Upper Eyelid Motility in Blepharoptosis and in the Aging Eyelid

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PURPOSE. To study the metrics of lid saccades in blepharoptosis and to distinguish any differences in the dynamics of eyelid movements that are related to the cause of blepharoptosis and to aging.

METHODS. The lid and vertical eye saccades of 7 patients with congenital blepharoptosis and those of 18 patients with aponeurogenic blepharoptosis, either involutional or rigid-contact-lens–induced, were recorded with electromagnetic search coils. For each saccade, two parameters were assessed: amplitude and peak velocity. Two age-matched control groups were assessed in the same manner. Repeated measures analysis of variance was used to investigate any observed differences between the included groups.

RESULTS. Congenital and rigid-contact-lens–induced blepharoptosis were readily distinguishable from one another, as well as from the age-matched control group, in both lid saccadic amplitude and peak velocity. For example, 40° downward lid saccades in the congenital blepharoptosis group averaged 22.9° ± 4.0° (SD), whereas 30.0° ± 4.7° lid saccades were made by the age-matched control group. The subjects in the two groups with aponeurogenic blepharoptosis also made lid saccades that were distinctive for their group ($P < 0.02$), in both amplitude and peak velocity. For 40° downward saccades in involutional and rigid-contact-lens–induced blepharoptosis, lid saccadic amplitude averaged 32.7° ± 4.3° and 40.3° ± 3.5°, respectively. Lid saccadic peak velocity declined significantly with age. Lid saccadic peak velocity for 40° upward saccades in the younger control group averaged 401.7 ± 11.4 deg/sec, whereas the older control group achieved an average peak velocity of 360.7 ± 60.4 deg/sec. The lid saccadic dynamics in the involutional blepharoptosis group proved to be similar ($P > 0.05$) in saccadic amplitude and peak velocity to those of age-matched controls.

CONCLUSIONS. In different forms of blepharoptosis, distinctive metrics of lid saccades occur. The current data suggest that involutional blepharoptosis is not a consequence of normal age-related changes in eyelid function. (*Invest Ophthalmol Vis Sci.* 2001;42:620–625)

There are several known causes of blepharoptosis, such as a diseased levator palpebrae muscle or its aponeurosis and neurologic and mechanical disorders.[1] Various types of blepharoptosis may be identified by proper assessment of established clinical parameters such as levator function, a commonly used parameter of the functional integrity of the levator palpebrae muscle. Levator function has been defined as the maximum eyelid amplitude (in millimeters), measured from downgaze to upgaze.[2,3] Another measure of levator function is the so-called levator force, which is infrequently used, because no clinically useful device is currently available.[4] Other parameters, such as the position of the upper eyelid crease, the interpalpebral fissure height, upper eyelid margin–corneal reflex distance, fatigue with sustained upgaze, and ocular motility may provide additional information toward establishing the correct diagnosis. Nevertheless, the cause of the blepharoptosis may remain obscure,[3,4] whereas a correct diagnosis facilitates its adequate management.

Aponeurogenic blepharoptosis is caused by disinsertion, or thinning, of the levator muscle aponeurosis.[5–7] Typically, the levator function is good,[8] and a high eyelid crease is usually found. In the elderly it is most often an involutional disorder.[4,9] In the younger population, a period of rigid contact lens wear is frequently the only identifiable cause.[3,10] In aponeurogenic blepharoptosis it is clinically difficult to discriminate between the possible causes—that is, involutional or contact lens wear. Only history and the age of occurrence can currently be used to differentiate between the two. Intraocular surgery, postoperative edema, ocular inflammation, and topically applied steroids are other factors related to aponeurogenic blepharoptosis.[1,7]

In congenital myogenic blepharoptosis, the levator function is typically diminished, and the eyelid shows a lag during downgaze. Upper eyelid crease position is unaffected. Although most congenital blepharoptoses are myogenic,[8] some are caused by a neurologic abnormality,[11] an aponeurotic defect,[4] or a mechanical distortion of the upper eyelid, as with neurofibroma.[12] During clinical examination, such other causes of congenital blepharoptosis are readily distinguished from the myogenic ones. Genetic linkage has recently been established for at least some cases of congenital blepharoptosis.[13]

Few studies have described the metrics of lid saccades in normal subjects.[14–17] Concurrent lid and eye saccades have repeatedly been shown to have similar amplitudes and peak velocities.[16] Several investigators[14,15,17] have found higher peak velocities in downward lid saccades than in upward ones. In one study,[16] however, the opposite was found, possibly because of the small number of subjects included in that study.

In the present experiments, we compared the metrics of lid saccades among several forms of blepharoptosis and in age-matched control groups.

MATERIALS AND METHODS

The investigations adhered to the tenets of the Declaration of Helsinki and were approved by the institutional human experimentation committee. Informed consent was obtained from each subject after the experiments were fully explained.

Patients and Control Subjects

We included seven patients with congenital blepharoptosis (CB; age range, 22–70 years). Each patient had a history of unilateral or bilateral blepharoptosis since birth. For inclusion, the maximum eyelid ampli-
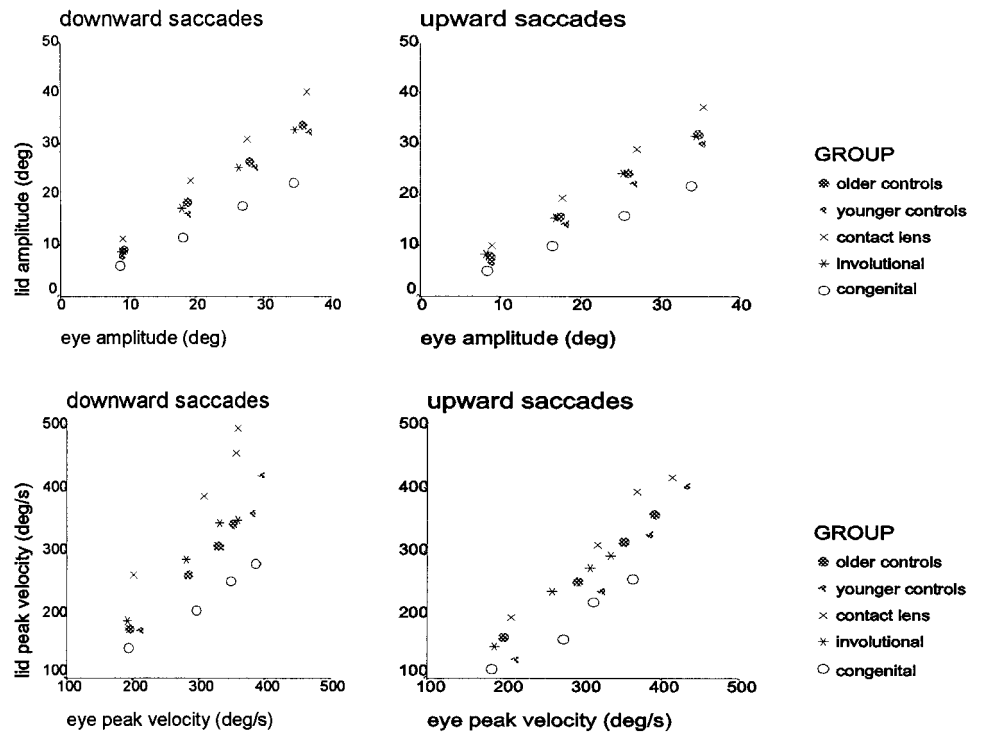
FIGURE 1. Lid saccadic amplitude (in degrees) and peak velocity (in degrees per second) with those of the eye in all five groups, pooled for saccadic direction.

tude had to be less than 8 mm at clinical examination, with lid lag during downgaze. In addition, 18 patients with the clinical signs of aponeurogenic blepharoptosis, either attributed to involutional changes (IB; $n = 13$; age range, 68–87 years), or secondary to rigid contact lens wear (CLB; $n = 5$; age range, 21–46 years) were included. For inclusion, the maximum eyelid amplitude had to be 10 mm or more, and a high upper eyelid crease had to be present. They had a history of gradually progressive unilateral or bilateral blepharoptosis.

If each upper eyelid showed blepharoptosis, the most affected upper eyelid was included for analysis, although both eyelids were simultaneously recorded. Blepharoptosis was defined as an interpalpebral fissure height of 7 mm or less, measured between the lower and the upper eyelid margin,[10] or an asymmetry between the two upper eyelids of more than 2 mm. Maximum eyelid amplitude was measured from downgaze to upgaze while the additional action of the frontalis muscle was blocked by digital pressure on the eyebrow on the orbital rim. Patients were excluded if they had previously undergone eye or eyelid surgery or if they had a systemic disease that might affect upper eyelid position or motility, such as Graves' disease or a generalized neuromuscular disease. In addition, patients were excluded if they showed any progression of blepharoptosis after sustained upgaze, jaw-winking, or a visible lid twitch.

Two groups of young normal control subjects (YC; age range, 25–51 years; $n = 10$, or older control subjects (OC; age range, 64–84

years; $n = 16$) took part in our experiments as age-matched control groups. All normal subjects had a vertical eyelid fissure of 8 mm or more, and each had a levator function of 10 mm or more. None of the subjects in the control groups had any history of ocular or oculomotor disease. We randomly included the measurements of one upper eyelid and the associated eye of each normal subject.

Recording Technique and Calibration

Lid and eye saccades were recorded simultaneously by means of the electromagnetic search coil technique.[14,16,18,19] Lid saccades were recorded with handmade search coils. Every such coil consisted of 50 turns of insulated copper wire (diameter, 0.05 mm). A typical coil had an outer diameter of approximately 4 mm, weighed 15 mg, and was less than 0.5 mm thick. To reduce spurious induction, the leads of the coil were tightly twisted together. The coils were fixed on the lower part of the eyelid, just above the eyelid margin and right above the center of the pupil with a piece of adhesive tape (diameter, 6.5 mm). Once the coils were attached, the subjects hardly noticed them. Eye saccades were recorded with commercially available search coils (Skalar, Delft, The Netherlands).

The field frequency used was 20 kHz. The recordings were amplified to a ±5-V range, low-pass filtered at 120 Hz (-3 dB), digitized with 12-bit precision, and sampled at a frequency of 250 Hz. The recordings
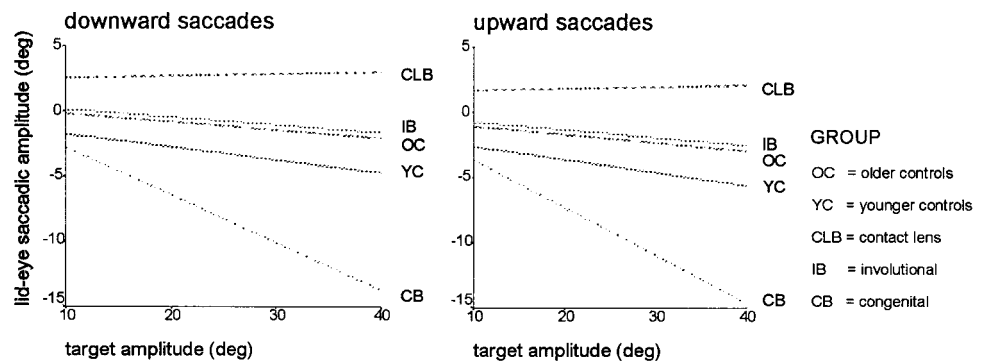

FIGURE 2. Regression lines for the estimated linear relationship of the saccadic amplitude (lid–eye; in degrees), as a function of the target amplitude for each group.
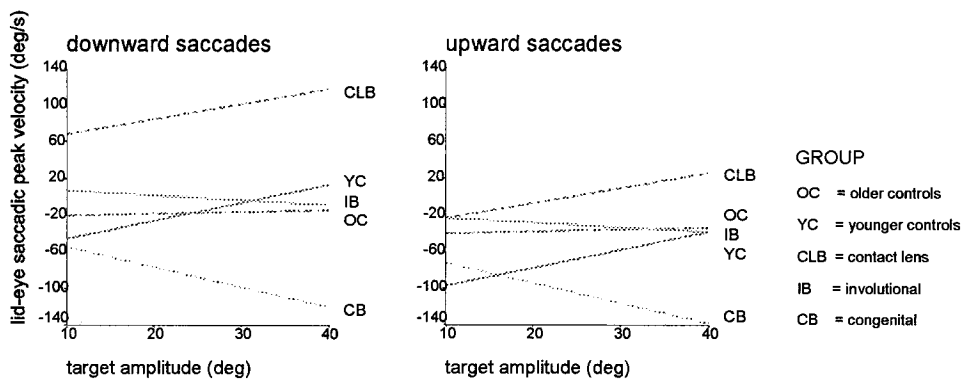
FIGURE 3. Regression lines for the estimated linear relationship of the saccadic peak velocity (lid–eye; in degrees per second), as a function of the target amplitude for each group.

were stored on disc for off-line analysis. Signal noise level was less than 1.8 minutes of arc. Both the recording equipment and the search coils were calibrated objectively before each recording session, with the coils mounted on a calibration device. Any misalignment of the coils on the eyes, determined when the subjects monocularly fixed a lit LED in the primary position of gaze, was later adjusted by software. The accuracy of the calibration procedure was better than 0.5%.

One search coil was attached to the upper eyelid, and a scleral search coil was placed on the ipsilateral eye under topical anesthesia (0.4% oxybuprocaine; Novesine; Chauvin, Düsseldorf, Germany). Subjects were then seated, with their heads centered in a cubic coil frame in which an alternating horizontal and vertical electromagnetic field was generated. Head movements were restricted by a chin rest and forehead support. The subjects faced a stimulus screen, containing red LEDs at a viewing distance of 1 m. The LEDs were positioned symmetrically around the straight-ahead position along the midvertical meridian, 10°, 20°, 30°, and 40° apart. The subjects were asked to shift their gazes from one lit LED to the other after hearing an electronically generated tone, at a pace of 1 per second. The four target ranges were tested in a randomized sequence. Each trial lasted 16 seconds, in which, typically, eight saccades in each saccadic direction were made. Before each trial, subjects were allowed to practice briefly.

Data Analysis

The recorded data were analyzed with a previously devised computer program.[14] The criteria adopted for observer-independent detection of saccadic onset were acceleration exceeding 1000 deg/sec^2 and velocity exceeding 25 deg/sec. Saccadic offset was detected by a deceleration of less than 1000 deg/sec^2 and a velocity of less than 50 deg/sec. The amplitude and peak velocity of each detected saccade were determined. Only primary eye saccades and the associated lid saccades were selected for analysis, by an eye amplitude criterion (set at 50% of the target amplitude). Repeated measures analysis of variance (mixed-model ANOVA)[20] was used to investigate any observed differences among the included groups. Two outcome (dependent) variables were defined: the difference in saccadic amplitude between lid and eye (in degrees) and the difference in saccadic peak velocity between lid and eye (in degrees per second). Each outcome variable was analyzed

separately in a linear model with random coefficients and with the following independent variables: patient group (five groups), saccadic direction (up and down), and target amplitude (10°, 20°, 30°, and 40°). Also interactions between group and target amplitude and between group and direction were tested. Amplitude squared was included to test for curvilinearity. The fitted linear model provided estimates for the mean coefficients. Pairwise comparisons were used to test whether these mean coefficients differed between groups.

RESULTS

Assessing the dynamics of eyelid saccades was valuable as a means of differentiating between two clinically similar forms— involutional and contact lens–induced— of aponeurogenic blepharoptosis. Moreover, large differences were found in the amplitudes and peak velocities of the eyelid saccades made by patients with congenital blepharoptosis on the one hand and by those with the aponeurogenic condition on the other. For example, in the group with congenital blepharoptosis the lid saccadic amplitude for 40° saccades averaged 23.6° (average peak velocity, 278 deg/sec), whereas the contact lens group achieved an average of 38.8° (average peak velocity 450.8 deg/sec). Lid saccadic peak velocity was affected by age, averaging 410.0 deg/sec for the younger control group and 352.2 deg/sec for the older control group for 40° saccades. Lid saccadic dynamics in the involutional blepharoptosis group were closely similar to those of the age-matched control group.

Both the amplitude and the peak velocity of the eyelid saccades increased with those of the eye in all five groups (Fig. 1). The eye saccadic amplitudes of the group of patients with congenital blepharoptosis were significantly smaller ($P < 0.05$; independent samples t-test) from those of the age-matched control group. No differences in eye saccadic amplitude ($P > 0.05$; independent samples t-test) were found between the other groups. However, eye saccadic peak velocities differed significantly between all groups ($P < 0.05$; independent sam-

TABLE 2. Estimated Linear Relationships of the Difference in Saccadic Amplitudes

| | Mean Intercept | | |
Group	Downward Saccades	Upward Saccades	Mean Slope
CB	0.892 ± 0.712	0.013 ± 0.757	−0.366 ± 0.040
IB	0.755 ± 0.492	−0.124 ± 0.560	−0.060 ± 0.028
CLB	2.445 ± 0.772	1.566 ± 0.817	0.013 ± 0.044
YC	−0.746 ± 0.550	−1.625 ± 0.611	−0.100 ± 0.031
OC	0.450 ± 0.438	−0.429 ± 0.513	−0.063 ± 0.025

Target amplitudes ranged from 10° to 40° for the five groups and two saccadic directions considered. Data are mean degrees ± SE.

TABLE 1. P for Testing the Null Hypothesis that the Regression Lines of Two Groups Coincide

Comparison between Groups	Lid–Eye Saccadic Amplitude (deg)	Lid–Eye Saccadic Peak Velocity (deg/sec)
YC vs. OC	0.0663	0.0368*
IB vs. OC	0.8674	0.5675
CLB vs. YC	0.0001*	0.0012*
CB vs. YC	0.0001*	0.0115*
CB vs. CLB	0.0001*	0.0001*
IB vs. CLB	0.0177*	0.0107*

* Statistically significant difference at $P < 0.05$.

TABLE 3. Estimated Linear Relationships of the Difference in Saccadic Peak Velocity

| Group | Mean Intercept | | Mean Slope |
	Downward Saccades	Upward Saccades	
CB	−32.56 ± 25.99	−50.34 ± 27.19	−2.186 ± 1.087
IB	12.17 ± 18.37	−17.81 ± 18.86	−0.512 ± 0.741
CLB	52.13 ± 29.16	−39.77 ± 29.49	1.644 ± 1.178
YC	−65.31 ± 20.67	−116.99 ± 20.97	1.971 ± 0.835
OC	−22.45 ± 16.40	−42.02 ± 16.71	0.209 ± 0.661

Target amplitudes ranged from 10° to 40° for the five groups and two saccadic directions (upward and downward). Data are mean degrees per second ± SE.

ples *t*-test). To counteract possible effects of eye motility variation on the lid motility metrics, we subtracted eye saccadic amplitude and peak velocity from those of the concomitant lid saccade. This approach enabled us to differentiate clearly between the various groups of patients with blepharoptosis. We also found age-related differences in normal subjects.

Figures 2 and 3 show the various regression lines for the estimated linear relationships of the saccadic amplitude (lid–eye) and the peak velocity (lid–eye) as a function of the target amplitude. Each regression line represents one group. The statistical differences between these lines are presented in Table 1. The estimates for mean intercepts and mean slopes for saccadic amplitude and peak velocity are given in Tables 2 and 3, respectively. Saccadic amplitudes (lid–eye; Fig. 2), yielded significantly different linear slopes and intercepts across the five groups ($P = 0.0001$ and $P = 0.0163$, respectively). Peak velocities (lid–eye; Fig. 3) only differed significantly in their linear slopes between the five groups ($P = 0.0197$), not in their intercepts.

Comparisons between Groups

Table 4 shows the mean amplitude (in degrees) and peak velocity (in degrees per second) for 40° lid and eye saccades (upward and downward) for all groups.

YC Versus OC. Lid saccades in the YC group could be readily distinguished from those of the OC group by saccadic peak velocity, but not by saccadic amplitude (Table 1). The lid saccades in the OC group were, on average, slightly larger (Table 4) than those in the YC group. By contrast, the amplitudes of the associated eye saccades in the OC group were, on average, smaller than those in the YC group. In both control groups, eye saccades were larger than those of the lid (Table 4). The YC group had, on average, higher peak velocities of both types of saccades, lid and eye, regardless of saccadic direction (Table 4).

IB Versus OC. The lid saccades in the IB group could not be clearly distinguished from those in the age-matched control group by any lid saccadic parameter (amplitude or peak velocity; Table 1), although, on average, slightly smaller lid saccades were made in the IB group (Table 4). Both groups made lid saccades that were smaller than the associated eye saccades (Table 4). In addition, the differences in saccadic amplitude between lid and eye saccades were somewhat smaller, on average, in the IB group than in the age-matched control group. In the IB group, lid saccadic peak velocity was affected by saccadic direction. Saccadic peak velocity was higher in downward than in upward saccades. By contrast, the peak velocities of downward and upward associated eye saccades were similar (Table 4).

CLB Versus YC. Lid saccades in the CLB group could be readily distinguished from those in the YC group by saccadic amplitude and by peak velocity (Table 1). Lid saccadic amplitudes were, on average, larger in the CLB group than in the YC group (Table 4). In both groups, downward lid saccades were larger than upward ones. In addition, lid saccades were larger than the associated eye saccades in the CLB group (Table 4), whereas in the YC group the opposite was found: larger eye saccades than lid saccades. The difference between lid and eye saccades (lid minus eye) in the CLB group was largest for downward saccades and averaged 3.9° ± 3.3° for 40° saccades, and −4.6° ± 3.9° in the YC group. In the CLB group, downward lid saccades had, on average, higher peak velocities than upward ones (Table 4). The associated eye saccades showed contrary results: Saccadic peak velocities were higher in upward than in downward saccades. In addition, the eye saccadic peak velocities were similar for the two groups (Table 4).

CB Versus YC. Lid saccades made in the CB group were markedly smaller and had lower peak velocities than those of the YC group (Table 1). On average, downward lid saccades were slightly larger than upward ones in the CB group (Table 4). Lid saccades made in the CB group were significantly smaller than the associated eye saccades (Table 4). The difference between lid and eye saccades (lid minus eye) averaged 10.9° ± 3.5° for 40° downward saccades, and 11.8° ± 3.6° for 40° upward saccades. The amplitudes of eye saccades in the CB group were significantly smaller than those in the YC group (Table 4). Downward lid saccades had higher peak velocities than upward ones in the CB group. By contrast, the peak velocities of the associated eye saccades were similar for the two directions (Table 4).

CB Versus CLB. The CB group could be readily distinguished from the CLB group by lid saccadic amplitude and by its peak velocity (Table 1). On average, only slight differences in the amplitudes and peak velocities of the associated eye saccades were noted (Table 4).

IB Versus CLB. Significant differences in lid saccadic amplitude and its peak velocity were found between the two

TABLE 4. Amplitude and Peak Velocity for 40° Downward and Upward Lid and Eye Saccades

| Group | Amplitude | | | | Peak Velocity | | | |
| | Downward Saccades | | Upward Saccades | | Downward Saccades | | Upward Saccades | |
	Lid	Eye	Lid	Eye	Lid	Eye	Lid	Eye
CB	24.3 ± 5.2	35.2 ± 2.6	22.9 ± 4.0	34.7 ± 1.8	291.1 ± 45.2	395.3 ± 84.6	264.7 ± 72.3	385.5 ± 62.6
IB	32.7 ± 4.3	34.8 ± 2.5	31.3 ± 4.0	34.5 ± 2.1	348.9 ± 72.9	361.1 ± 70.3	295.6 ± 78.7	341.1 ± 70.6
CLB	40.3 ± 3.5	36.4 ± 1.7	37.3 ± 3.5	35.7 ± 2.4	490.5 ± 152.4	358.2 ± 70.5	411.1 ± 104.6	408.9 ± 83.3
YC	32.3 ± 5.4	36.9 ± 2.4	30.0 ± 4.7	35.4 ± 1.7	419.7 ± 143.7	395.7 ± 94.7	401.7 ± 11.4	431.8 ± 83.3
OC	33.7 ± 5.3	35.9 ± 2.1	31.8 ± 4.3	35.0 ± 2.1	343.7 ± 72.6	352.5 ± 65.1	360.7 ± 60.4	395.7 ± 57.4

Amplitude is expressed as mean degrees ± SD; peak velocity is expressed as mean degrees per second ± SD.

aponeurogenic blepharoptosis groups (Table 1). The lid saccades in the CLB group were, on average, larger and had higher peak velocities (Table 4).

DISCUSSION

Our data, obtained through search coil registration, showed clear differences in the eyelid metrics of patients with either congenital or aponeurogenic blepharoptosis. In addition, marked differences were found between the two forms of aponeurogenic blepharoptosis (involutional and contact-lens–induced).

Aging affects the metrics of spontaneous blinks[21] and vertical eye saccades.[22] Our data confirmed aging's effects on vertical eye saccades: reduced amplitudes with significantly lower peak velocities. Lid saccades also displayed a reduced peak velocity with age, albeit, with an increased amplitude. We may speculate that changes in the elastic properties of the levator muscle, its aponeurosis and the eyelid tissues, contribute to these effects of aging, because the elastic fibers become fewer and thinner with age.[23]

Because age-related (involutional) aponeurogenic blepharoptosis is assumed to be caused by disinsertion or laxity of the levator muscle aponeurosis,[1,7] we expected to find a different amplitude and peak velocity in such patients with blepharoptosis compared with the age-matched control group. However, no differences between the two groups were found, which suggests that either the anatomic changes that cause aponeurogenic blepharoptosis do not affect eyelid motility proper, or they are compensated for, or our recording method may have been too insensitive to detect any differences in eyelid motility. This result partially concurs with a previous study by Frueh Musch[4] who measured levator force and established no difference between patients with aponeurogenic blepharoptosis and the control group. There apparently is no muscular degeneration in aponeurogenic blepharoptosis.[24] Therefore, the integrity and motility of the levator neuromuscular system probably remains unaffected, despite a lower lid position with a higher lid crease in some older subjects.

The blepharoptosis associated with contact lens wear is clinically similar to that in patients with age-related aponeurogenic blepharoptosis, which suggests a similar pathogenesis. Of interest, our patients with CLB showed markedly different motility, which was not age-related. The amplitude and peak velocity they produced were significantly larger, suggesting that either the cause of the blepharoptosis was different, or that the compensatory oculomotor mechanisms of the two groups were different. Such mechanisms may vary with age.

Eyelid excursion relates to the number of functioning sarcomeres in a myofibril.[25] Muscle force, however, does not depend on this number but on the cross-sectional area of functioning muscle fibers.[26] Maxwell et al.,[27] in their study on a chronically stretched masseter muscle found an increased sarcomeres count, without any change in the cross-sectional fiber area. We therefore propose that repetitive stretching of an eyelid, such as may occur when removing a contact lens, might similarly increase the sarcomeres count and eyelid excursion. Lengthening of the levator muscle may occur, yielding a lower eyelid position. Such an explanation is corroborated by the finding of a strong correlation between levator function and exophthalmometer readings in Graves' disease.[28] Muscle strength, however, is unaffected by stretching, as was demonstrated by Frueh and Musch.[4]

Patients with congenital myogenic blepharoptosis clinically show a smaller eyelid amplitude, supposedly because of the poor development of the levator palpebrae muscle proper. We also found smaller eyelid amplitudes. Moreover, saccadic peak velocity was disproportionately lower. Possibly, this was due to the absence of myofibrils and to changes in the elastic tissues of the levator muscle. Apparently, search coil registration can differentiate reliably between congenital myogenic blepharoptosis and aponeurogenic ptosis.

In patients with bilateral blepharoptosis, the most ptotic upper eyelid was included for analysis, although the two were simultaneously recorded. Several clinical studies suggest that Hering's law of equal innervation of the extraocular muscles may apply to lid movements,[29,30] which may lead to overelevation of an eyelid contralateral to a ptotic eyelid. Neuroanatomic studies in primates have shown that the motor neuronal pool for both levator palpebrae muscles lies within the unpaired central caudal nucleus.[31–33] However, in eye movements Hering's law probably results from nonconjugate adaptation to the effects of aging and disease.[33–37] The bilateral control of lid saccades is much less conjugate than that of eye saccades.[14] Probably, adaptation occurs only if a functional need arises, (e.g., to retain sight in both eyes). It is unclear from our study to what extent, if any, an equal innervation of the lid movements, similar to Hering's law, affected our measurements.

We have demonstrated that search coil registration is of additional value in the examination of patients with blepharoptosis. However, we have not yet established its full clinical potential, notably on an individual level. The assessment of eyelid motility in other kinds of blepharoptosis would be of further interest.

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