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Spontaneous Reattachment of the Medial Rectus After Free Tenotomy

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Abstract

Purpose: To assess the outcome of free tenotomy of the medial rectus muscle in post-natal monkeys.

Methods: The medial rectus muscle was disinserted in both eyes of 6 macaques at age 4 weeks to induce an alternating exotropia. After the impact on the visual cortex and superior colliculus was investigated, the animals were examined post-mortem to assess the anatomy of the medial rectus muscles.

Results: After tenotomy, the monkeys eventually recovered partial adduction. Necropsy revealed that all 12 medial rectus muscles had reattached to the globe. They were firmly connected via an abnormally long tendon, but at the native insertion site.

Conclusions: Medial rectus muscles are able to reattach spontaneously to the eye following free tenotomy in post-natal macaques. The early timing of surgery and the large size of the globe relative to the orbit may explain why reinsertion occurs more readily in monkeys than in children with a lost muscle after strabismus surgery.

INTRODUCTION

In monkeys, one can probe the impact of strabismus on the anatomy and physiology of the visual system using invasive experimental techniques that cannot be employed in humans.[1–6] To induce strabismus in macaques, we perform a free tenotomy of the medial rectus muscle in each eye at age 1 month. The animals develop an alternating exotropia that shares many features of human exotropia.[7]

Immediately after bilateral medial rectus tenotomy, infant macaques display a large angle exotropia, with virtually no adduction in either eye. Over a period of weeks, the deviation angle diminishes and adduction improves. However, the monkey is always left with an exotropia, which varies in magnitude from animal to animal. Previously, we adduced

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radiological and histological evidence for spontaneous reattachment of the medial rectus muscle to the globe.[7] We now report necropsy findings showing that reattachment occurs at the tendon's natural insertion. This observation suggests an innate affinity of the cut tendon for this unique site on the sclera.

MATERIALS AND METHODS

Strabismus was induced in 6 full-term male Rhesus macaques born at the California National Primate Research Center over a period of 12 years. The animals were aged 4 weeks and weighed 310 to 350 g. All procedures were approved by the Institutional Animal Care and Use Committees at the University of California Davis and the University of California San Francisco.

Anesthesia was provided by intramuscular injection of ketamine hydrochloride (10 mg/kg) and topical application of proparacaine hydrochloride 0.5%. Using a sterile surgical technique, a nasal limbal peritomy was performed and the medial rectus muscle was grasped with a muscle hook. The hook, designed for surgery in infant macaques, had a width of 2.5 mm and a gauge of 0.46 mm. The globe was rotated into abduction. Vannas scissors were used to divide the intermuscular septum superiorly and inferiorly. The muscle was exposed posteriorly for 5 mm by blunt dissection with a cellulose spear. The tendon was cut flush with the sclera. On release, the muscle retracted out of view. The insertion site was inspected to confirm that the entire tendon had been divided (Figure 1). The procedure was repeated in the other eye. Antibiotic ointment was applied to both eyes and the infant was returned to its mother after regaining consciousness. Photographs were taken periodically after surgery, using a 100-mm macro lens with a ring flash to document the strabismus angle.[8]

Once the animals were mature enough for testing, they were transported to the University of California, San Francisco. A titanium headpost was implanted on the frontal bone to stabilize the head during experiments.[9] The animals were trained to sit in a primate chair and to fixate visual targets for a food reward. Eye positions were monitored continuously using an infrared video camera focused on each eye. Full details of the experimental set-up have been published.[5,7]

After neurophysiological or neuroanatomical experiments were completed, each animal was killed by intravenous injection of pentobarbital (150 mg/ kg). Normal saline was perfused through the heart followed by 1 L of 1% paraformaldehyde in 0.1 M phosphate buffer, pH 7.4. The brain was removed for histological processing. The orbits were dissected, with particular attention to the anatomy of the previously tenotomized medial rectus muscles.

RESULTS

The 6 monkeys demonstrated an alternating exotropia the day after bilateral medial rectus tenotomy. The magnitude ranged between 30° and 70°, judging from the position in each eye of the corneal light reflex from the camera flash. No monkey was able to adduct either eye beyond primary position. These results indicated that in all 6 animals the medial rectus tendon in each eye had been successfully separated from the globe.

Over subsequent weeks, each monkey showed a reduction in strabismus angle, followed by a more gradual improvement that lasted several months. The exotropia stabilized at final values ranging between 7° and 60°. Reduction in exotropia was accompanied by an improvement in adduction. One monkey regained up to 40° of adduction in each eye, but 10° to 20° was the typical value.

Figure 2 shows an eye movement tracing from a head-fixed monkey pursuing a light spot that moved sinusoidally back and forth along the horizontal meridian. The monkey alternated fixation of the target, acquiring it with the right eye when it was rightward and with the left eye when it was leftward. The right eye was dominant, making a 20° nasal saccade to meet the target when it was moving toward the right side.

Figure 3 shows the findings at necropsy in this monkey after removal of the conjunctiva and Tenon's fascia. The medial rectus muscle inserted into the globe via a broad sheet of fibrous tendon, measuring 3 mm in length. It was firmly attached to the sclera, 4 mm from the nasal limbus. Necropsy was performed in the 6 monkeys at a mean age of 6.5 years (range: 3 to 12 years). In all animals, the medial rectus muscle was found to terminate at its normal insertion site. The tendon appeared longer than usual, ranging between 2 and 4 mm, but otherwise one would not have known that the muscle was previously severed from the globe.

Figure 4 shows a horizontal computed tomographic scan through the orbits of a different monkey, who underwent postnatal tenotomy of the medial rectus muscles 3 years earlier. The eyes occupy a much larger fraction of the volume of the orbits than in a human. The major finding is that the medial rectus muscles appear to be inserted in a normal position onto the globes.

DISCUSSION

It is surprisingly difficult to create strabismus in newborn macaques by operating on the horizontal rectus muscles. Von Noorden and Dowling[10] reported no success after a free tenotomy of a single muscle in 10 infant monkeys. They resorted to monocular surgery on two muscles, extirpating one and advancing the other to the limbus. Later investigators confirmed that when surgery is confined to 1 eye, an aggressive recess/resect procedure is required.[11–14]

In unpublished experiments, we performed a free tenotomy of the lateral rectus muscle in both eyes of 4 infant macaques to produce esotropia. The animals maintained fusion simply by fixating at near. Over a period of months their abduction returned until they were orthotropic at distance. This spontaneous recovery made them unsuitable for neural studies of experimental strabismus. Subsequently, we switched strategy and elected to tenotomize the medial recti.[7] This approach works because the animals cannot fuse on any visual target during the critical period for development of binocular vision.[15] By the time their adduction deficit lessens, the fusion deficit is permanent.

Free tenotomy of a horizontal rectus muscle is never performed deliberately in human infants. For this reason, it seemed worthwhile to report our experimental findings in non-human primates. In children, a lost muscle during strabismus surgery does not reattach to the globe, although partial recovery of function may occur.[16–18] A more common scenario is a muscle that has slipped posteriorly because only the capsule was sutured to the sclera.[19] In a recent study of 129 patients with consecutive exotropia, an abnormal medial rectus attachment to the globe was encountered during surgery in 33% of eyes.[20] There often was a translucent membrane connecting muscle fibers to the sclera, just as we observed (Figure 3).

It is unclear whether the fibrous tissue reconnecting the muscle to the globe represents an elongated tendon, a pseudotendon, or a muscle capsule.[21,22] We previously described the histology of the medial rectus muscle after spontaneous reattachment in a 4-year-old macaque with exotropia.[7] The muscle inserted via a band of connective tissue into the sclera at the normal insertion site. It is impossible to ascertain the strength of a muscle's attachment to the globe from examination of histological sections. To assess this property, one must apply tension to the tissue at necropsy. When this was done, by placement of a hook under the muscle belly, it was evident that the muscle was robustly anchored to the eye (Figure 3).

It is interesting to speculate why a disinserted muscle reinserts more avidly into the globe in infant monkeys than humans. In macaques, the globe alone accounts for half of the volume of the orbit.[23] In newborn macaques, the proportion is even higher. This means that after free tenotomy the tendon stump remains in close proximity to the globe because it does not have much room to retract. The cut surface of the scleral insertion site may attract the tendon stump during the healing process, perhaps by secreting signaling molecules. If it is only a small distance away, the muscle may be able to creep forward and reunite with the scleral insertion site. In mature monkeys, forward migration has been shown to occur after hang-back recession,[24] but the amount is modest. In rabbits after a slanted recession, both edges of the muscle moved anteriorly, with a greater shift in the more recessed edge that largely erases the slant.[25] In newborns, wound healing occurs with extreme efficiency.[26] This property may enable the cut tendon in infant macaques to bridge the few millimeters that separate it from the normal scleral insertion site.

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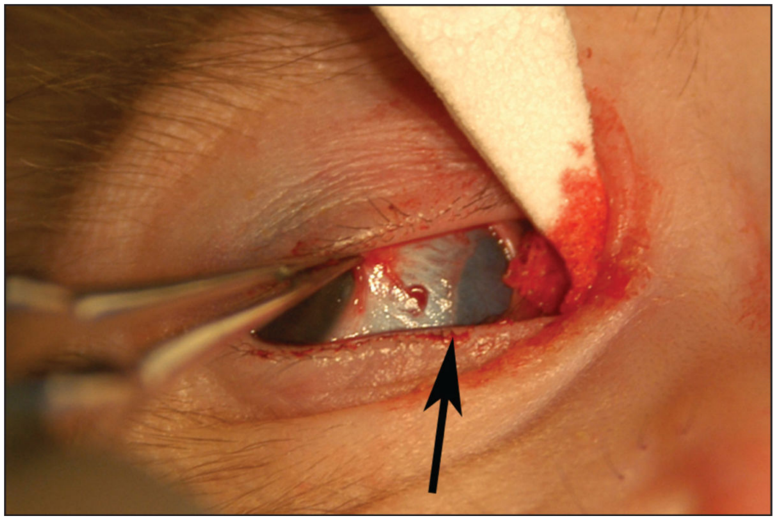

Figure 1.

Right eye immediately after disinsertion of the medial rectus muscle in a 4-week-old macaque. The globe was rotated laterally by forceps at the limbus to reveal the insertion site (arrow) and thin blue sclera underneath the former location of the muscle. The cellulose spear was used to retract the limbal edge of the conjunctiva medially.

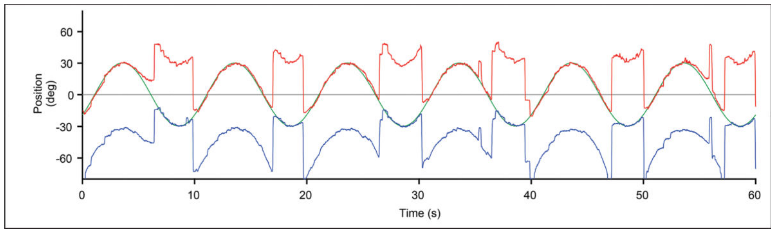

Figure 2.

Eye movement recording from an 8-year-old monkey who underwent bilateral medial rectus tenotomy at age 4 weeks. The exotropic animal swaps fixation on a 1° spot moving horizontally (0.1 Hz, ±30°) back and forth across the screen. It is able to adduct the right eye at least 20°. Green line = target position, red = right eye position, blue = left eye position

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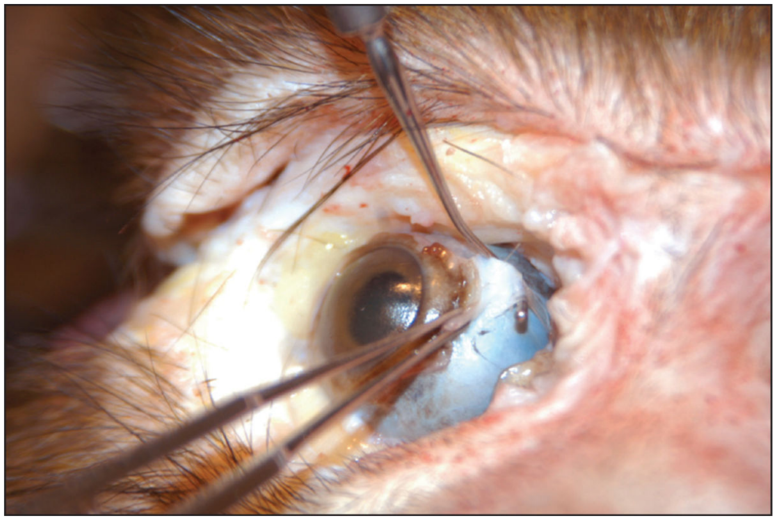

Figure 3.
At necropsy, the medial rectus muscle tendon is anchored firmly to the normal scleral insertion site, despite free tenotomy 8 years earlier.

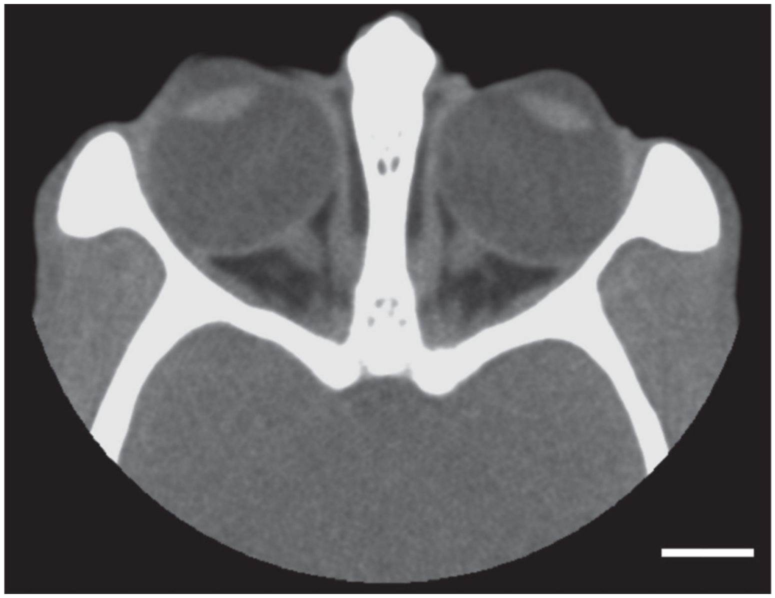

Figure 4.
Horizontal computed tomographic scan in a 3-year-old monkey with exotropia induced by bilateral medial rectus tenotomy at age 4 weeks. The muscles are normally inserted. Note the large size of the globes relative to the orbits. Scale = 1 cm