruments, Depew, NY) was used to monitor changes in IOP in the treated and control eyes. Although noncontact applanation tonometry (air puff) is not considered to be the most accurate technique available for the measurement of IOP, it is reliable,[23] and we were measuring changes in comparison with baseline measurements taken before insertion of the coil. The advantage of the method is that we could be certain that any corneal effects observed were due to coil wear and not secondary to multiple contacts of a tonometer probe with the corneal surface.

Corneal Topography

Corneas were assessed for distortion and overall changes in corneal curvature by using a topographic modeling system (TMS-1; Computed Anatomy, Inc., New York, NY). With instruments such as this, one can see corneal changes in discrete areas. For example, changes in the peripheral cornea may be more likely when using a scleral search coil annulus than changes in the central corneal, which can be measured with conventional instrumentation, such as the various keratometers.

The TMS-1 uses a solid-state videokeratoscope (Light cone; Computed Anatomy, Inc.) with a short working distance. Illuminated concentric rings create corneal reflections at approximately 180-μm intervals from the apex outward. The digital image of the corneal reflection is analyzed by identification of the location of a set of circumferential points within the reflected rings. This is then converted to diopters of corneal power or radius of curvature. Axial accuracy of ± 50 μm is achieved using a laser range finder, based on the principle of triangulation.[24]

Biomicroscopic Examination

Examinations were performed by licensed optometrists and included evaluations of conjunctiva, iris, and cornea. Corneal evaluation included staining with sodium fluorescein before insertion and after removal of the coil. Bulbar conjunctival redness and corneal staining (type, depth, and extent) were assessed using the Cornea and Contact Lens Research Unit (CCLRU, University of New South Wales, Sydney, Australia) grading scales. These scales use a 1 to 4 rating for each parameter. Corneal staining is rated on type, depth, and extent. Anomalies of the cornea, conjunctiva, and iris were photodocumented.

Eye Discomfort

A rating scale was used ranging from none (1) to extreme discomfort (5).

RESULTS

Scleral search coils produced a variety of ocular effects. These effects appeared as early as 15 minutes after coil insertion and dissipated after coil removal. Ocular discomfort and hyperemia of the bulbar conjunctiva were consistent across subjects. The corneal integrity was affected in all subjects, however, the

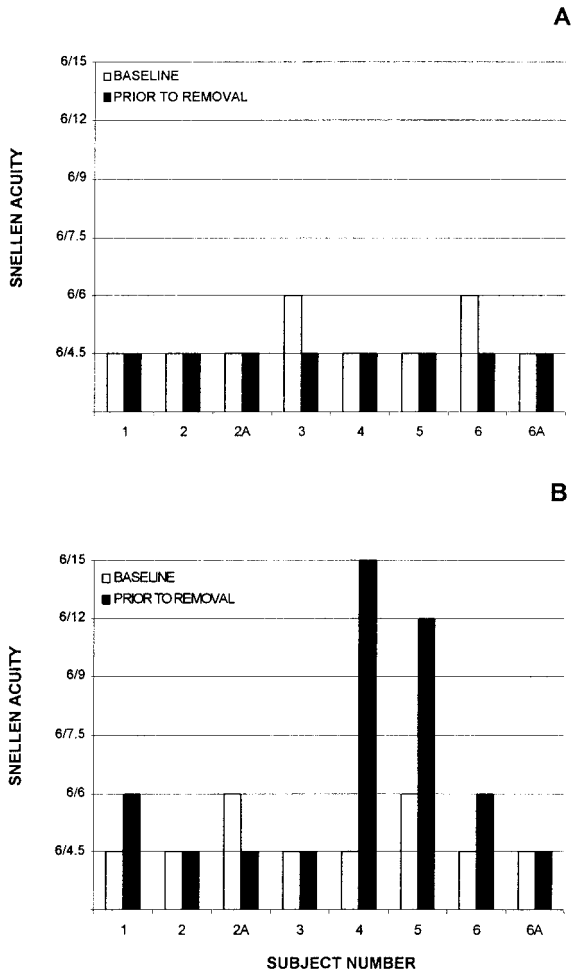

FIGURE 1. Snellen visual acuity for each of the eight treated eyes is shown at baseline and for the last interval before removal of the coil in (**A**) the untreated eye and (**B**) the treated eye. Each eye is represented by a different grouping and the fellow eyes of two subjects are designated by 2a and 6a.

severity and location was highly variable between subjects. Visual acuity was decreased by at least one line in half of the eyes tested. Less common findings were increased IOP and buckling of the iris. In general, decreases in visual acuity tended to be associated with corneal changes, either integrity, topographical, or both. The eye with the most severe corneal and conjunctival changes was also the eye with the greatest reduction in visual acuity and the greatest topographical changes. IOP changes were loosely related to observed deformation of the iris root in that the eyes with iris changes had increased IOPs. However, not all eyes with increased IOP had iris root deformation.

All eyes had 6/6 or better visual acuity with habitual correction before insertion of the coils. At the time of coil removal, the visual acuity of the control eyes was the same or better than at baseline (Fig. 1A). In one subject there was a transient decrease of one line after insertion and before removal of the coils. One subject actually showed a one-line decrease in acuity of the control eye after the coil was removed. A drop of one or more lines of visual acuity was seen in five treated eyes. One of these was transient, in that it was seen only immediately after insertion and then returned to baseline. In the remaining four, the decrease in vision was still present at the time of coil removal (Fig. 1B). The largest reduction in visual acuity was from 6/4.5 to 6/15. At one hour after coil removal, all eyes had returned to 6/6 or better visual acuity. Different charts were used to minimize the effects of memorization. This does not preclude other types of learning, nor does it guarantee that no memorization occurred. Learning effects would result in underestimation, as opposed to overestimation of any degradation in visual acuity.

The mean IOP in the treated and untreated eyes at baseline was 11.8 ± 2.1 and 11.9 ± 1.7 mm Hg, respectively. The mean IOP after 15 minutes of coil wear was 13.3 ± 4.0 mm Hg in the treated eye and 12.4 ± 1.9 mm Hg in the untreated eye. This represents an average increase in the treated eye of 1.6 mm Hg and an average increase in the untreated eye of 0.5 mm Hg, which *t*-tests showed were not statistically significant increases ($P = 0.349$ and $P = 0.601$, respectively). Not all eyes reached their maximum IOP at 15 minutes of wear. However, as a result of the early removal of the coils from two eyes because of decreased acuity, this was the only wearing time for which data were available for all subjects. Treated eyes showed an increase in IOP in 62% of cases, whereas 37.5% of untreated eyes had an increase in IOP. The maximum increase in IOP of a treated eye was 5.8 mm Hg. IOP measurements for wearing times and postremoval times are shown in Figure 2.

Corneal topography changes (Table 1) were variable between subjects. Topographic changes occurred immediately after insertion and remained stable until coil removal. The most dramatic change (Fig. 3, subject 4) consisted of a gross distortion of the cornea accompanied by a 9-D steepening in a small central portion of the cornea. There was a fairly large area in this eye where the corneal integrity was too poor to obtain any reflection from the rings. Two more eyes showed centrally steepened (1.5 D) regular corneas. Three eyes showed no change, one eye showed central flattening (1.5 D), and one eye showed overall corneal flattening (3 D).

All treated eyes had bulbar hyperemia. In five (62.5%) of the eight eyes, it was grade 3 or higher. While the coil was on the eye, there was blanching of the limbal vessels. Immediately after removal of the coils, 62.5% of eyes had grade 2 or higher limbal hyperemia. All treated eyes had some corneal staining, but none had corneal edema. In all cases, the staining was superficial epithelial (grade 1 or less on the depth scale), and in most cases, staining was punctate (appear as small dots, grade 2 or less on the type scale). However, two eyes had coalesced staining (localized areas or patches of dense staining, grade 3). The extent of staining was grade 2 in five of the treated eyes. Staining in two eyes was at grade 3, and one eye had staining over most of the cornea (grade 4). The area of staining tended to be variable. Some eyes showed peripheral punctate staining, whereas in others the staining was more central. Most subjects showed a bright ring of staining on the conjunctiva in the area of the coil's edge. Grading for ocular changes immediately after removal of the coil is shown in Table 2.

Subject 2 showed a clear buckling in the area of the iris root immediately after insertion of the coil, which dissipated while the coil was still on the eye. Subject 6a (fellow eye of subject 6) showed a similar but less pronounced effect. This effect was not seen in all subjects nor was it seen in both treated eyes of subject 2 and 6, who had the fellow eye treated on a subsequent day.

No subjects reported a change in ocular comfort, at any time, in the untreated eye. However, all subjects reported a significant increase in eye irritation in the treated eye compared with baseline (Table 3). The mean subject rating on our scale was 1.0 with no variance at baseline and 3.0 ± 0.3 at the point of maximum discomfort (just before removal, in all subjects except Subject 6, who reported maximum discomfort immediately after insertion followed by a slight improvement). The maximum individual discomfort rating was 3.5, and the minimum was 2.5.

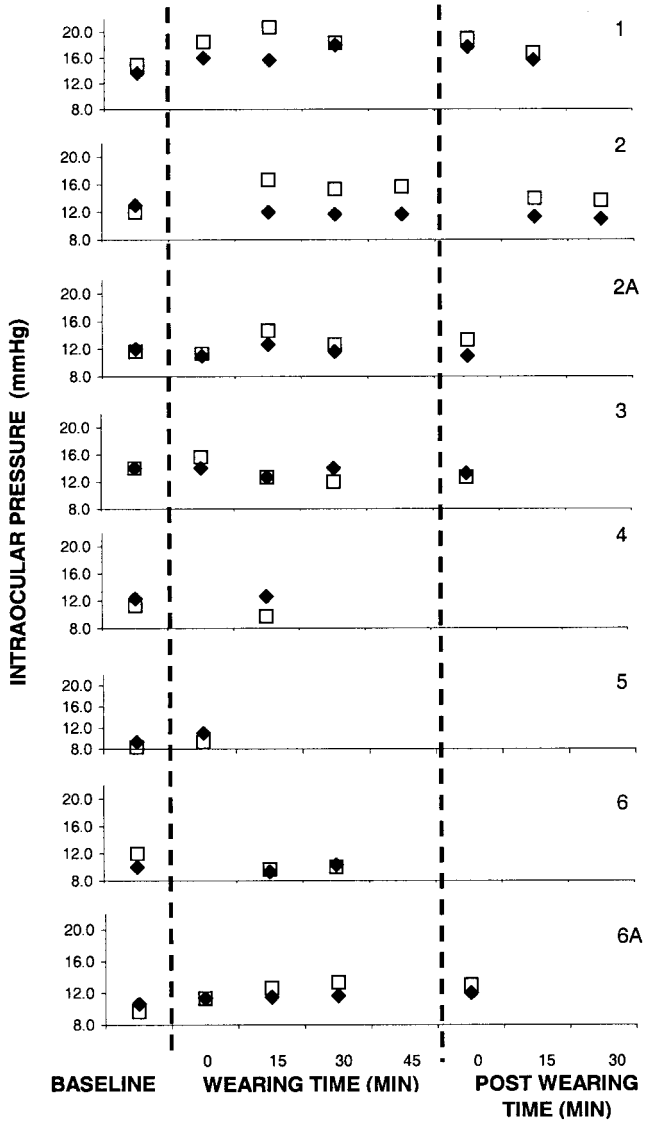

FIGURE 2. IOP in each treated eye (□) and the corresponding untreated eye (♦). Data for individual eyes are shown in separate subplots, with the fellow eyes of two subjects designated by 2a and 6a. IOP in each eye is shown before insertion of the coil, immediately after insertion, and at up to three successive 15-minute readings with the coil in place, followed by readings immediately after removal of the coil and three postremoval readings. Missing data correspond to intervals missed because of the early removal of the coil or the time needed to photodocument significant biomicroscopy findings.

DISCUSSION

In this study, we have replicated and quantified some of the anecdotally reported visual and ocular side effects of wearing scleral search coils. As well, for the first time, corneal deformation and an effect in which the iris root appears to undergo localized buckling were noted. After an initial report of our findings in abstract form,[25] Murphy et al.[26] tried to replicate our study. They found irritation of the eyelids and bulbar redness but did not observe any of the other effects we report here. Besides the present study and the replication study by Murphy et al.,[26] there have been no systematic studies of visual function during scleral search coil wear.

The matter of ocular safety during search coil wear has received some limited attention.[5,17,27] The coil manufacturer has claimed that the annulus causes minimal side effects such as slight, transient, irritation of the conjunctiva, and slight degradation of visual acuity.[5,17] Few data were provided to support these claims. Although we have not specifically addressed safety issues, we can make several observations. In this study, we found increased IOP in some subjects in the initial wearing period with a subsequent decrease. IOP decreased after removal of the annulus. Collewijn et al.[5] reported that the IOP for their single subject rose steadily over the first 20 minutes from 12 to 20 mm Hg, where it remained for the duration of the session. In an abstract, Demer[27] reported a slight increase in mean IOP across his 30 subjects after scleral search coil wear but did not report on increases in individual subjects. Murphy et al.[26] and Demer[27] did not attempt to measure IOP during coil wear and hence their results were insensitive to any transient increase in pressure. Our finding that scleral search coil wear can cause a buckling deformation of the iris suggests that the action of the annulus is localized and that the increase in IOP may arise from local constriction and interference with normal outflow through the anterior chamber angle (as Robinson[4] discussed with the original technique). As Demer[27] found, all the subjects started with IOP well within the normal range, and the transient increase did not result in excessive pressure. A similar increase in pressure starting from an elevated baseline may be more worrisome and suggests that a prescreening of subjects is advisable.

TABLE 1. Results of Corneal Topography in Treated Eyes

Eye	Max Change from Baseline	Change from Baseline after Recovery
1	1.5 D steeper central	0.5 D steeper central
2	3.0 D flatter overall	1.5 D flatter overall
2a*	No change	No change
3	1.5 D flatter central	No change
4	9.0 D steeper central	1.0 D steeper central
5	1.5 D steeper central	No change
6	No change	No change
6a*	No change	No change

Results are given as the maximum change in corneal topography from the baseline measures during coil wear and the change in corneal topography from the baseline measures at the last time interval measured after coil removal.

* The fellow eye of the same subject.

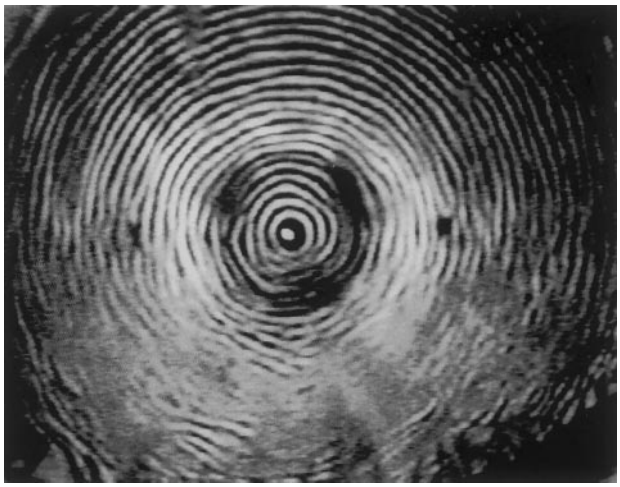

FIGURE 3. Topography image showing corneal distortion during coil wear in subject 4. The image was taken 24 minutes after insertion of the coil.

Lid irritation and conjunctival hyperemia is a common finding that presumably reflects the disturbance caused by the adhesion of the annulus to the globe. The corneal staining that we found was also similar but perhaps slightly more severe than that found by others.[26,27] Because of the small number of subjects in the studies to date, it is unclear whether this simply reflects a sampling of the range of staining to be expected. In some vision science studies, there are significant demands on fixation, and blinking may be reduced. Murphy et al.[26] attributed the staining to drying of the eye caused by inadequate blinking. However, in our study, subjects were encouraged to blink regularly, and no visual tasks were required of the subjects between the measures. That staining was observed relatively early in the session also argues against drying as an explanation. Another explanation may be that the staining is a manifestation of the corneal distortion and deformation that we noted in the corneal topography.

The main goal of our study was to investigate the effects of scleral search coil wear on visual function. In most cases, degradation of visual acuity was modest, as we had expected from our experience in the laboratory. To our surprise, two subjects had a significant, transient degradation of visual acuity. This seems to substantiate the anecdotal results reported by Duwaer et al.[19] Further study is necessary to determine the incidence of such decreases. If it is true that an effect of this magnitude is relatively rare, the negative findings of Murphy et al.[26] should come as no surprise. By the same token, if indeed it is rare, it is somewhat surprising that we should encounter two cases within our small sample. However, the possibility of such a large effect compels us to advise that researchers should guard carefully against such an artifact in studies requiring optimum visual acuity.

Degradation of visual acuity occurred relatively early in our sessions and not only with extended wearing times, as has been previously concluded.[18] The loss of visual acuity appeared to be loosely correlated with corneal changes. With proper procedure and adequate adhesion, risk of corneal abrasion is slight and in no case in which visual acuity was degraded was there any evidence of corneal abrasion or other ocular trauma resulting from insertion of the coils. Our results cannot be explained on the basis of aggressive and unreasonable force during insertion. Some pressure must be applied to the annulus to ensure proper adhesion. Without proper adhesion, the technique will give uninterpretable results. Proper adhesion can be verified when the forceps are used to remove the coils.

TABLE 2. Results of the Biomicroscopic Examinations

	Hyperemia		Corneal Staining			
Eye	Bulbar	Limbal	Type	Depth	Extent	Notes
1	2	1	1	1	2	
2	2	1	2	1	2	Iris buckle (with coil on eye)
2a*	3	1	2	1	2	
3	2	3	2	1	2	
4	3	3	3	1	4	
5	3	2	2	1	3	
6	3	3	3	1	3	
6a*	4	2	2	1	2	Iris buckle (with coil on eye)

Data are for the eight treated eyes immediately after removal of the coils. Bulbar and limbal conjunctival redness and corneal staining were assessed using the CCLRU 4-point grading scales: 1 is minimal and 4 is severe.

* The fellow eye of the same subject.

TABLE 3. Results of Ocular Discomfort Ratings for Treated and Untreated eyes

	Discomfort at Baseline		Maximum Discomfort	
Subject	Treated	Untreated	Treated	Untreated
1	1	1	3.5	1
2	1	1	3	1
2a*	1	1	3	1
3	1	1	2.5	1
4	1	1	3	1
5	1	1	3	1
6	1	1	3	1
6a*	1	1	3	1

Data were obtained before coil insertion and at maximum discomfort during coil wear. Discomfort was assessed using a subjective rating scale: 1 is no discomfort and 5 is extreme discomfort.

* The fellow eye of the same subject.

In summary, magnetic scleral search coil wear is probably safe and accurate for most subjects. However, in some subjects substantial degradation in visual acuity is possible. Although this may be an uncommon problem, such a significant confounder should be taken into consideration. Furthermore, scleral coils may not be appropriate for all subjects, and thorough prescreening is recommended. All observed undesirable effects seemed to be transient and dissipated after coil removal. Although we feel confident that the safety risks are relatively minor, a comprehensive study should be undertaken involving a large number of subjects, considering the general clinical usage that has been proposed.[18] More research also is needed to determine the maximum wearing time for properly screened subjects. If appropriate studies confirm that maximum wearing time can be increased beyond the generally accepted 30-minute limit, then the flexibility of the technique would be enhanced. It is interesting that Murphy et al.,[26] although critical of our results, come to similar conclusions. Thus, we conclude that the scleral search coil technique is well suited for use in visual science experimentation, but that investigators should carefully screen subjects and should be alert for the possibility of compromised visual acuity.

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