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Eye Muscle Prosthesis

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ABSTRACT

We inserted a silicone rubber elastic band along the course of a paralyzed lateral rectus and of a paralyzed superior oblique to restore alignment and to provide a spring against which the antagonist could pull. The lateral rectus band has been in place for 7 years. It provides alignment and a field of single binocular vision of 20°. The superior oblique band has been in place for 17 months. It provides alignment and single vision over 30° from the primary position except for a restriction in upgaze-adduction to 25° (Brown syndrome) and in downgaze-adduction to 20°. Such engineered elastic bands are a useful addition to current surgical techniques for management of cases of paralysis and restriction.

INTRODUCTION

A prosthetic band to replace a paralyzed or absent extraocular muscle must provide tension in the primary position to balance the antagonist, linear elasticity to allow eye movement by the antagonist over as wide a range as possible, sufficient stiffness to restore the eye to the primary position and beyond upon antagonist relaxation, tissue tolerance, and permanence of elasticity.

An initial report on the clinical application of such engineered elastic bands of silicone rubber to replace the passive component of extraocular muscles was made in 1984.[1] We report now on this patient with a lateral rectus band after a 7-year follow up and on a second patient in whom we replaced the superior oblique muscle with such a band, after a 17-month follow up.

METHODS

We cut the bands from Dow-Corning silicone rubber sheets, product number 500-3. About 2 mm of the end of the band is folded over a 5-0 polypropylene or dacron suture (Fig 1) and silicone adhesive is used to glue the folded part of the band. This is clamped overnight. Band stiffnesses are empirically measured after assembly by hanging weights on the end and measuring the stretch induced. The assembled band with an attached suture at each end was sterilized by autoclaving. When cut into a form .254 mm × .7 mm × 27 mm, the band used for superior oblique replacement had a stiffness of 1.15 g per millimeter. For an adult eye of 22.9 mm diameter, this is .23 grams per degree of rotation. If the band is longer or shorter, wider or narrower, the stiffness is less or greater in proportion. These bands need to be made in several lengths to fit at the time of surgery. Engineering details for the calculation of length and stiffness of these prostheses are contained in previous publications by the authors.[2,3]

CASE REPORTS

Case 1. A 30-year-old male electronic engineer was seen in 1984, 18 months following a motorcycle accident that left a complete right trigeminal first division paralysis and a complete right abducens nerve paralysis. Forty prism diopters of right esotropia were present with no abduction, no active force, and no electromyographic activity in the right lateral rectus. Following right medial rectus botulinum injection, the eye would abduct nearly to the mid line and the deviation was reduced to 5-10 RET. The band was inserted 4 months later, after the botulinum-induced medial rectus paralysis had recovered substantially. A right lateral limbal conjunctival incision exposed the lateral rectus and the inner aspect of the lateral orbital wall. An external incision through the skin and temporalis muscle exposed the outer aspect of the lateral orbital wall. A hole 4 mm in diameter was drilled about 25 mm posterior to the lateral orbital rim, just anterior to the middle cranial fossa. A band with a stiffness of 2.35 g/mm (0.47 g per degree of rotation) was used. One end of the band with attached suture was threaded through this hole and tied to the sclera anterior to the insertion of the lateral rectus. The suture at the other end of the ban was threaded through a silicone rubber block 5 × 5 × 10 mm beneath the temporalis muscle. The conjunctiva wound was closed. The sutures on the silicone block were adjusted under local anesthesia to place the eye in a position of about 10° exotropia. The following day, this exotropia persisted, and the sutures were loosened 5 mm, bringing the eye into alignment in the primary position. The initial amplitude of movement, about 35° adduction, 20° abduction, became reduced to 25° adduction, 15° abduction after 2 months, but has remained stable since. The field of single binocular vision extends from 5° right (abduction to 15° left (adduction) and the patient considers himself rehabilitated.

Case 2. A 58-year-old man was first seen in 1984 with a history of left superior oblique myokymia for many years. His health was otherwise normal. He had tried many medications, including phenytoin (Dilantin) and carbamazepine, without relief. The eye examination was normal except for typical intorsion and infraduction of the left eye occurring irregularly and repeatedly, intensified with downward gaze or with head tilt to the left. Electromyography of the left superior oblique muscle was typical of myokymia, showing irregular discharges similar

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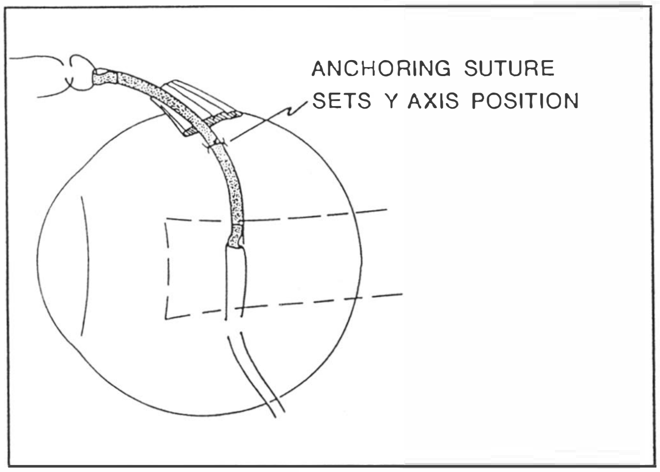

FIGURE 1: Superior oblique muscle prosthesis: silicone band with ends folded over sutures.

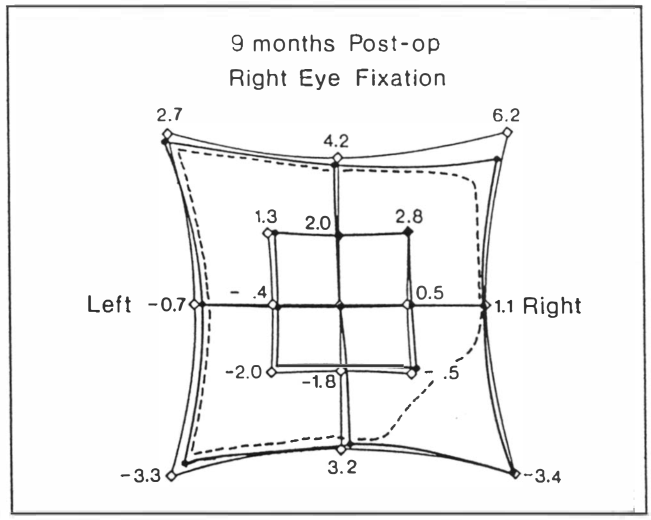

FIGURE 2: (Case 2) Hess Screen. Field of single binocular vision, 17 months postoperative, is indicated by the dashed line (not tested beyond 30°). No torsional deviation is present in any field of gaze. The numbers at the 15° and 30° gaze positions indicate the calculated millimeters of lengthening (+) or shortening (−) which the superior oblique muscle or the band undergoes in changing from the primary position to the eccentric gaze position.

to the pattern in hemi-facial spasm. A trial of superior oblique paralysis induced by botulinum toxin was helpful, but temporary. Surgery to detach the left superior oblique was deferred. He patched his left eye most of time. In 1990, the left superior oblique tendon was transected anterior to the trochlea. A silicone band 0.254 mm × 0.7 mm × 27.5 mm was sutured to the trochlea and orbital periosteum as an origin. The insertional end was led under the superior rectus and along a course slightly anterior to the middle of the superior oblique tendon, to insure that the band had a strong intorsional vector. A mattress suture in the superior temporal sclera 18 mm from the limbus limited anterior or posterior movement of the band. With the eye in the primary position and with no tension on the band, its insertional end lay near the horizontal meridian under the lateral rectus. The distal 5-0 polypropylene suture was placed through the sclera in a convenient position to allow postoperative adjustment, 8 mm posterior to the insertion and 3 mm below the left lateral rectus muscle, and tied in a bow knot (Fig 1). On the 1st postoperative day, the eye was in good alignment and no torsional deviation was present. There was a moderate defect to elevation in adduction (Brown syndrome). The suture was tied. A small increase in the restriction in upward gaze occurred progressively for about 2 months. The field of single binocular vision is restricted to 25° in gaze up-right and to 20° in gaze down-right, but it extends beyond 30° from the primary position in all other directions (Fig 2).

DISCUSSION

In the primary positions, the horizontal rectus muscles have about 10 g of tension and the oblique muscles about 5 or 6 g.[1,2] The band is stretched to provide this tension, and adjustment of this stretch is a necessary component of the surgical plan. To allow eye rotation away from the band into the field of the antagonist, stiffness of the prosthetic band must be that of a normal muscle, about 0.3 to 0.5 g per degree for a horizontal rectus muscle, and about 0.2 to 0.3 g per degree for an oblique muscle. Otherwise, the antagonist will be progressively unable to overcome the load of the band. For gaze into the field of the elastic band, the tension of a normal horizontal rectus muscle would ordinarily increase up to 30 or 40 g of force. Clearly, this cannot be achieved by an implanted band. What it can do, however, is to provide a linear and constant spring very similar to the spring effect of transposed muscles. At the end of surgery, under anesthesia, the eye was placed in an overcorrected position, relying on the antagonist muscle(s) to bring the eye to the primary position. Relaxation of the antagonist muscle allows the eye to spring back, pulled by the elastic band. These mechanics are the same as that of muscle transposition operations such as the Hummelsheim procedure or its modifications.

In our cases, there was a slight reduction in motility in the 1st month or two following surgery. This was probably due to the development of a fibrous membrane surrounding the implant which acts as a further restriction to the antagonist. Elsas has reported experimental application to extraocular muscles of synthetic elastin materials which do not elicit fibrosis.[4] His elastin or other materials which will not create a fibrotic surrounding and yet which will maintain their elasticity over many years might improve this system. Making our .254- × .7-millimeter implant into a round rod would reduce the cross-sectional area of a membrane 0.1 mm in thickness by about 22%, only a small reduction. Placement of a doubled 1-millimeter silicone tubing from the front of the globe to the orbit was recently reported by Bicas[5] in five clinical cases with restrictive strabismus. This is an improvement over purely holding the eye to the orbital periosteum with sutures, as done by Urist (personal communication, 1969) with permanent nylon sutures, or by others with temporary "stay sutures."[6] The cross-sectional area of the tubing used by Bicas is about 0.6 mm^2. When doubled, this will have a stiffness about 5× greater than the optimum to provide maximum motility of a horizontal rectus. Nevertheless,

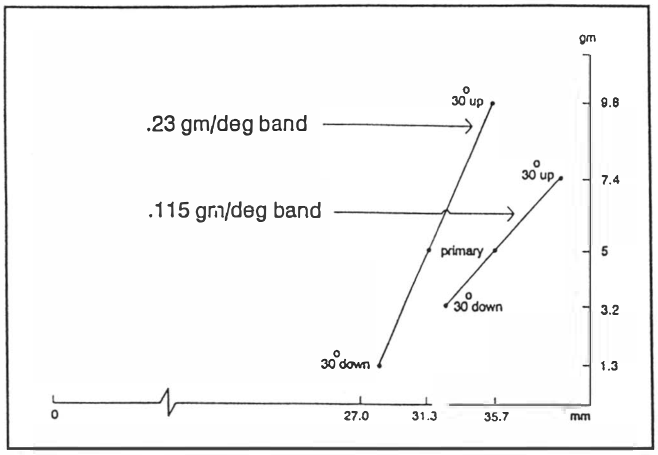

FIGURE 3: Superior oblique band forces graphed for actual 27 mm band of 0.23 g/degree stiffness, and for a theoretical 27 mm band with stiffness of 0.115 g/degree.

this will be advantageous to overcome the high angle strabismus with restriction in the cases which he reported and to anchor the eye in the primary position. In such cases, alignment is more important than rotation amplitude.

Figure 2 shows that very little shortening or extension of the superior oblique occurs with 30° abduction to 30° adduction. Since we know that superior oblique innervation does not normally change during such horizontal movements, a band which works for the primary position works in these lateral gaze positions. With 30-degree changes of vertical gaze, there is about 4.0 mm of length change of the superior oblique (or the band), and the implanted band can relax or stretch effectively over this range. Thus, for extreme gaze upward and inward, where the 6.2-millimeter stretch of the implant represents a moderate restriction to motility and in extreme downward and inward gaze when the absence of increased superior oblique activity limits infraduction, the restoration of function, especially of torsion, is remarkably satisfactory. The superior oblique anatomy allows a long extension of the band from the point of trochlear attachment around the globe, permitting construction of an implant of low stiffness. This diminishes the restrictive Brown syndrome. However, enough stiffness has to be present to release energy and provide infraduction. As seen in Figure 3, the band is stretched 4.3 mm to 31.8 mm to achieve 5-gram force in the primary position. If we used a theoretical band of 0.115 g/degree stiffness, it would need to be stretched 8.7 mm to 35.7 mm to achieve 5-gram force. By reducing stiffness to 0.115 g/degree there would be less restriction to 30° upgaze (force against the band increases 2.4 g instead of 4.8 g). However, in 30° downgaze, the 0.115 g/degree band could not yield up as much force to aid infraduction as the actual band (1.8 g vs 3.6 g). The current stiffness represents a compromise.

Achieving adequate length for bands of 1.5 to 2.5 g per mm (0.3 to 0.5 g per degree) to replace rectus muscles is difficult. In case 1, we achieved that by extending the band through a hole in the orbital wall. However, that approach required substantial additional surgery and would not be practical for other rectus muscles. We have constructed and mechanically tested a simple wire appliance sutured to the orbital wall extending backward into the orbit. It can support the tension of the origin of the band, and anterior and posterior sliding of the appliance can adjust its position to change tension on the band. A similar attachment to the orbital roof might replace levator tension in paralytic ptosis. Extending the band around the posterior part of the globe, for example, from the anterior medial orbit around to the lateral rectus insertion, a distance of about 50 mm, and placing the band through a J-shaped tubing (Fig 4) are other approaches to achieve sufficient band length to produce an adequate range of motion. An essential aid in the development of these approaches has been a computerized-based eye movement model which allows simulation of band insertion, origin, stiffness, and other parameters.[7]

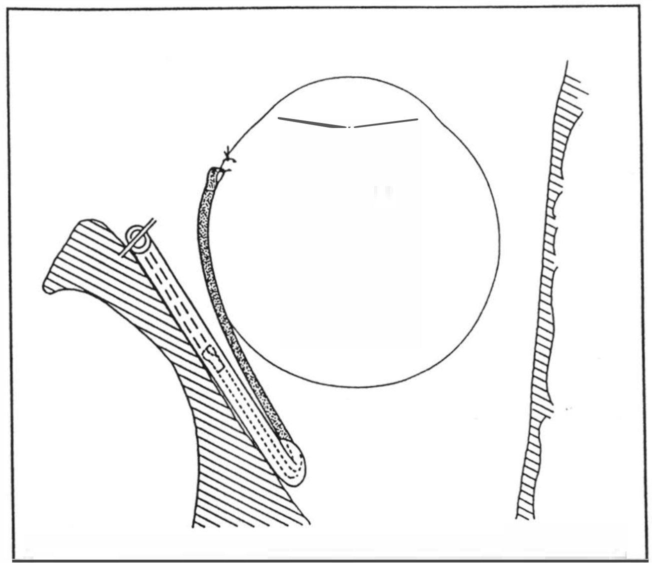

FIGURE 4: Placement of the band through a tubing that acts as a pulley, with sutures at the end.

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