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Functional topography as a guideline for differential diagnosis of vertical eye movement disorders and oblique muscle surgery

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Summary. *Aims:* The differential diagnosis of congenital superior oblique paresis (strabismus sursoadductorius), acquired superior oblique paresis and inferior oblique overaction are discussed. In this study the purpose of the graphic description of a lever arm, "equal-line", crossing points of equal lines, "functional pole", in primary position (functional topography), are described. The efficacy of functional and mechanical guidelines for oblique muscle surgery are discussed.

Patients and methods: The pattern of motility disorders (clinical measurements of three patients), congenital oblique paresis (strabismus sursoadductorius SSA), aquired superior oblique paresis (SOP) and inferior oblique overaction (IOO) are compared with the mechanical situation (functional topography) of eye-motility.

Results: In a mechanical eye model SSA can be created as a concomitant vertical pattern of movement disorder with excyclorotation by a sagittalisation of the functional inferior oblique muscle origin (pulley-displacement). SOP with normal functional origin and insertion of superior and inferior oblique muscle can be created only by weakening (less muscle strength) the superior oblique muscle. IOO is constructed by a sagittalisation of muscle insertion of inferior oblique muscle and desagittalisation of insertion of superior oblique muscle. An ideal insertion line of the oblique muscles can be created at the surface of the eyeball by connecting points of the same main function. There are crossing points (areas) of this equal line projected at the "functional pole" at different gaze positions. At this equal-line the oblique muscle has to be fixed in recession or reforcing surgery to get a normal eye function.

Conclusion: The findings of Bielschowskys' strabismus sursoadductorius as a vertical motility disorder with its own typical clinical appearance as well as SOP and IOO are confirmed by the clinical and vectorial results. In oblique muscle surgery a functional topography helps to prevent errors in eye muscle surgery.

Key words: Functional topography, equal lines, functional eye pole, origin-, insertion-sagittalisation, str. sursoadductorius, inferior oblique overaction, superior oblique palsy.

Zusammenfassung. *Einleitung:* In dieser Studie wird die Differentialdiagnose der kongenitalen m.obliquus superior-Parese (strabismus sursoadductorius, SSA), der erworbenen m.obl.superior-Parese (SOP) und der m.obliquus inferior-Überfunktion (IOO) erläutert. Dem Zweck der Beschreibung und graphischen Darstellung von idealen Ansatzlinien in Primärposition und deren Kreuzungspunkte – „funktionelle Pole" (funktionelle Topographie) wird nachgegangen. Die Bedeutung dieser Richtlinien für die Chirurgie der schrägen Augenmuskeln wird aufgezeigt.

Patienten und Methode: Die Motilitätsmuster klinischer Messungen eines SSA, einer SOP und einer IOO werden mit Mustern eines mechanischen Augenmodells verglichen.

Ergebnisse: Der SSA als konkomitante vertikale Abweichung mit typischer Excyclorotation kann in unserem mechanischem Augenmodell nur durch Sagittalisation des funktionellen *Ursprungs* (pulley displacement) des m.obl.inferior, geringer des m.obl.superior nachempfunden werden. Die SOP wird allein durch geringere Muskelstärke (Gewichtung) bei normalen Ursprungs- und Ansatzverhältnissen dargestellt. Die IOO ist durch Sagittalisation (steiler Ansatzwinkel) des m.ob.inferior-*Ansatzes,* Desagittalisation (weniger steiler Ansatz) des m.obl.superior-*Ansatzes* zu simulieren. Eine ideale Ansatzlinie der schrägen Augenmuskeln läßt sich durch Vereinigung aller jener Punkte gleicher Wirkung (keine Buchstabensymptomatik) auf die Augenoberfläche projezieren. Der Schnittpunkt dieser Linie ohne Buchstabensymptomatik – „funktioneller Pol" in den Blickrichtungen lässt sich festlegen. Bei der Rücklagerung oder der stärkenden Operation muss der schräge Augenmuskel in Richtung funktionellem Pol verlagert werden um eine normale Augenfunktion zu erreichen.

Schlussfolgerung: Die Erkenntnisse Bielschowskys der SSA sei eine vertikale Augenmotilitätsstörung mit eigenem typischem Erscheinungsbild, deutlich von der SOP und IOO abgrenzbar, lässt sich klinisch und mechanisch nachweisen. Eine „funktionelle Topographie" hilft bei der obliquus-Chirurgie Fehler zu vermeiden.

Schlüsselwörter: Funktionelle Topographie, Linien gleicher mechanischer Wirkung – equal lines –, funktioneller Pol, Ursprungs-, Ansatzsagittalisation, strabismus sursoadducto-

rius, Überfunktion des m.obl.inferior, erworbene m.obl.superior Parese.

Introduction

The movement apparatus of the eye is surprisingly complex to describe. Each eyeball is moved by six extraocular muscles (EOMs), each of which has a different pulling direction. Therefore a certain eye position does not automatically determine the innervation of the six EOMs. For example there may be a situation of muscle contraction of two antagonistic horizontal muscles, where the eyeball remains stationary in spite of a mechanic imbalance of the two muscles. To relate different eye positions to a muscle activity and mechanical situation different models have been developed [9, 12]. While each of the different models has its own advantages, they sometimes lead to different guidelines and predictions for operations [2, 7, 8].

In the present paper we introduce a model, in which the action of each of the EOMs is described by a string with a fixed origin and a fixed insertion point on the eyeball. In addition to previous models, this provides a simple visualisation of eye movements, motility disorders and surgical methods. By varying functional muscle origin, -insertion and weighting this model allows us to simulate different patterns of eye motility disorders. The model is especially suited to visualize the actions of the oblique muscles, because of their changing of the pulling direction in different gaze positions. Predictions of the model are compared with the results of actual operations on three patients and show good correlations.

Methods

Model

The human eye – like any other body – has six degrees of freedom: it can move up-down, left-right, and forward-backward (three degrees of freedom), and it can rotate about any of the three axes of a Cartesian coordinate system (the other three degrees of freedom). In our descriptions of movement, we use a coordinate system such that the x-axis points to the left, the y-axis forward, and the z-axis up (Fig. 1). The dominant movement of the eye is the rotation, and in the following discussion we will ignore the small translations of the eye in the orbit. Thus, the movement of the eye can be approximated by the rotation of a sphere around its center. Rotations of the eye are caused by contractions of at least one of the six extraocular muscles. For simplicity, let us approximate the action of a muscle by a string, which is attached to the globe. The point of attachment of the string on the globe is called "attachment point" ("AP" in Fig. 1). The last point of contact between the string and the sphere, before the string leaves the globe, is called "insertion point" ("IP" in Fig. 1). The line between AP and IP is the "arc of contact". If the extraocular muscles would move freely in the orbit, they could be approximated by a straight line between their origin and the IP. But recent studies [9] have shown that the extraocular muscles are attached to the walls of the orbit by elastic and fibrous tissue. The effect of this holding structure can be approximated by a pulley, which is introduced in the path of the extraocular muscles. Since the action of the string-muscle on the globe is not determined by its real origin, but by the location of this pulley, the location of the pulley is referred to as "functional origin" ("FO" in Fig. 1).

Now what happens to the sphere when the muscle contracts? The only movement the sphere can execute is by definition a rotation. The rotation is elicited by the torque acting on the sphere. Mathematically, the torque is given by the cross product between the vector C-IP and the force F. The eye is rotated about an axis perpendicular to the plane spanned by the points FO, AP, and C (Fig. 1). Therefore, we describe the action of the muscle pull by a vector along the axis of the rotation, the length of this vector being proportional to the magnitude of the torque. For the left eye, a positive component of this vector along the z-axis corresponds to an abduction of the eye, a positive component along the y-axis to an intorsion, and a positive component along the x-axis to a downward movement.

This simple model already reveals a number of points which are relevant for strabismus operations:

a) if the AP is shifted along the arc of contact (or even along the small sector of the circle which is generated by the continuation of that insertionline), the direction of the eye movement caused by a contraction of the muscle stays unchanged. In other words, a transposition of the muscle attachment along this line described later on as "equal-line" can only weaken or strengthen the muscle, but not affect its pulling direction.
b) Conversely, transposition of AP to any point which does not lie along this small circle changes the pulling direction of this muscle.
c) A change of the location of FO also changes the pulling direction of the muscle.
d) Attaching the muscle somewhere along the line generated by the posterior extension of the "arc of contact" decreases the torque generated by this muscle (according to the so called "Fadenoperation").

Taking into consideration eye movements, especially

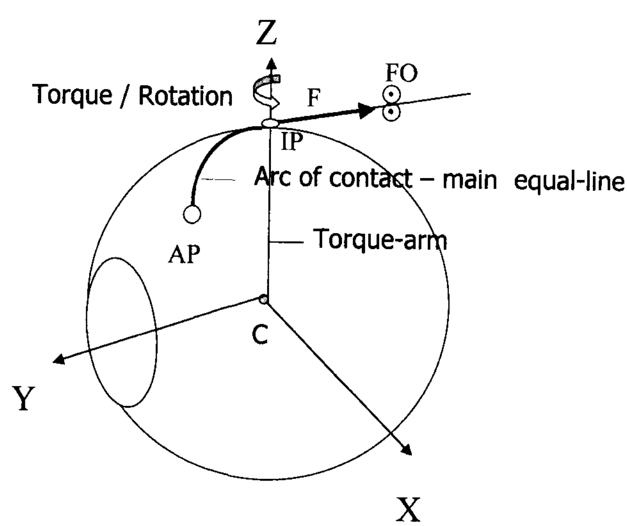


Fig. 1. The functional situation of an eye and muscle is determined in an orbital coordinate-system by x-, y- and z- coordinates. AP attachment point (tangential point); IP insertion point; AP–IP arc of contact, Z-0-equal line for superior and inferior oblique muscle; FO functional origin, pulley

those of the oblique muscles, the model is used to describe the action of a muscle pull by its vector components in the nine positions of gaze. The function of a muscle is to influenced by its weight in the model.

An important factor for the physiological course of an eye motion is the arc of contact (Fig. 1). An adequate arc of contact (Tables 1, 2) makes gaze motions possible *without retracting effect* in the common field of gaze [1], then there is only a physiologic rotation of the eye without deformation of the bulb. Every eye muscle has its main function in a certain field of gaze [7]. In addition to elastic, contractile and neural factors, the position of the "rotation center or centrode" (Fig. 1) influences in eye movements the covering distance of eye muscles.

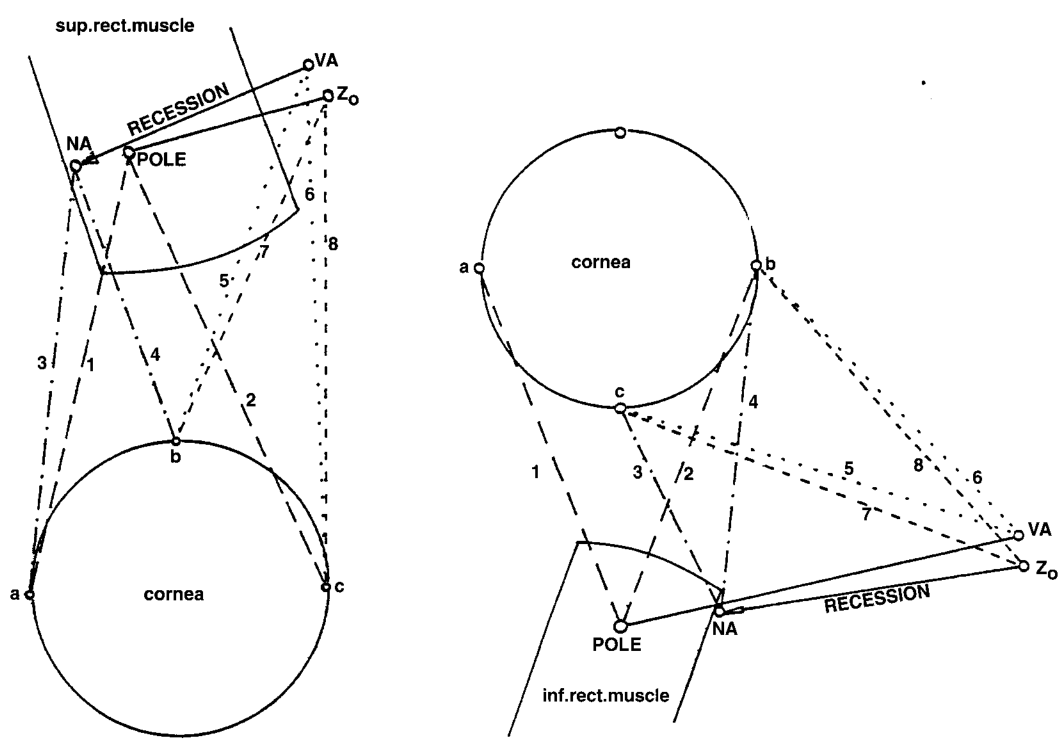
A term equal-line (Fig. 1) is useful for understanding our concept. A set of all insertion points with the same effect of a certain elevating-, depressing-, rotating and ab-, adducting components is denoted as equal line. Normally all possible torque lines with Z-component 0, where no ab-or adducting effect exists, run over the *functional pole* (Fig. 13), (directed and stabilised there by the *pulleys*). With respect to the so-called equal-line the purpose of muscle surgery must be to achieve a defined pulling direction of a muscle by recessing or resecting the muscle at this *well defined equal-line.* This is not the problem in combined surgery of recti muscles but especially in *surgery of oblique muscles* with their essential alterations of function (pulling directions) in adduction (elevation, depression) and abduction (cycloratation).

In primary position and vector balance of the four recti muscles the oblique muscles are responsible for the orthoptic situation as well. If the resulting muscle insertion (in modified thread model) is situated in front (in the direction of cornea) or behind (in the direction of n.opticus) the ideal Z-0-equal line (deflected for example by displaced muscle sheets-functional origin) an abducting or adducting effect, a horizontal incomitance in the vertical direction of gaze, an alphabet pattern developes (see simulations Fig. 6).

Thus for the oblique muscles the resulting muscle power is ideally situated at the Z-0-equal line in our "normal eye model". The vector components (pulling direction) of the oblique muscles of our patients were simulated in our computer program and writen down similar to a clinical alignment test which is used for a Synoptometer. We obtained the eye position in 30 degrees abduction, adduction, 30 degrees up-and down-gaze and primary position, that means the nine main positions of gaze. The cyclorotation (incyclo minus, excyclo plus) is symbolised in numbers. The deviation of a gaze position (small circles in Figs. 4–10) is depicted by the tip of a line (Figs. 4–10).

(Data of coordinates of muscle origins used by Robinson-Miller and Simonsz 9, 12 were used and modified in relation to MRI measurements).

Strabismus surso-, deorsoddutorius, acquired superior oblique paresis and inferior oblique overaction were simulated and their pattern of motility compared with three clinical patients also suffering from strabismus sursoadductorius, deorsoadductorius and overaction of both oblique muscles (Patient 1–3). Our computer program also allowed us to ob-



Figs. 2, 3. 1. Preoperative: The length of the eyeball is measured with an ultrasound unit of Storz (Combi-Scan). Two distances (1, 2) for marking the eyeball are determined. 2. From the measurement points at the margin of the cornea (b, c, distance 5, 6) the distance to the point in front of the oblique muscle insertion is measured. 3. An arc of contact is calculated (not shown) and the insertion point is marked at the equal line with no abduction (Z-0-equal-line, distance 7, 8). 4. The desired recession slightly beyond the upper or lower functional eye pole (arrow) and the designated distances (3, 4) at the Z-0-equal line are calculated. NA: New insertion point. VA: anterior insertion point tain the measurement marks of three patients for recession and strengthening in oblique muscle surgery (the consent to publication was given by the patients).

Results

The pulling directions of the superior and inferior oblique muscle of our "normal computer model" were calculated and the arc of contact in the nine main gaze position determined to get information about the dynamics of these muscles.

Table 1. Arcs of contact of the superior and inferior oblique muscle in the nine positions of gaze (functional origin and insertions see above) in mm. Arc of contact of the superior oblique muscle:

Adduction	Primary position	(PP) Abduction
9.0	8.4	6.9
5.4	5.4	4.3
2.4	3.2	3.1

The *dynamics* of muscle is in accordance to the *difference between contraction and relaxtion* in 25 degrees gaze up position and 30 degrees gaze down position in adduction: 6.6 mm, in abduction: 3.8 mm

Table 2. Arc of contact of the inferior oblique muscle:

Adduction	Primary position	(PP) Abduction
13.0	13.6	12.0
14.8	16.6	15.6
16.9	20.1	20.6

Dynamics of inferior oblique muscle in adduction: 3.9 mm; Dynamics of inferior oblique muscle in abduction: 8.6 mm

We have tested which changes to a normal superior and interior oblique muscle (funct. origin of obl.sup.m.: x: 15 y: 6.95 z: 12; insertion coordinates:x: –3.4 y: –4.1 z: 11.2; origin of inf.obl.m.: x: 11.0 y: 8.9 z: –15.46; insertion: x: –8.4 y: –9.1 z: –.4) are necessary to reproduce the eye movement pattern observed in patient 1, who suffered from SSA. Fig. 4

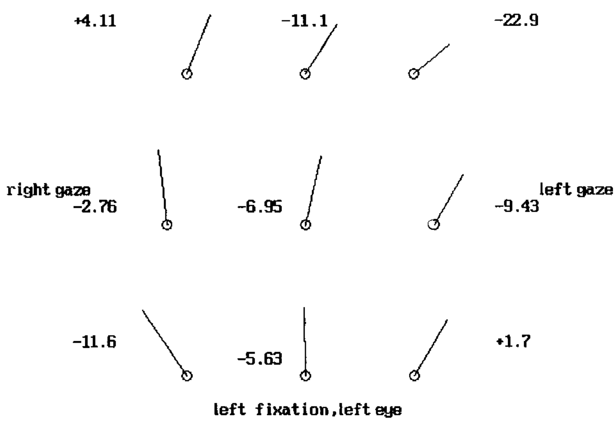


Fig. 4. Sagittalised origin coordinates of the superior oblique muscle: (mm) x: 15, y: 6.95, z: 12; Weighting: 0.5; Insertion coordinates: x: –4.5, y: –2.1, z: 11.41; Sagittalised functional origin coordinates of the inferior oblique muscle: x: 11.1, y: 15, z: –15.4; Weighting: 1.5; Insertion coordinates: x: –7.3, y: –9.9, z: –1.0

shows the result. In our experience the ideal equal-line for the superior oblique muscle is defined by the trochlea and the pole (ideal Z-0-Line, Fig. 1). In the computer model it is necessary to sagittalise (the angle between insertion- line and primary postion becomes smaller) the origin of the inferior oblique muscle more than that of the superior oblique muscle and to strenghten the vector components of the inferior oblique muscle by 50 %, to weaken that of superior oblique muscle by 50 %,in order to get a pattern similar to that of strabismus sursoadductorius in the nine positions of gaze.

The pulling directions of the strabismus deorsoadductorius (Fig. 5) demonstrate a reverse situation.

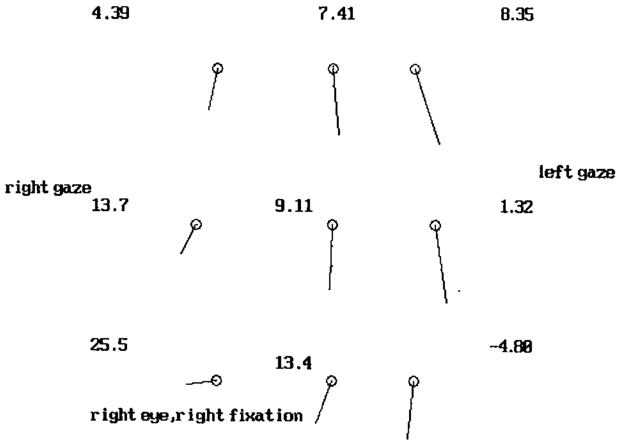


Fig. 5. Computer simulation of SDA. Patient number 2, Table 2; Sagittalised origin of the superior oblique muscle: x: 12, y: 12, z: 13; Insertion coordinates according to Z-0 torque line; Weighting: 1.5; Inferior oblique muscle: coordinates of origin: x: –11.1, y: 8.9, z: –15.46; Weighting: 0.5; Instertion coordinates according to Z-0 equal line.

Inferior oblique overaction of both eyes, patient Nr. 3, Table 5 is not simulated, but the clinical data for patient Nr. 3 are given in Table 5. The cyclorotation and horizontal deviation would add up. But in Fig. 6 the model of the desagittalisation of the inferior oblique muscle insertion and the desagittalisation of the superior oblique muscle insertion of one eye is demonstrated.

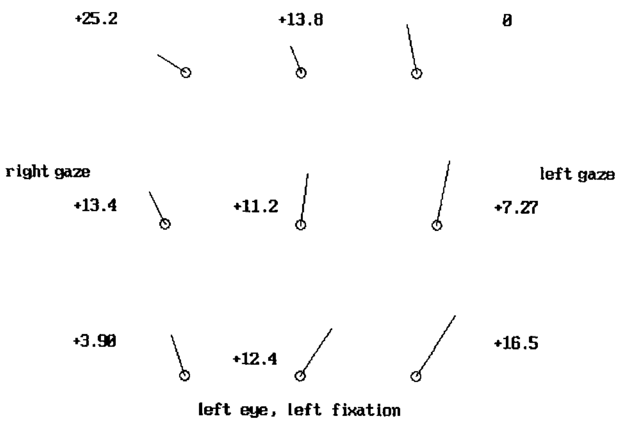


Fig. 6.

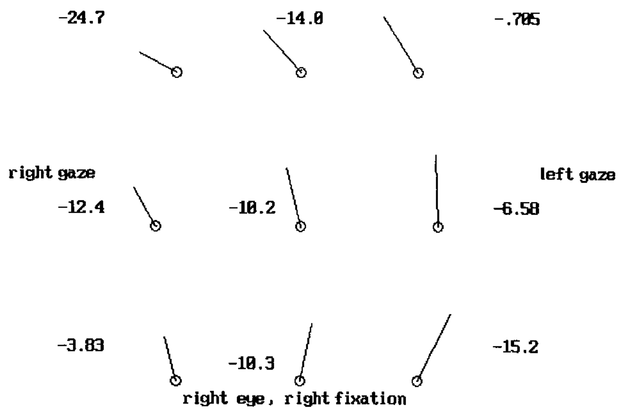


Fig. 7.

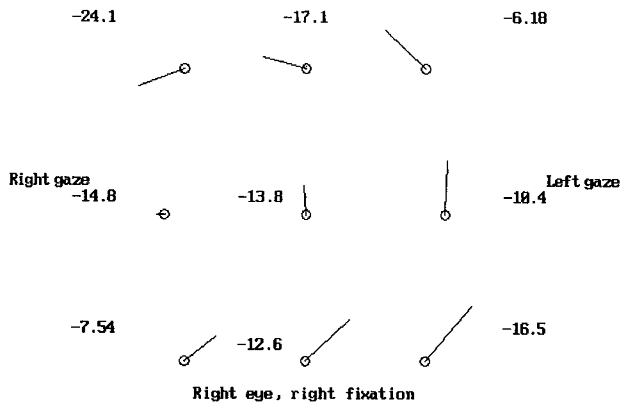


Fig. 9.

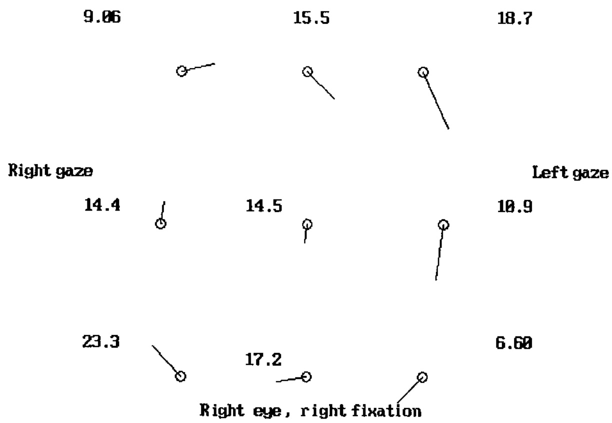


Fig. 8.

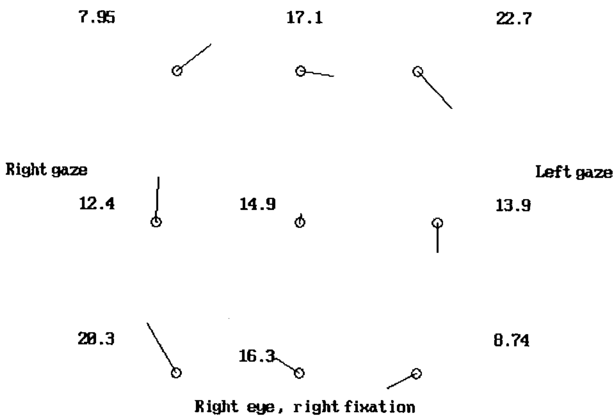


Fig. 10.

In the model a superior oblique palsy (Fig. 7) is generated by its *normal muscle orgin* of the superior and inferior oblique muscle and in our eye model 90 % weakened vector components of the superior oblique muscle and 90 % strenghtened vector components of the inferior oblique muscle (incomitant pattern in up and down gaze in Fig. 7).

In Fig. 8 the model of a superior oblique muscle *reinforcing surgery-modified Harada-Ito-operation* – (patient Nr. 1) is combined with an inferior oblique muscle recession nearest the functional pole. In our patient Nr. 1 the vertical deviation was more than ten degrees.

Figure 9 demonstrates the model of recession (patient Nr. 2) of the superior oblique muscle at the superior pole.

Figure 10 demonstrates a simulation of a normalising effect (computer model) of fixation of the inferior oblique muscle alone nearest to the inferior functional pole-recession – (our patient Nr. 3).

Case reports

Patient number 1

aged fourty two years, suffering from strabismus sursoadductorius sin., subjective diplopia since two years, especially at near distance, elevation of the eye in left gaze, primary position and right gaze.

Praeoperative:

Horizontal and vertical deviation at a distance of six meters, measured with the prism positioned in the direction of maximal adduction and abduction of both eyes and in the nine directions of gaze. The first number for the nine directions of gaze (in the following tables Nr. 3–5) is the horizontal deviation, the second number the vertical deviation.

Table 3a. Right fixation, left fixation: Small right head tilt. Alphabet pattern. Two prism diopters limitation of depression in adduction sin. Binocular function: Bagolini pos (near and far distance)

Right gaze		PP		Left gaze	
–6	–2	0	–10	0	–17
0	–28	0	–28	–2	–28
0	–25	0	–28	–2	–23

Adduction

	Right tilt	Left tilt
Up gaze	–20	> –25 in prism diopter
Primary position	–25	> –25
Down gaze	–18	> –25

Cyclorotation

	Right gaze	PP	Left gaze
Right fixation	2 degress excyclo	3 degrees excyclo	2 degrees excyclo
Left fixation	0 cyclo	1 degree excyclo	0 degree cyclo

Postoperative:

Table 3b. Binocular function: without head tilt for near and far distance positive

Postoperative

Right gaze		PP		Left gaze	
–2	–4	0	–3	0	0
2	8	0	–5	0	1
0	–10	0	–8	0	0

Adduction

Bielschowsky head tilt test:

	Right tilt	Left tilt
Up gaze	0	–6 in prism diopter
Primary position	–1	–6
Down gaze	–4	–8

Patient Nr. 1, Table 3, was corrected by a recession of the left inferior oblique muscle along the Z-0-equal line toward the inferior eye pole (analogous to Figs. 3, 8) and the left superior oblique muscle was reinforced by splitting its tendon.

Patient Nr. 2

aged fourteen years. Diagnosis: strabismus deosoadductorius dxt.>sin. (Table 4), nystagmus congen., variable convergent angle, congential nystagmus and ptosis congential on the right side (function of levator muscle: zero mm) three degrees incyclotropia with right eye fixation; minimal head tilt with variation from right to left and twenty prism diopters A pattern.

Praeoperative:

Horizontal and vertical deviation at a distance of six meters, measured with the prism positioned in the direction of maximal adduction and abduction of both eyes and in the nine directions of gaze.

Table 4a. Right fixation: Five degrees right to left tilt. Left Fig fixation: Three degrees left turn

Right gaze		PP		Left gaze	
0	–12	+14	–24	0	–16
0	–6	–6	–14	0	–14
0	–25	–6	+2	0	–6

Alphabet pattern: Twenty prism dptr. A-exotropia. Motility: Reduction of elevation in adduction on the right side, depression in adduction on both sides, nystagmus latens on both sides. Forced duction test: Limitation of passive duction up and down in adduction on the left side.
Bagolini test: At near distance positive.

Cyclorotation:

	Right gaze	PP	Left gaze
Right fixation	0 degree incyclo	3 degrees incyclo	0 cyclo
Left fixation	0 cyclo	0 cyclo	0 cyclo

Postoperative:

Table 4b. Right fixation: Two degrees right turn. Left fixation: Two degrees left turn. Alphabet pattern: Sixteen degrees A-exotropia

Right gaze		PP		Left gaze	
0	0	+8	–4	+6	–5
0	+12	0	+4	0	–6
0	+18	–8	+6	–10	+4

Motility: Slight reduction of depression in adduction on the right side, mild reduction of elevation and depression in adduction on the right side.

Bagoloni test: At far distance and at near distance positive.

Cyclorotation:

	Right gaze	Left gaze
Right fixation	5 degree excyclo	0 cyclo
Left fixation	0 cyclo	2 degrees excyclo

Previous surgery of patient Nr. 2 had consisted of suspension of the right eye lid and splitting surgery of both recti int. muscles.

On the present occasion: surgery of the right superior oblique muscle was performed. The sup. obl. muscle was cut off at its insertion and refixated with a single suture at the superior functional eye pole, i.e a ten-millimeter recession along the Z-0-equal line (Figs. 2, 9) was performed.

Patient Nr. 3

A fifteen years old patient. Diagnosis: Musculus obliquus overaction sin.>dxt., after m.rect.internus Faden surgery on both eyes, presented now with *alternating hyperdeviation* in primary position, pronounced elevation and overaction of *both* inferior oblique muscles, no head tilt and slight exotropia.

Praeoperative:

Horizontal and vertical deviation at a distance of six meters, measured with the prism positioned in the direction of maximal adduction and abduction of both eyes and in the nine directions of gaze.

Table 5a. Right fixation, left fixation, binocular: No head tilt. Alphabet pattern: V-esotopia of five prism. dptr. Motility: Elevation in adduction sin.>dxt., inferior oblique muscle overaction sin.>dxt., superior oblique muscle underaction sin.>dxt. Bielschowsky head tilt test negative. Forced duction test: Regularly

Right gaze		PP		Left gaze	
+10	−13	+10	−2	−6	−2
+14	−10	+14	0	−4	+6
+16	−8	−5	+16	+12	+6

Cyclorotation:

	Right gaze	PP	Left gaze
Right fixation	3 degrees excyclo	0 cyclo	0 cyclo
Left fixation	0 cyclo	0 cyclo	3 degrees incyclo

Postoperative:

Table 5b. Right fixation, left fixation, binocular: No head tilt. No alphabet pattern. Motility: Mild evalation in adduction sin.>dxt., small overaction of the oblique m.

Right gaze		PP		Left gaze	
+8	−3	0	0	−2	0
+4	−4	0	−1	+6	+3
+6	0	0	0	+6	+2

Cyclorotation: Right fixation: 0. Left fixation: 5 degrees incyclorotation.

The patient Nr. 3 was operated by recession of both inferior oblique muscles along the Z-0-equal line (Figs. 3, 10) toward the lower functional pole of the eye (on both eyes ten mm, therefore on the right side 2.8 mm away from the inferior pole, on the left side fixed immediately at the pole).

Discussion

Vertical eye motility disorders

Vertical eye motility disorders were classified by Bielschowsky and Kolling as follows:

1. Concomitant vertical deviation in all directions of gaze
2. Strabismus surso-and deorsoadductorius
3. Dissociated vertical divergence
4. Vertical deviation with palsy
5. Special vertical deviations

Kolling characterises strabismus sursoadductorius as a congenital *concomitant* vertical deviation especially in adduction, with *excyclorotation* in abduction and a slight horizontal incomitance (alphabet pattern) and binocular functions (patient Nr. 1, Table 3). Bielschowsky describes this disorder as a "primary predominance" of the inferior oblique muscle [1]. Kaufmann [7] is of the opinion that this is not plausible, because of strabismus convergens and the *V-pattern.* He suggests the *sagittalisation* of the muscle *insertion* of the inferior oblique muscle and desagittalisation of the superior oblique muscle *insertion* would cause an *incyclorotation* and not an *excycloratation;* a slight excyclorotation being typical for a strabismus sursoadductorius.These situations are demonstrated with our computer model (Fig. 6). This pattern of squinting in Fig. 6 is not in accordance with that of Kolling's well defined concept of strabismus sursoadductorius (incyclorotation-plus numbers- predominates in the nine gaze positions).

In contrast in our model strabismus sursoadductorius was created by *sagittalisation* of the *inferior* and less the superior oblique muscle *origin* as demonstrated in Fig. 4, and therefore is a vertical movement disorder with *its own typical clinical appearance.* Sagittalisation of these muscle origins is associated with *excyclorotation* as seen by the dominance of excycloration data (Fig. 4, negative torsion values). The elevating component (tips of the lines) is observed. There is only a small V-pattern (small deviation of the tip of the lines in up and down gaze in comparison to the basic circles). A medial rectus muscle superior dislocation of the muscle-sheet brings also a concomitant eye elevation of the same side but with less elevation and less *excyclorotation!* [9]

In contrast a superior oblique palsy (Fig. 7) is defined as an incomitant pattern of motility disorder [8]

Clinical signs of trochlear palsy according to Boergen [4]:
Incomitant excyclodeviation in down gaze
Negative head tilt test by Bielschowsky in up gaze
Vertical incomitant deviation
Alphabet pattern
Less vertical deviation in primary position
Small fusion

The pattern of vertical incomitance of superior oblique palsy (Fig. 7) can be seen in the simulation of up and down gaze and depends on weighting of vector components of the superior oblique muscle. In comparison to strabismus sursoadductorius (Fig. 4) larger *excyclorotation and elevation in downgaze* of trochlear palsy is apparent.

The strabismus deorsoadductorius (patient Nr. 2 ,Table 4), page 21, Fig. 5, is explained in the same manner by sagittalisation of the muscle origin.

Kaufmann mentions normally 51 degrees sagittalisation of the inferior oblique muscle, but he does not distinquish between sagittalisation of origin or insertion.

In comparison to the "normal eye" there is much more sagittalisation of the inferior oblique *muscle origin* and the superior muscle origin in strabismus sursoadductorius and reverse in strabbismus deorsoadductorius.The predominance of the inferior oblique muscle described by Bielschowsky can be explained in our eye model by a slight sagittalisation of inferior oblique muscle origin.

Surgical considerations

Neither can the origin of the inferior or superior oblique muscle be ascertained exactly anatomically by MRI, nor can be operated there. Therefore the weakening of the inferior oblique muscle predominance by its recession is the best solution.

Kolling also describes an effective long lasting effect of inferior oblique muscle recession.

For the recession of the superior resp. inferior oblique muscle the *functional eye pole* and for orientation the ideal Z-0 equal line as an insertion line with no ab-or adducting ef-

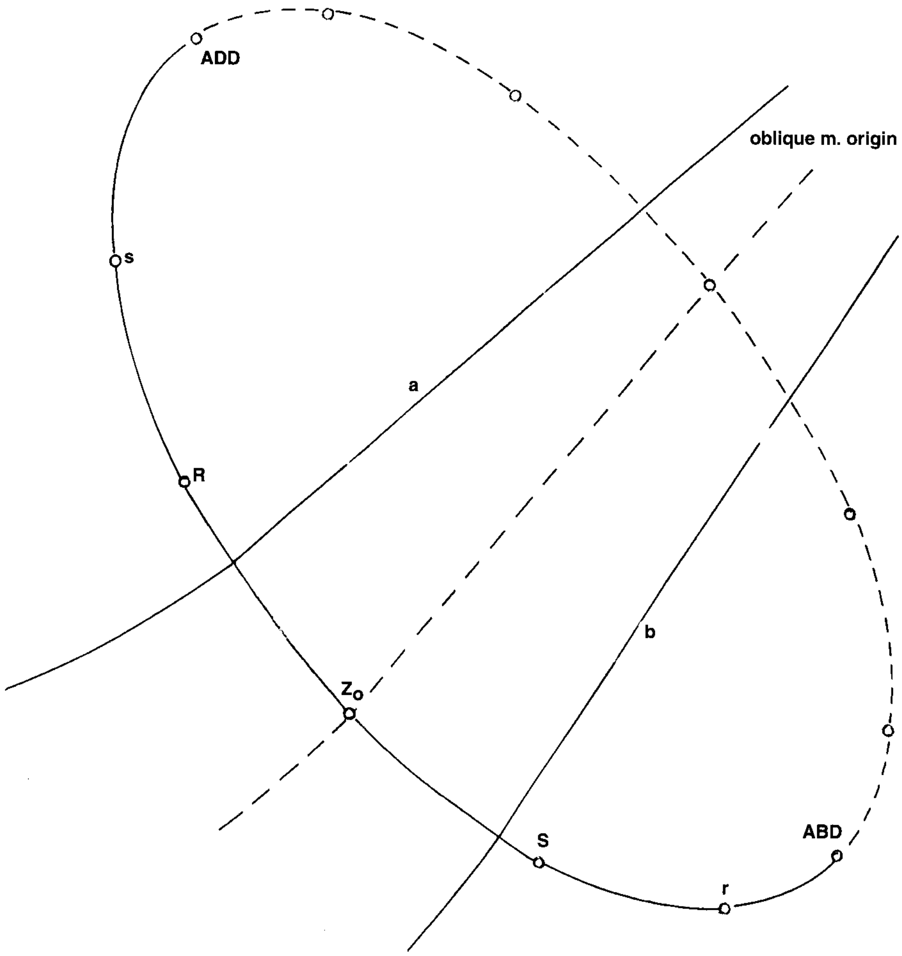


Fig. 11. This figure demonstrates the theoretically possible tangential muscle insertions (limited by pulleys) away from the oblique muscle origin (of the superior or inferior oblique muscle) at the surface of the eye, without the arc of contact. Z0 insertion point with z-component zero (no adduction or abduction; R insertion point with predominance of the torsion-component; r insertion point with minimal torsion-component; S insertion point with maximal depression; s insertion point with minimal depression; Add insertion point with maximal adduction; Abd insertion point with maximal abduction; a, b borders of the oblique muscle

fect are very important in oblique muscle surgery (see page 24, Fig. 12).

Approaching the pole (Figs. 2, 3) diminishes in all cases the vector components, especially the alphabet pattern. The alphabet pattern is corrected *independent* of the operated distance. Kolling [8], Boergen and Brenner [4], Kaufmann [7] suggest a possible dose-effect relationship in the surgery of vertical deviations of oblique muscles (Kolling, for instance uses 6-, 8–10 mm recessions) but *not in the alphabet pattern.* This can now be explained by the topographic situation as demonstrated in Fig. 11: Z-0-line with no ab-or-abducting effect.

Irrespective of wheather the oblique muscle insertion was close or far from the ideal Z-0-equal line, maxima and minima were left and a new insertion may me reached at the Z-0-equal line with *no adduction* (Fig. 12).

Before and during oblique muscle surgery (case reports and Figs. 2, 3) a Z-0-equal line is to be calculated in accordance with the muscle origin of assumed normal data. These data are compared with the measured insertion point of the anterior part of the oblique muscle (case reports 1–3).The arc of contact, the distance from the determined eye pole and the necessary muscle recession can be derived from it with the aid of a computer program.

Since we are not aware of the exact oblique muscle origin or the rotating center of the eyeball, the ideal Z-0-equal line can neither be calculated exactly nor measured, but all possible Z-0-equal lines of oblique muscle origins are crossing at the functional eye pole (Fig. 13).

Knowledge of the position of the superior and inferior pole (projection of coordinates: x: 0, y: 0, z: + –; page 4, Figs. 2, 3) is very important for orientation in oblique eye muscle surgery.

Besides the functional pole as a point for orientation, the clinical investigation is decisive for our calculations (Boergen [2], Kolling [8]:

Earlier photographs
Head tilt in up and down gaze
Vertical and horizontal deviation in greatest adduction and abduction

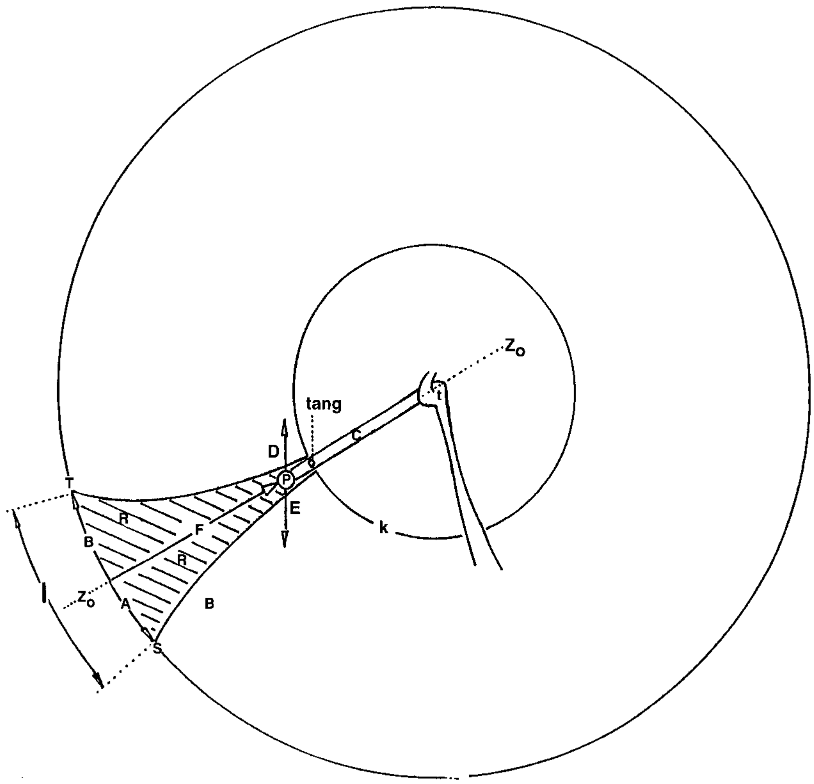


Fig. 12. Projection of the trochlea (t) and of a possible tangential point (tang) on the surface of the eye (view from above) creating a small circle ... k; Zo insertion line (equal line) with the arc of contact; I Possible sector of muscle insertion with the arc of contact R; P functional pole with rotating center; R lined area, covering of oblique muscle; I insertion of the oblique muscle at the insertion line I. The resulting muscle strength (Z-o-equal line) moves at arrow A to point S, the maximal depression (S) predominates. Conversely, in abduction the distance from arrow B to point T is followed, the maximal incyclorotating component predominates. C symbolises the small insertion string at the functional pole, there is no movement in adduction or abduction. D, E the arrows demonstrate the movement of the functional pole in up and down gaze (fibromuscular connections – also termed pulleys – may hold the muscle or tendon near this functional pole). In recession or resection (reinforcement) of the oblique muscles the new insertion has to be in approximation of P (arrow F) at the Z-0 equal line

Concomitance, incomitance and alphabet pattern
Measuring of cyclorotation in all directions of gaze
Subjective: fundussoope
Marlow occlusion

To get closer to the functional eye pole and muscle origin at the ideal Z-0-equal line is to get the best functional correction by surgery. This is most important as the equal lines with their convergent course in the direction of the muscle origin minimise their distances, and consequently the *width* of a possible muscle insertion is also *minimised.*

It is therfore dangerous to insert the oblique muscle with a broad muscle width near the functional pole. Otherwise equal lines (lever arms) with inappropriate vector components become effective in relation to gaze position (Fig. 11).

A *single muscle suture* (Boergen) is in conequence therefore prefered (Fig. 15). We followed these directions in oblique muscle surgery in our patients (Tables 3–5). The inferior oblique muscle of patient Nr. 1 was recessed by ten millimeters. The new insertion was then made at a distance of four millimeters from the inferior functional pole (at the lateral margin of the inferior rectus muscle, advanced by two millimeters toward to the inferior rectus muscle insertion (Fig. 3).There was still an arc of contact.

In patient Nr. 2 (Table 5) the superior oblique muscle was situated postoperatively at the medial margin of the superior rectus muscle, at a distance of four millimeters from its insertion, two millimeters behind the medial border of the muscle (Figs. 2, 9). The operated data are in accordance with reference values for oblique muscles given by Boergen, Kolling and Kaufmann. In contrast to the weakening procedure of the superior oblique muscle the reverse situation demonstrates the reinforcing surgery of the superior oblique muscle, the so called modified Harada Ito operation (strengthening of oblique superior muscle with splitting, Table 3, Fig. 14). It demonstrates in our computer model (Fig. 8) that in horizontal gaze direction and minimally in other positions of gaze, the adducting and abducting components are nearly zero (horizontal deviation of the tips of the lines from the *circles; alphabet pattern*). The elevating function of the inferior oblique muscle is weakened, the depression and incyclorotation is done *simultanously* by recession of the inferior oblique muscle (Patient Nr. 1), simulated in Fig. 8.

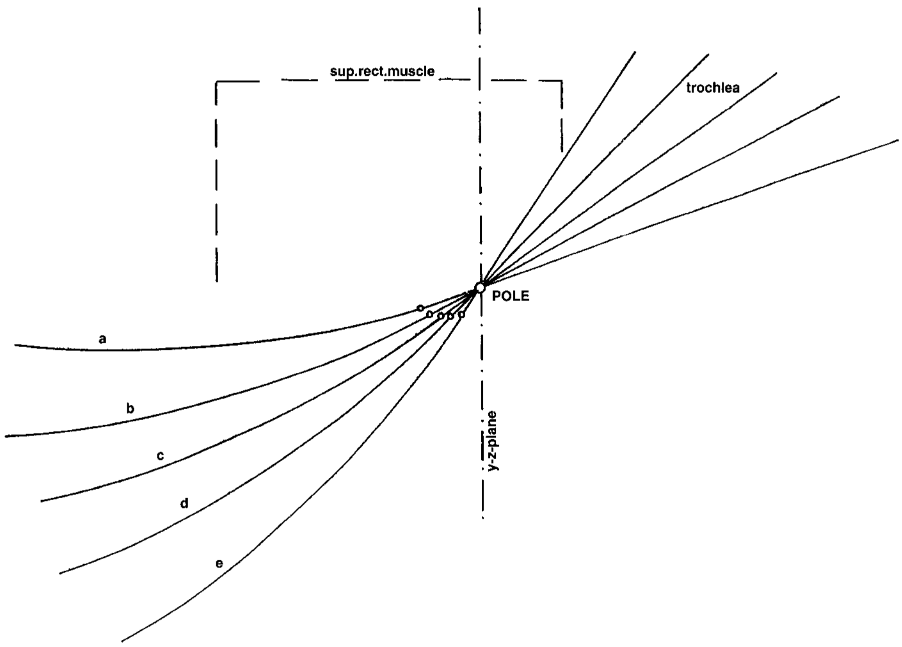
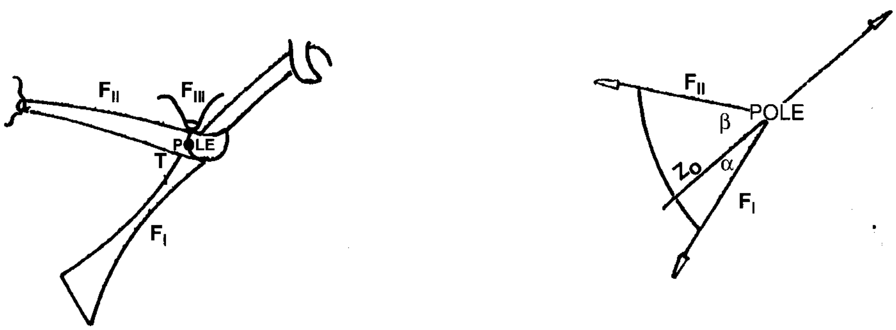


Fig. 13. Z-0 equal lines a, b, c, d ... Different possible angles of Z-0 equal lines crossing the y- and z-plane (sagittalisation, desagittalisation). All possible Z-0-lines are crossing at the functional eye pole



a **b**

Fig. 14. Splitting of the superior oblique muscle (right eye). **a** Tying the anterior portion (F2) of the superior oblique tendon around the posterior one (F1); increasing muscle tension, and approximation of the crossing point T nearest to the functional eye P●LE; (F3) a suture for stabilizing the splitting distance (10–14 mm) (Stangler-Zuschrott) may be possible; **b** Situation of the crossing angle after tendon splitting of the superior oblique muscle: the angle alpha between the Z-0-equal line and F1 becomes smaller in adduction, therfore the tension of F1 increases and eye depression improves

The *long arc of contact of the inferior oblique muscle* in contrast to that of the superior oblique muscle is conspicious (Tables 1, 2).That, and the vector predominance of the inferior oblique muscle have to be taken into account when selecting the surgical method.The *recession* in the direction of the functional pole brings, apart from its normalising effect on the alphabet pattern, a remaining arc of contact for rolling up and down (Table 6). There is also *less arc of contact* required at the pole with its *minimal muscle dynamics* and *small width* of muscle insertion (Fig. 1 , Table 6).

For the presevation of arc of contact it makes sense, as

Table 6. Requirements for rolling up (U) and down (D) at pole fixation in mm

Superior obliqe muscle			Inferior obique muscle		
Add.	PP	Abd.	Add.	PP	Abd.
3.9 U	2.8 U	1.8 U	3.6 D	2.3 D	0.2 D
0.0	0.4*	0.0	0.0	–2.4**	0.0
2.3 D	0.6 D	0.0	3.2 U	0.0	0.8 D

* arc of contact in PP ** deficit of the arc of contact in PP

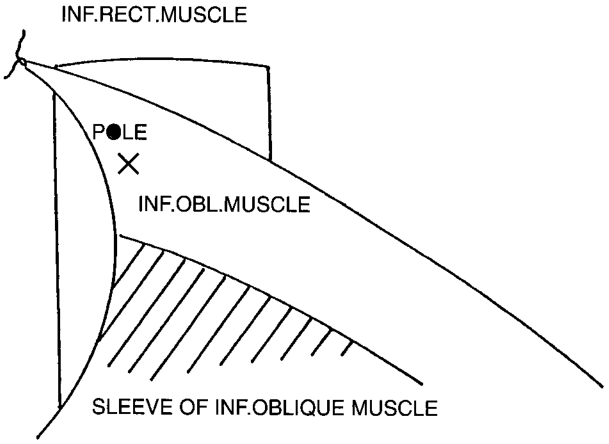


Fig. 15. Situation of recession of the inferior oblique muscle with one muscle suture; sliding back of the posterior part of the muscle and sleeve permits localisation of the effective muscle insertion (X) near functional pole (•)

recommended by Kolling, to perform a combined oblique muscle procedure (at the Z-0-equal line) in vertical deviation of more than ten degrees (Patient Nr. 1).

Reinforcement of the superior oblique muscle should in principle, also bring an approximation of the functional insertion, can be seen in the modified Harada-Ito-Boergen operation, to the functional eye pole (Simulation Fig. 8). The functional insertion is the crossing point of the divided superior oblique muscle that remains quietly at the functional pole! At a distance of 18 to 20 mm from the trochlea to the superior oblique muscle insertion, a tucking surgery (eight to ten mm) certainly brings the new insertion near the area of the functional eye pole with minimal muscle dynamics especially in horizontal eye movements. However, there may then be no arc of contact-a deficit of muscle length due to oblique muscle tucking – and as a result a so called Brown-Syndrome.

But a modified Harada-Ito-Boergen operation preserves an arc of contact.

Figure 14a demonstrates the splitting situation of the superior oblique tendon by ten millimeters while the anterior portion is tied around the posterior one toward the upper border of the lateral rectus muscle in such a way that their crossing point is nearest to the functional eye pole (functional muscle insertion).

The result is, as Fig. 14b demonstrates, in accordance with the situation of the angle between the muscle and the resulting Z-0-equal line, namely an increasing muscle tension at adduction and down gaze and, in consequence, an improved eye depression of the superior oblique muscle [3]. In addition muscle tendon becomes smaller (only a few torque lines are required at the pole) and disturbing torque effects are avoided. The small tendon string makes it easier to withdraw the tendon into the trochlea.

The simultaneus *recession of the inferior oblique muscle* with a *single muscle suture* (see patient Nr. 1) of the anterior muscle portion and sliding back of the posterior part and sleeve probably localises the divided angle also near to the functional inferior eye pole (Fig. 15, similar to Fig. 14).

In conclusion the rules for surgery of oblique muscles in conformity with Bielschowskys' recommendations, are as follows:

Recommendations

1. Removal of squinting in the area of action

The *torque line* (Z-0-equal line) is chosen so as to obtain "dose-effect relationship" for elevation, depression and cyclorotation and to prevent an alphabet pattern.

2. Recession of the oblique muscle with a surplus of eye motion to decrease vector predominance by *approaching the pole.* There is less muscle dynamics close to the pole and minimal requirements of torque lines (small width of muscle or tendon insertion, small arc of contact) beside the ideal Z-0-equal line. Therefore, especially in horizontal gaze directions, where the muscle takes part in motion, there is nearly no change in vector situation, while the recession (directed by pulleys) are effective in up and down gaze.

3. Motion surplus and defect equalize each other.

Approaching the pole normalises the superior oblique muscle (splitting technique with functional insertion at the pole) as well as the inferior oblique muscle recession. Together, these factors cause minimal muscle dynamics at the *lower and upper pole* in horizontal gaze directions. In vertical direction the reinforcing effect of the superior oblique muscle (Fig. 14) is effective as is the recession (relaxing) of the inferior oblique muscle (Fig. 15).

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