

New approach in strabismus surgery in high myopia

Thomas H Krzizok, Herbert Kaufmann, Horst Traupe

Abstract

Aims—To develop appropriate methods of eye muscle surgery in highly myopic patients with esotropia and hypotropia, with respect to the pathological findings in high resolution magnetic resonance imaging (MRI).

Methods—35 patients with unilateral or bilateral high myopia and strabismus—that is, axial length of the globe averaged 29.4 mm. Multiple coronal, transverse, and parasagittal MRI image planes were obtained using a Siemens Magnetom 1.5 tesla MRI scanner. In 15 patients with a pathological plane of recti extraocular muscles found by MRI and confirmed intraoperatively, a new technique of eye muscle surgery was performed to re-establish the physiological muscle plane. This was checked postoperatively in addition to the measurement of alignment and motility by MRI.

Results—The new MRI finding of a dislocation of the lateral rectus (LR) into the temporocaudal quadrant by 3.4 mm requires new surgical techniques. Only fixing the LR in the physiological meridian at the equator with a silicone loop ('guide pulley') or a non-absorbable suture is a causal therapy. This yields alignment and improves abduction and elevation.

Conclusions—If the described misalignment of the LR is detected by MRI, a common high dosage recess-resect procedure for esotropia may even aggravate the deviation. The most important aim of eye muscle surgery is to normalise the pathological path of the LR. The restoration of the physiological function of the dislocated LR is remarkable.

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Numerous theories¹⁻⁴ about the aetiology of acquired esotropia and hypotropia in high myopia have been published. This reflects the difficulties in the surgical treatment of this restrictive motility disorder with limited abduction and elevation.

(1) In 1969 Hugonnier¹ described a 'myositis' and found a reduced number of muscular fibres included in fibrous tissue in the lateral rectus (LR). Knapp could not verify

this and found no histological abnormality in his examinations.

(2) Paufique, among others, attributed its pathology to sixth nerve palsy.

(3) Duke-Elder and Wybar² suggested structural changes in the oculomotor muscles as well as a shortening of the optic nerve. Other investigations described pathological findings in the tendon of the LR.

(4) In some studies³⁻⁸ the deviation, especially the hypotropia, is characterised by the name 'heavy eye syndrome'. Here, supposedly, the increased weight of the eyeball or the forward movement of the centre of mass of the globe results in a drop of its anterior half (clinical examination without imaging).

(5) Bagolini *et al*⁹ assumed, by echography, myopathic paralysis of the LR by pressure from the lateral orbital wall.

(6) Roth *et al*¹⁰ observed a limited motility even after severing of the rectus muscles.

(7) For Demer and von Noorden¹¹ (magnetic resonance imaging (MRI) study) the mechanical restriction limiting rotation was due to contact between the posterior aspects of the elongated globe and the bones of the orbital apex.

(8) Kolling¹² (examination by computed tomography (CT) and MRI scans) found the superior and inferior rectus muscles transposed medialwards; alternatively the medial rectus (MR) and LR muscles were transposed downwards, depending on the existence of an esotropia or hypotropia. A simultaneous transposition of the horizontal as well as the vertical extraocular recti muscles (EOMs) was also described.¹³

(9) Herzau and Ioannakis¹⁴ observed intraoperatively an abnormal path of the LR. However, they could not confirm this finding preoperatively by CT or MRI. They described good results in seven recess-resect (R&R) procedures with additional supraposition of the LR at the insertion site.

All these existing theories may be confusing and reflect disappointing results in conventional surgical therapy. Therefore, we intended to verify existing theories by means of high resolution MRI. Our aim was to establish a better understanding and a reasonable, effective therapy—eye muscle surgery.

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Material and methods

We examined 35 patients with unilateral or bilateral high axial myopia—that is, axial length of the globe averaging 29.5 mm (the refractive error being more than -15 D). These patients

were referred to our department because of strabismus or diplopia. Routine ophthalmic examinations were performed as well as an A- and B-scan echography. Ocular ductions were measured by the synoptometer. Deviations were measured with the prism and cover test at 5 metres and 0.33 metres and at the tangent screen at 2.5 metres in nine diagnostic positions of gaze. All orbits were imaged using a Siemens Magnetom (SP 63) 1.5 tesla MRI scanner. High resolution coronal, transverse, and sagittal T1 weighted, spin echo images were obtained with repetition time (TR) = 550 ms and echo time (TE) = 15 ms; field of view = 21×21 cm, pixel matrix = 256×512 , three acquisitions, slice thickness 2 mm, distance factor 0.25. In an additional dynamic (motion) MRI the patient had to fixate with the less restricted eye for 50 seconds in different positions of gaze. For these 'flash sequences' (T1 weighted, gradient echo), TR was reduced to 140–200 ms and the pixel matrix to 160×256 , maintaining sufficient spatial resolution.

In all patients, the findings during eye muscle surgery could be compared with the MRI results. Distances between the insertion sites of the EOMs as well as distances of the EOMs from the corneal limb were measured (mm). In the 15 patients with a pathological plane of recti EOMs, found by MRI and confirmed intraoperatively, a new technique of eye muscle surgery was performed. This was checked postoperatively in addition to the measurement of alignment and motility by MRI.

Results

The first step for a more causal eye muscle surgery consisted of high resolution MRI scans of the orbit. This resulted in three groups with different surgical approaches.

GROUP 1

In 13 patients (median age 52 years) with typical limitation of elevation and abduction, causing an eso- and hypotropia, the MRI showed a dislocation of the LR in the mid orbital region at a median value of 3.4 mm. The clinical characteristics and the eye muscle surgery performed are described in Table 1. In some cases a V pattern esotropia was present. Mean axial length of the globes was 31.8 (SD 2.1) mm. Measurements of the ocular ductions (for example, synoptometer) averaged a maximum abduction of 30° and maximum elevation of 22.5° . The LR had a dislocated, insignificant curved path, taking its course from the origin, shifting into the temporocaudal quadrant, and proceeding to the insertion. The insertion site itself was either in the physiological meridian, which was the case in all patients without preceding surgery, or between the physiological insertion and that of the inferior rectus (in patients RG and MA (Table 1) it was after previous eye muscle surgery). The MRI also revealed the anatomical reason for this unphysiological pathway. The distension and enlargement of the globe, mostly localised in the temporocranial quadrant, will stretch and

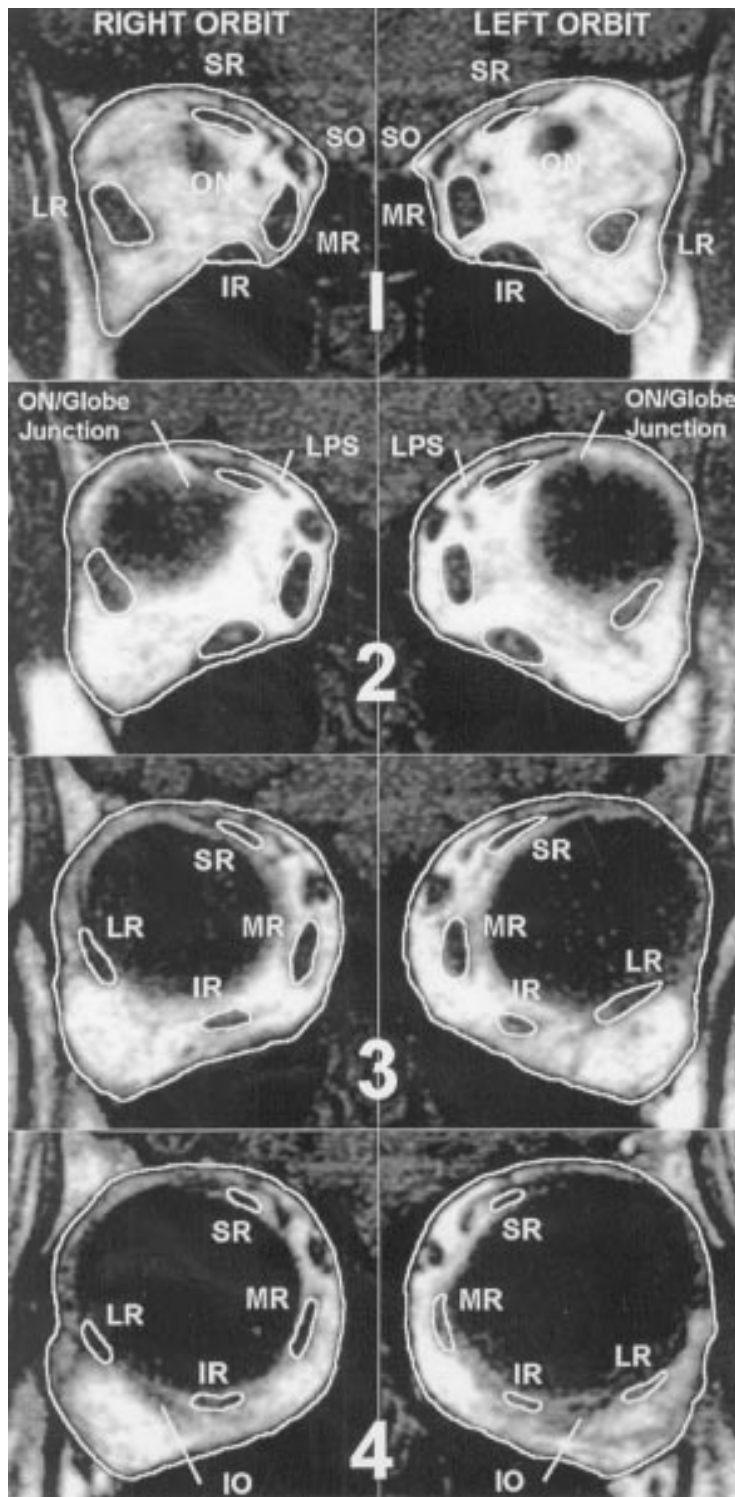


Figure 1 Coronal magnetic resonance image (T1 weighted, spin echo) of the right and left orbit of a characteristic subject (RG) in group 1 (Table 1). Images were obtained preoperatively fixing with the right eye in 10° downgaze and 5° adduction. From the images obtained at multiple levels of the orbit (from posterior, top (1) to anterior, bottom—that is, insertion site, (4, right)), the mislocation of the left lateral rectus (LR) into the lower temporal quadrant by 6 mm becomes obvious in the scans of the mid orbital region in (2). In this subject, even the insertion site of the left LR is shifted downwards as a result of previous surgery.

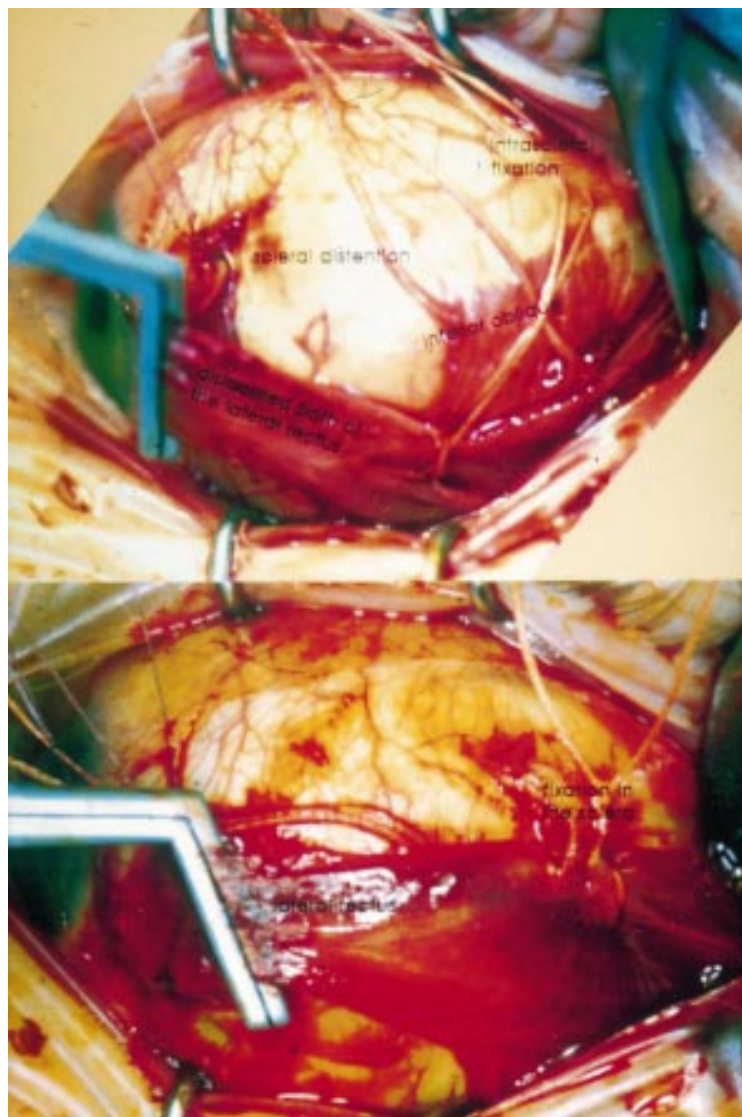


Figure 2 Top. Intraoperative situs of subject HJ in group 1 (Table 1). After recession of the MR by 16 mm, the LR is resected by 12 mm in the usual way and sutured with Vicryl 6/0 to the site of the original insertion. The path of the LR is still dislocated into the temporocaudal quadrant of the globe and orbit, caused by the scleral distention. Owing to this dislocation, the insertion site of the inferior oblique, white suture as label, is visible above (cranially) the LR. Another non-absorbable 4/0 suture is already in one third of the LR and fixed intrasclerally, the surgical knot not yet tightened. Bottom. The left LR is now fixed with a non-absorbable 4-0 suture (white Suturamid) in the sclera in the way of a modified retroequatorial myopexia in the physiological meridian.

shift the LR downwards. The characteristic MRI image of the orbit in a patient of group 1 is shown in Figure 1.

According to our MRI findings, the most important aim of eye muscle surgery in group 1 was to normalise the pathological path of the LR. This could be achieved by a large recession of the MR (approximately 12 (SD 3) mm) and a careful resection or anteropositioning of the LR. The LR was additionally fixed in the physiological meridian with a non-absorbable 4/0 suture (white Suturamid) in the way of a modified retroequatorial myopexia ('faden operation'). Figure 2 shows the characteristic intraoperative situs of group 1 without previous eye muscle surgery. Photographs are of subject HJ, in whom a common R&R surgery of the right eye, in which no LR dislocation was present, was performed 3 months later. Figure

2 exhibits the path of the left LR before and after the described procedure. In no case did problems with the sclera occur by suturing the LR in the way described. Postoperatively, these patients had an improved, or even normalised function of the LR, which resulted in a much better ability to elevate and abduct the myopic eye and with good alignment (Table 1).

The described surgical procedure was performed without complications in all subjects in Table 1 labelled 'f'. An exception is patient RG (Figure 3): the dislocated LR was fixed at the equator in the physiological meridian with a 3.5 mm wide silicone loop ('guide pulley'). This was necessary because the 'downwards pulling force' of the LR was too high for single 4/0 sutures. The fixation of the silicone loop was possible in the sclera in the 1 o'clock position (Fig 3). Figure 2 displays a coronal MRI of the same patient in Figure 1 (RG) 2 weeks after eye muscle surgery of the left eye: the MR was recessed 10 mm and the LR was fixed in its physiological meridian with a silicone loop which is detectable in the mid orbital region of the left LR. Alignment was achieved and stable up to the 1 year follow up examination. In subjects in Table 1 without fixation of the muscle path of the dislocated LR, the sclera was too thin for anchoring sutures.

In one patient (JB) the mislocated, resected LR was suprapositioned 8 mm above the insertion site, according to Herzau and Ioannakis.¹⁴ But the surgical outcome without normalisation of the muscle path was poor (Table 1).

The typical deviations in a subject in group 1, in which the right LR was shifted downwards, measured at the tangent screen (distance 2.5 m) in nine positions of gaze are presented in Figure 4.

GROUP 2

In two anisometric patients with *exo-* and *hypotopia*, the MR but not the LR showed a caudal dislocation. Thus, the MR had a curved path, taking its course from the insertion to the origin into the lower medial quadrant. The insertion site itself showed normal morphology. In the first subject the right MR showed a caudal dislocation by 4 mm. The preoperative deviation measured 25° exotropia and 15° hypotropia of the right eye. The right eye could be adducted 35° beyond midline. According to the procedure described for the LR in group 1, a recession of the LR of 7 mm and a resection of the MR of 7 mm with an additional fixation in the physiological meridian with a non-absorbable 4/0 suture were performed. Elevation was improved postoperatively from 5° to 15° beyond midline and alignment was achieved.

In the second subject adduction and elevation were not restricted. Exotropia was -28° and hypotropia 6°. In both eyes (axial length right eye 28.8, left eye 24.0 mm) the MR was shifted downwards by 3.5 mm. During intraoperative inspection the sclera appeared too thin for anchoring sutures. In order to shift the dislocated MR upwards, we tried to apply a 6 mm wide silicone loop between the superior rectus and the MR. This unfortunately

Table 1 Clinical characteristics of group 1 (dislocation of LR)

Patient, sex, age (years)	Axial length of the globe (mm)		Preoperative deviation in 5 metres (prism and cover test or corneal reflex)		Maximum ductions, abduction/elevation		Dislocation of the lateral rectus (shifting from the horizontal meridian (mm)) [†]	Surgical procedure [†]	Postoperative deviation in 5 metres (prism and cover test or corneal reflex)	Maximum ductions/abduction/elevation/adduction of the operated eye postop
	R	L	R	L	R	L				
RG, F, 43	31	34.2		+45°, L hypo 30°	20°/30°		only L (6‡)	R&R 10/6; f	-6°, L hypo 5°	25°/10°/10°
MA, M, 29	35.3	36.3		+40°	40°/5°		R (7) + L (6‡)	R&R 8/8; f	+10°	10°/15°/30°
HJ, M, 61	33.4	31.2		+140°, L hypo 25°	-15°/15°		only L (5)	R&R 16/12; f	+30° L hypo 10°	5°/40°/40°
JB, F, 35	24.6	32.8		+30°, L hypo 10°	50°/40°		R (3) + L (7)	R&R 6/7; supra	L hypo 15°	40°/25°/40°
AL, M, 36	34.9	34.7		+20°, L hypo 7°	50°/20°		R (2) + L (2)	R&R 7/7; f	0°	50°/30°/40°
KH, M, 57	30.8	30.9		+13°	35°/20°		R (2) + L (2)	R&R 4/4	0°	40°/20°/40°
KR, F, 55	35.8	32.9		+30°, R hypo 4°	5°/10°		R (4) + L (3)	R&R 8/8; f	+5°	20°/20°/35°
SA, F, 32	32.1	31.5		+42°, L hypo 6°	40°/40°		only L (4)	R&R 10/10; f	+10°	20°/30°/40°
IK, F, 52	30.1	31		+40°	20°/40°		R (3) + L (3)	R&R 10/10	+3°	30°/20°/35°
CJ, F, 56	30.1	30.2		+26°, L hypo 3°	40°/20°		R (3) + L (5)	R&R 8/8; f	+5°, L hypo 1°	45°/20°/35°
HS, F, 48	29.8	31.9		+10°, L hypo 2°	35°/40°		R (3) + L (4)	R&R 3/3	0°	40°/40°/40°
IL, F, 55	31.5	32.1		L hypo 14°	30°/25°		R (2) + L (4)	vert R&R 4/5	0°	30°/30°/40°
TD, F, 21	29.1	29.3		+36°, L hypo 4°	40°/40°		R (3) + L (4)	R&R 6/8	+6°	45°/40°/35°

Initially horizontal deviation: + = esodeviation; because by chance in all unilaterally affected subjects the lateral rectus of the left eye is shifted, a vertical deviation occurs in the left eye—that is, a left eye hypotropia or -VD.

*Measured in the mid orbital region on the coronal MRI scans; the described surgical procedure was performed on left or right eye as indicated by bold letters.

†R&R = recession of MR (first number (mm)) and resection of LR; f = fixation of LR in the physiological meridian; supra = supraposition of the insertion site of the resected LR; vert R&R = recession of inferior rectus and resection of superior rectus.

‡Not only the path of the LR in the mid orbital region, but also the insertion site was shifted towards the inferior rectus in these cases with previous eye muscle surgery; the measured values refer to the shifting of the muscle path in the mid orbital region.

caused a pathological path of the superior rectus. Therefore, we suprapositioned the MR insertion by 7 mm.

GROUP 3

In 20 subjects (median age 44 years) with median axial length of 28.1 (SD 2.3) mm, the plane as well as the insertion site of the rectus EOMs, was normal. In group 3, abduction averaged 40° and elevation 40°. Therefore, the resulting esotropia averaged only 13° (group 1, median 30°). Conventional R&R surgery was performed and alignment was achieved in all 20 patients.

Discussion

Before surgery, an orbital MRI scan may be useful in patients with high myopia and strabismus, resulting from restricted abduction and elevation. If the scan shows the described pathological course of the LR, a common R&R procedure for esotropia may even aggravate the deviation. The described dislocation of the LR will reduce its abducting torque and create depressing and extorting torques. This will result in increased esotropia and hypotropia in abduction, because the more the eye is abducted, the more the LR becomes a depressor (Figure 4).

In view of our new findings, we had good results by suturing the LR to the physiological (3 or 9 o'clock) meridian respiratory muscle path with a non-absorbable suture or silicone loop at the equator as a 'guide pulley'. An additional, conventional highly dosed recession of the MR in combination with a dosed resection of the LR was also performed. A possible problem in these highly myopic patients may result (compared with retinal detachment surgery) from a potentially thinned sclera. Fortunately, even the highly stressed 4/0 sutures (spatula needles) did not create retinal problems.

A simple supraposition of 8 mm of the insertion site of the LR may be performed because of possible scleral, and consequently retinal, problems. But this procedure has the disadvantage of a persisting pathological muscle path of the LR in the equator region—that is, in the anterior and mid orbital region. Thus, the continuous force of the LR into the non-physiological direction may prevent the normalisation of the motility and alignment. Moreover, the high tension may shift even the resected and sutured tendinous insertion of the LR downwards. Because the sclera may be too thin for anchoring sutures, we discussed the concept of an artificial intermuscular membrane—for example, by a silicone loop between the superior rectus and the LR. Even though this idea is convincing, practical problems resulted from a pathological direction of the superior rectus caused by the generated force.

Conflicting surgical concepts may appear in cases with bilateral LR shifting and symmetrically limited elevation but no vertical deviation. If the new technique of fixing the LR in its path in the physiological meridian is substantiated

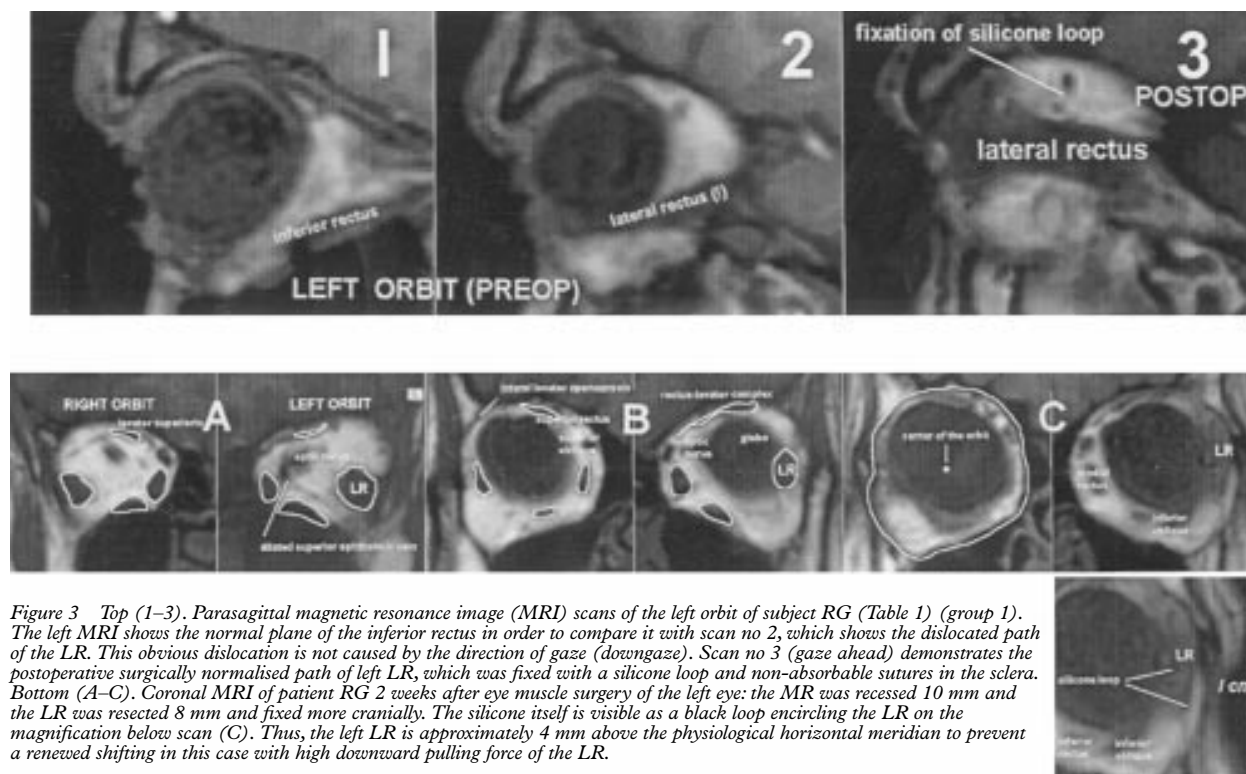


Figure 3 Top (1–3). Parasagittal magnetic resonance image (MRI) scans of the left orbit of subject RG (Table 1) (group 1). The left MRI shows the normal plane of the inferior rectus in order to compare it with scan no 2, which shows the dislocated path of the LR. This obvious dislocation is not caused by the direction of gaze (downgaze). Scan no 3 (gaze ahead) demonstrates the postoperative surgically normalised path of left LR, which was fixed with a silicone loop and non-absorbable sutures in the sclera. Bottom (A–C). Coronal MRI of patient RG 2 weeks after eye muscle surgery of the left eye: the MR was recessed 10 mm and the LR was resected 8 mm and fixed more cranially. The silicone itself is visible as a black loop encircling the LR on the magnification below scan (C). Thus, the left LR is approximately 4 mm above the physiological horizontal meridian to prevent a renewed shifting in this case with high downward pulling force of the LR.

then a bilateral procedure is necessary to improve elevation and to avoid the induction of a vertical deviation.

The pathophysiology can be explained by the increased stretching of the LR as the length of the globe increases and a staphyloma as well as a scleral ectasia develops. The best evaluation of the mainly temporocranial distension of the globe in high myopia is possible in transverse and coronal MRI (or CT) scans. While the side slip of normal rectus muscles is approximately zero,¹⁶ in these cases of high myopia the structures normally stabilising the path of LR are not able to fulfil their task. These structures are the check ligaments, intermuscular membranes, and the pulleys.^{17–19} The LR is highly stretched by the mostly temporosuperior distension of the globe and will gradually assume the shortest distance. The reasons for the localisation of the distension mostly in the temporosuperior quadrant of the globe, are very probably histological changes in fibre bundles and fibrils of the posterior sclera, possibly being hereditary, together with antagonistic pull of the superior and inferior oblique muscles.²⁰ This fits in with the accumulation of retinal degenerations in myopia in this quadrant between the insertion of the superior and inferior oblique muscles, where the sclera is stretched and thinned (up to 0.1 mm, normal =1.0 mm). Thus, the globe develops a bubble-like distension in the middle and posterior segment, sparing the anterior segment with the insertion site. It is well known that the anterior scleral ring, into which the recti EOMs insert, fails to show the histopathological light and electron microscopic fibre bundle and fibril changes.²⁰ Therefore, the insertion site of the LR in group 1 and the dis-

tances between the insertion sites of the recti EOMs muscles were in the normal range.²¹

Measurements were performed with a caliper during eye muscle surgery. An increased distance between the insertion of the superior and lateral rectus—that is, a simultaneous shifting of the insertion site of the LR between the physiological insertion site and that of the inferior rectus in the anterior orbit, was observable only in patients 1 (RG) and 2 (MA) (Table 1). This was probably a consequence of

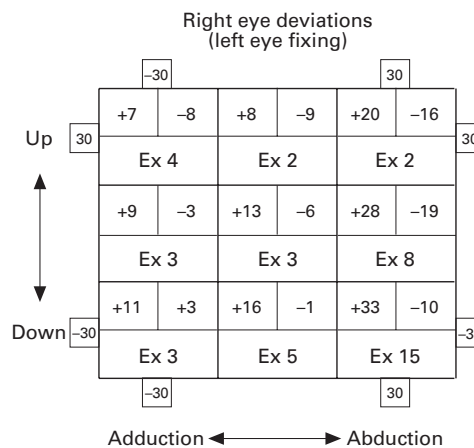


Figure 4 Deviations measured on the tangent screen at a distance of 2.5 metres in nine positions of gaze in a typical patient in group 1 with a dislocation of the right LR, simulated with the program ORBIT 1.5.1 (Miller and Shamaeva²²). In each rectangle the upper left field indicates the value of the horizontal deviation ('+' for esotropia), the upper right the value of the vertical deviation ('+' for left eye hypotropia—that is, +VD) and the lower field shows the cyclotropia. Subject fixating with the left eye, in which the motility is not restricted. Note the V pattern esotropia of 16° versus 8° of esotropia. The more the eye is abducted, the more the LR becomes a depressor. This will result in increased esotropia and hypotropia in abduction.

preceding eye muscle surgery, in which the LR was cut off and the insertion site adhered further below because of the 'downwards pulling force' of the LR. The findings in group 2 show the potential variability of the high myopic globes. In group 3 it was evident in some globes that the elongation was not only present along the anterior-posterior axis, but also along the x axis. This resulted in a 'large sphere', typically described for buphthalmos. In these cases, the missing distension decreases the probability of LR shifting.

The other theories mentioned could either not be validated by MRI scans or did not yield these clinically found deviations. Especially, the (motion) MRI 'flash sequence' scans in our patients could not detect a mechanical restriction by the bony orbit comparable with the case report of Demer and van Noorden.¹¹ An anatomical objection to the assumption of restricting contact between the enlarged globe and the bony orbit would be that the eyeballs are expected to adapt to the position of least friction, which is in exotropia, with the ocular axis aligned with the orbital axis. In MRI scans or during eye muscle surgery a simultaneous transposition of the superior and inferior rectus medialwards or a transposition of the MR and LR downwards was never detected. Kolling¹² and Kommerell¹³ described this finding and explained it by the increased stretching of all rectus muscles. This theory is not convincing, because the increasing stretch would change the insertion site along the y axis in a cartesian coordinate system. Finally, the theory or expression of the 'heavy eye syndrome', which was still being published in 1995⁵: of course, a myopic eye with too much weight would have to rotate around the x axis of the orbit to produce a hypotropia without any esodeviation. A lot of anatomical and physiological imagination is needed to envisage such a mechanism. None of the authors supporting this theory⁵⁻⁸ ever determined the actual weight and, more importantly—the shape of highly myopic eyeballs—for example, post mortem in cadavers.

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