Die Kontraktion, die sich durch Zugabe von Adrenalin oder Noradrenalin ins Organbad auslösen lässt, wird in gleicher Weise wie die zweite Phase der nervalen Kontraktion durch α-Blocker aufgehoben (am isolierten Muskel geprüft). Es darf also geschlossen werden, dass die Federmuskeln von adrenergen bzw. noradrenergen Nerven innerviert werden, die die zweite Phase der nervalen Kontraktion vermitteln.

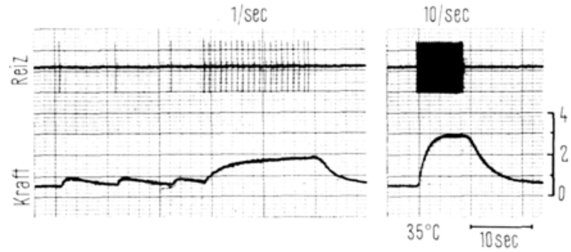

Fig. 1. Kontraktion des Federmuskels bei Nervenreizung, am isolierten innervierten Hautlappen vom Taubenflügel gemessen. Oben Reizmarkierung, unten Muskelkraft in Pond. Ein elektrischer Reizimpuls bestand aus einer vollen Sinuswelle von 10 msec Dauer.

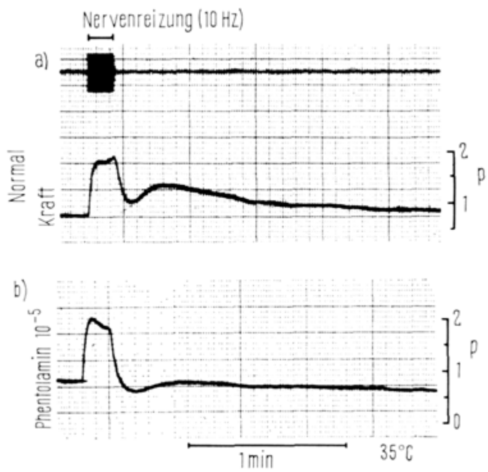

Fig. 2. Kontraktion des Federmuskels bei Nervenreizung mit 10 Imp/sec. (a) Biphasische Kontraktion unter Normalbedingungen, am isolierten Hautlappen in Krebs-Lösung. (b) Blockade der zweiten Kontraktionsphase 23 min nach Zugabe des α-Rezeptoren-Blockers Phentolamin (Handelsname: Regitin). Alle Ausschnitte vom gleichen Versuch. Muskelkraft in Pond geeicht.

Die Initialphase der nervalen Kontraktion lässt sich weder durch Curare noch durch Atropin unterdrücken. Der β-Rezeptoren-Blocker Propranolol hat in dem spezifisch wirksamen Konzentrationsbereich (bis 10^{-5} g/ml) gleichfalls keinen Effekt. Erst höhere Konzentrationen unterdrücken über eine lokalanästhetische Wirkung auf die Nerven den Effekt der Nervenreizung. Auch der Serotonin-Antagonist Methysergid (1-Methyl-D-Lysergsäurebutanolamid) hat in einer Konzentration von 10^{-5}, bei der die durch Zugabe von Serotonin auslösbare Kontraktion völlig unterdrückt wird, keinen erkennbaren Effekt auf die Initialphase der nervalen Kontraktion.

Der Federmuskel der Taube gehört zu den «elastisch-muskulösen Systemen»[1], d.h. zu den glatten Muskeln, die in ein System elastischer Fasern eingeordnet sind, wie z.B. auch in den grossen, elastischen Blutgefässen. Der innervierte Federmuskel der Taube ist offenbar ein Präparat, das sich gut zur Untersuchung dieses wichtigen Typs glatter Muskulatur eignet, sowohl für eine elektrophysiologische Analyse des Muskels[3] als auch zum Studium der neuromuskulären Erregungsübertragung[4].

Summary. The tension development of the smooth feather muscles of the pigeon was measured (a) on the wing in situ (b) on an isolated innervated skin preparation and (c) on an isolated muscle preparation. The contraction produced by nerve stimulation is biphasic. The second phase can be blocked by α-receptor blocking agents. The mechanism of the first phase is unknown. The preparation seems very suitable for the investigation of neuromuscular transmission in smooth muscle.

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A Mechanical Study of the Cat Retractor Bulbi Muscle

In the cat, the retractor bulbi muscle splits into 4 slips a few millimeters after its origin. These 4 slips and the lateral rectus are innervated by the VI nerve[1].

The cat retractor bulbi has been shown to differ physiologically[2], pharmacologically[3], and histologically[4] from the other 6 extraocular muscles. These studies suggest that the retractor bulbi lacks the slow tonic fibers found in the rectus and oblique muscles, and that the fibers of the retractor bulbi, in keeping with a role in reflex retraction of the eyeball and resulting nictitating membrane excursion, resemble the fast muscle fibers of the other 6 extraocular muscles. In the present study, an attempt has been made to assess the mechanical properties of the retractor bulbi in comparison with the fast and slow fibers of the inferior oblique muscle.

Methods. Ten cats anesthetized with sodium pentobarbital were included in this study. The orbital muscles were exposed by partial removal of the temporalis muscle,

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zygomatic arch and temporal bone to allow superior and lateral access to the entire orbital cavity. The right superior or inferior slip of the retractor bulbi with the scleral attachment was removed from the eyeball. The globe was eviscerated and tied under tension to the head holder to prevent mechanical drag from contraction of the other 3 retractor bulbi slips. The VI nerve supply to the lateral rectus was cut to prevent its co-contraction with VI nerve stimulation. The retractor bulbi slip was attached to a RCA 5734 strain gauge for tension recording. Muscle contraction was produced in separate experiments either by stimulation of the VI nerve at its emergence from the pons with a pair of platinum wire hook electrodes, by stimulation of the VI nerve nucleus through a concentric bipolar electrode placed stereotaxically into the VI nerve nucleus, or by direct muscle stimulation. The electrode for the latter was a triangular wick of paper tissue, one side of which was placed over the length of the muscle. The wick was kept moist with a saline drip through a No. 20 needle surrounded by a heating coil[5]. Temperature was monitored by a thermistor in the saline drip. A constant temperature isotonic saline drip of $37 \pm 1.0\,°C$ was used in all experiments. A Grass stimulator was used to deliver stimuli of supramaximal voltage, 0.1 msec pulse duration. For direct muscle stimulation the cat was given a paralyzing dose of D-tubocurare to prevent stimulation of neuromuscular endings. An average tension of approximately 1.0 g was applied to the muscle.

Rise time was measured from the beginning to the peak of tension and half-decay time was measured from the time of peak tension to half-decay from peak tension. Fusion frequency was determined as the lowest frequency of stimulation which produced a fused contraction.

Results. Responses of the retractor bulbi muscle were elicited by stimulation of VI nerve, VI nerve nucleus and by direct muscle stimulation. Inasmuch as all sites of stimulation revealed comparable responses, results obtained with all methods of stimulation are combined.

For the retractor bulbi muscle the following mechanical properties were determined. Ranges have been noted in parentheses.

Twitch response to single pulse stimulation: The mean rise time was 12.7 msec (9–18 msec) with a mean half-decay time of 12.9 msec (10–16). The mean contraction duration was 60.1 msec (45–84 msec) with a mean maximum tension of 0.66 g (0.4–1.3 g).

Tetanic response to stimulation at fusion frequency: The rise time was 151.6 msec (120–180 msec) with a mean half-decay time of 23.8 msec (18–35 msec). Fusion frequency varied from 120–220/sec with a mean of 176/sec. Mean maximum tension was 10.5 g (7.3–18.6 g).

Discussion. For comparative purposes, data on the retractor bulbi from the present study are summarized in the Table together with the mechanical properties of the inferior oblique fast and slow twitch fiber types obtained from the study of BACH-Y-RITA and ITO[5].

It will be noted that twitch responses of the retractor bulbi reveal a rise time and a half-decay time intermediate between those of the fast and the slow twitch fibers of the inferior oblique. The contraction duration is shorter than that of the slow inferior oblique fibers, and presumably longer than that of the fast inferior oblique fibers. Tetanic responses indicate an overlap between the retractor bulbi and the inferior oblique in terms of rise time and half decay. However, the slow fibers in the inferior oblique may be responsible for the somewhat longer rise and half-decay times than would be expected from the fast fibers alone. The fusion frequency of the retractor bulbi is lower than that of the inferior oblique.

The retractor bulbi also differs from the other extraocular muscles in its innervation ratio. The lateral rectus, which is comparable in structure to the inferior oblique[6] has a ratio of nerve fiber to muscle fiber of 1:6[7], while the retractor bulbi has been found to have an innervation ratio of approximately 1:50 (STEINACKER and BACH-Y-RITA, in preparation).

The lack of slow fibers in the retractor bulbi, together with the variation in mechanical properties and large innervation ratio compared with the other extraocular muscles, may reflect the absence of tonic properties and of highly controlled, finely graded movements in this muscle, whose primary purpose is reflex retraction of the globe and resulting nictitating membrane protrusion[8].

Summarized results of present experiments with comparison to results of inferior oblique fast and slow fibers from BACH-Y-RITA and ITO[5]

Single twitch response of muscle to 0.1 msec pulse	Inferior oblique fast fibers	Retractor bulbi	Inferior oblique slow fibers
Rise time, msec	5.7–6.9	9.0–18.0	20.0–27.0
Half decay, msec	7.0–8.0	10.0–16.0	38.0–44.0
Contraction duration, msec	100.0[a]	45.0–84.0	200.0
Maximum tension, g	0.9–1.2[b]	0.4– 1.3	0.3– 0.7

Tetanic response of muscle at fusion frequency	Inferior oblique fast and slow fibers[c]	Retractor bulbi
Rise time, msec	125.0–150.0	120.0–180.0
Half decay, msec	13.0– 20.0	18.0– 35.0
Fusion frequency, pulse/sec	400.0 +	120.0–220.0
Maximum tension, g	17.0– 40.0	7.3– 18.6

[a] It was not possible to eliminate completely the slow fiber contribution to the twitch. The long total duration, which is evident only at high magnification, reflects the contribution of the few slow fibers activated. [b] The single twitch tension of the inferior oblique fast fibers is not maximum since it is at threshold voltage. [c] It was not possible under these experimental conditions to separate the fast from the slow fibers in the tetanic response. These figures are given to illustrate the maximum total muscle response to tetanic stimulation.

Zusammenfassung. Die mechanischen Eigenschaften des M. retractor bulbi in der Katze (Anstiegs- und Abfallzeiten der Einzelzuckung und der tetanischen Kontraktion und Fusionsfrequenz) liegen zwischen den Eigenschaften der schnellen und langsamen Zuckungsfasern des M. obliquus inferior.

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