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Rapid communication

Oculomotor parasympathetic pathway to the accessory ciliary ganglion bypassing the main ciliary ganglion by way of the trigeminal nerve

Satoshi Kuchiiwa *, Toshiko Kuchiiwa, Shiro Nakagawa and Miharu Ushikai

Department of Anatomy, Faculty of Medicine, Kagoshima University, Sakuragaoka 8-35-1, Kagoshima 890, Japan

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Summary

When an HRP or WGA-HRP solution was injected into the rostral midbrain including the oculomotor visceral nuclei, densely distributed HRP/WGA-HRP-positive granules were observed around the ganglion neurons in the accessory ciliary ganglion (ACG) and ectopic neurons in the communicating branch from the long ciliary nerve to the ACG. The same injections labeled fibers within the communicating branch as well as the fibers between the ACG and the main ciliary ganglion (CG). These findings indicate that some oculomotor parasympathetic preganglionic fibers reach the ACG bypassing the CG by way of the trigeminal nerve.

The most generally accepted view of the efferent pathway to the smooth muscles of the iris is that all preganglionic parasympathetic pupillo-constrictor fibers pass through the oculomotor nerve and terminate in the ciliary ganglion in synaptic relation with postganglionic fibers that distribute to the pupillary sphincter muscle. If this is the only pathway to the sphincter, the removal of the ciliary ganglion would result in a pupil that neither responds to light nor accommodates for distance. However, ganglionectomy produces a pupil that does not react to light, but which constricts briskly to accommodate for near vision (peripheral Argyll-Robertson pupil) (Foerster et al., 1936). This experiment indicates that there must be two separate pupillo-constrictor pathways, one mediated in the main ciliary ganglion (CG), and the other concerned with the pupillary reflex which accompanies near vision (pupillary near reflex), leaving the oculomotor nerve at some point, bypassing the CG and relaying the other oculomotor parasympathetic ganglion, i.e., the accessory ciliary ganglion (ACG).

The ACG is common to all or most mammalian species (Kuchiiwa et al., 1989), including the cat (Christensen, 1935/6; Grimes and von Sallmann, 1960; Kuchiiwa, 1990) and it fuses with a communicating branch from the long ciliary nerve of the trigeminal nerve in many species (Kuchiiwa et al., 1989). This indicates that the ACG has a route joined by nerve fibers which are not associated with the CG. If indeed

* Corresponding author. Tel.: 0992-75-5212.

Abbreviations: 3N, root of the oculomotor nerve; II, optic nerve; III, oculomotor nerve; ACG, accessory ciliary ganglion; C, interstitial nucleus of Cajal; CB, communicating branch from the long ciliary nerve; CG, ciliary ganglion; D, nucleus of Darkschewitsch; Et, ethmoidal nerve; Fr, frontal nerve; IF, interfascicular nucleus; Io, branch to the inferior oblique muscle; Ir, branch to the inferior rectus muscle; It, infratrochlear nerve; La, lacrimal nerve; LC, long ciliary nerve; Lp, branch to the levator muscle of the palpebra; Mr, branch to the medial rectus muscle; NC, nasociliary nerve; PAG, periaqueductal gray; PC, posterior commissure; RF, retroflex bundle; SCl, lateral branch of the short ciliary nerve; SCm, medial branch of the short ciliary nerve; Sr, branch to the superior rectus muscle; TG, trigeminal ganglion; V1, ophthalmic nerve; V2, maxillary nerve; V3, mandibular nerve.

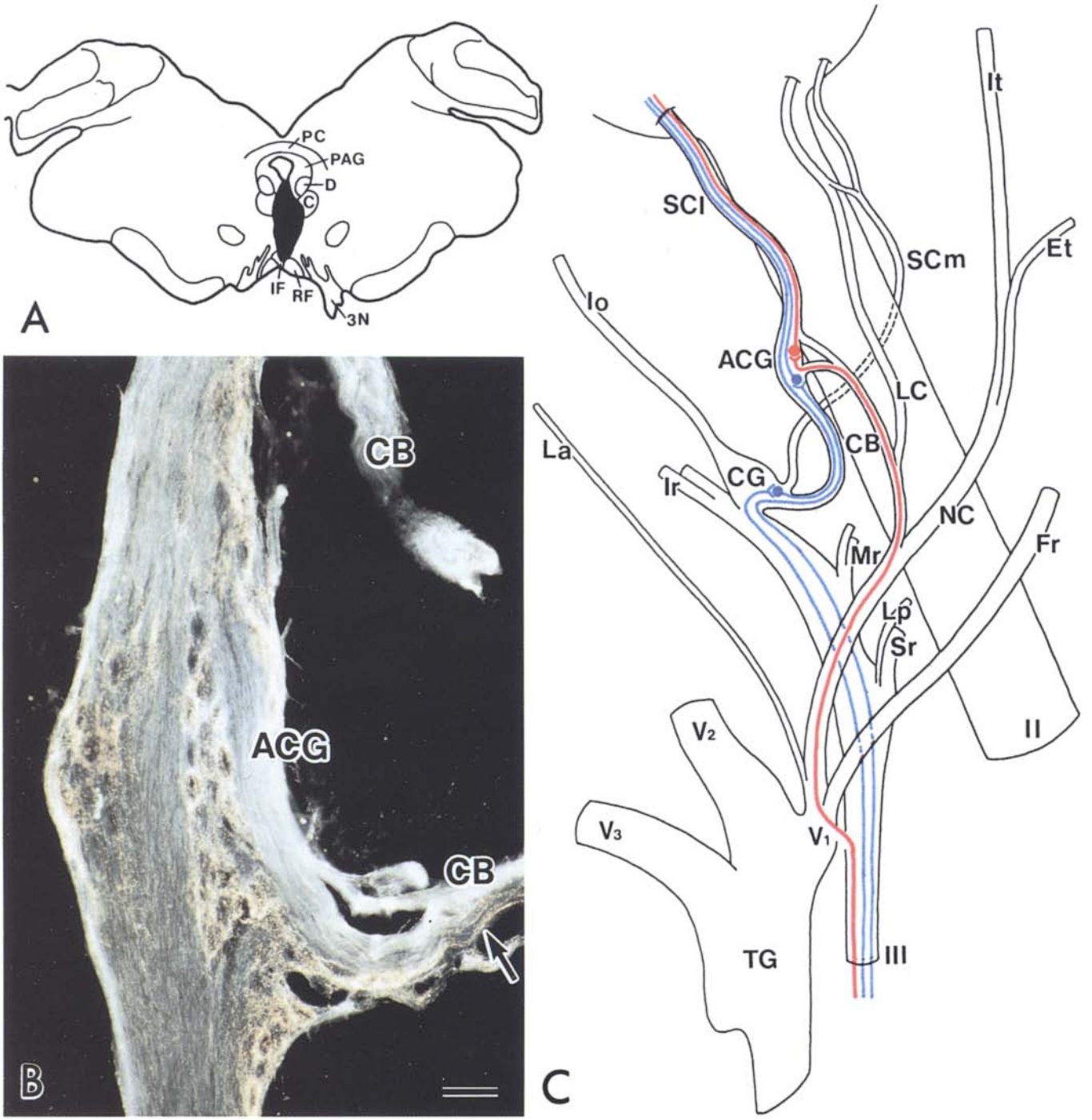

Fig. 1. (A) Diagram showing the site of maximum extent of an injection of WGA-HRP into the rostral midbrain. Frontal section. (B) Photomicrograph of the ACG and the communicating branch from the long ciliary nerve showing labeled terminals around the ACG cells and labeled fibers in the communicating branch (arrow). (C) Schematic diagram showing two separate oculomotor parasympathetic outflows. The red line indicates the efferent pathway to the ACG by way of the trigeminal nerve, demonstrated in the present study. The blue lines indicate the conventional pathway passing through the CG.

there are two separate efferent pathways, it is expected that labeled nerve fibers will be found in the trigeminal communicating branch after injection of a tracer into the oculomotor visceral nuclei. In the present study, we used cats to demonstrate that fibers arising in the oculomotor visceral nuclei project to the ACG bypassing the CG by way of the trigeminal nerve.

Experiments were performed on a total of 7 adult cats weighing 1.8–3.8 kg using horseradish peroxidase (HRP) and HRP-conjugated wheat germ agglutinin (WGA-HRP) techniques. The animals were anesthetized with intramuscular injections of ketamine hydrochloride at a dose of 20–40 mg/kg, and with an intraperitoneal injection of nembutal (sodium pentobarbitone: 20–30 mg/kg), and placed in a stereotaxic head holder. In 5 cats, the brain was exposed under sterile conditions and a 1 μl solution of 30% HRP (Toyobo Grade I-C) or 5% WGA-HRP (Toyobo) dissolved in saline was injected stereotaxically into the rostral midbrain including the oculomotor visceral nuclei. In 2 other cats, a 10 μl solution of 30% HRP was injected stereotaxically into the orbit as approached through the lateral ocular angle in order to examine whether some oculomotor fibers leave the brain stem by way of the trigeminal nerve root or not. After a 45–51 h post-injection survival period, the cats were reanesthetized and perfused through the aorta with 1 l saline followed by 2 l 1.0% formalin and 1.25% glutaraldehyde in 0.1 M phosphate buffer at pH 7.4. The brain stem and both sides of the ACG with the communicating branch were removed and immersed in a cold buffer containing 30% sucrose, and 50 μm thick sections were cut using a frozen microtome. All sections of the ganglion and every third section of the brain stem were prepared for peroxidase histochemistry by the tetramethylbenzidine reaction method (Mesulam, 1978), and treated with a 5% ammonium molybdate solution adjusted to pH 3.5 with 1 N hydrochloric acid. The sections of the brain stem were counterstained with neutral red.

In all animals receiving an injection in the brain stem, the injected HRP/WGA-HRP was found to be restricted to the rostral portion of the midbrain including the oculomotor visceral nuclei, namely the anteromedian and Edinger-Westphal nuclei, the median region between each side of the oculomotor somatic nuclei and the median region of the ventral tegmental area (Fig. 1A) (Sugimoto et al., 1977; Loewy et al., 1978; Toyoshima et al., 1980; Burde et al., 1982; Maciewicz et al., 1983). However, the tracers did not diffuse into any nuclei of the trigeminal nerve.

In the ACG, a large number of HRP/WGA-HRP labeled granules were observed around each neuron in the ganglion (Fig. 1B). These pericellular granules are considered to be terminals of preganglionic fibers of the oculomotor visceral nuclei, since the distribution is similar to that of electron microscopically identified axon terminals of cat CG cells (Tobari, 1971). Moreover, labeled fibers were found within the communicating branch from the long ciliary nerve as well as the short ciliary nerve between the ACG and the CG (Fig. 1B; arrow). In two cases a few ectopic ganglion cells were observed in the communicating branch and they were also found to be surrounded by densely distributed labeled granules.

In the animals receiving an injection of HRP in the orbit, labeled neurons were observed in the oculomotor, trochlear, abducens and facial nuclei and the mesencephalic and motor nuclei of the trigeminal nerve, and labeled terminals were found in the sensory nucleus of the trigeminal nerve. Labeled fibers arising in the oculomotor nuclei were observed exclusively to leave the brain stem by way of the oculomotor roots. No labeled fibers were found to enter the trigeminal roots.

In most species the ACG is located at the point of fusion of the short ciliary nerve with the communicating branch from the trigeminal nerve (Kuchiiwa et al., 1989). The communicating branch of the cat contains many small myelinated fibers (Christensen, 1935/6) that are impossible to distinguish from the fibers in the short ciliary nerve, and these fibers have been postulated to be parasympathetic (Kuchiiwa, 1990). In the present study the HRP or WGA-HRP injections into the rostral midbrain including the oculomotor visceral nuclei resulted in the labeling of fibers in the communicating branch from the trigeminal nerve, and the ectopic ganglion neurons in the branch were surrounded by orthogradely labeled terminals. These findings indicate that at least some oculomotor parasympathetic preganglionic fibers reach the ganglion bypassing the CG by way of the trigeminal nerve as shown in Fig. 1B. It is therefore thought that there are two separate parasympathetic preganglionic pathways for efferent projections to the ACG.

After HRP injection into the orbit, no labeled fibers arising from the oculomotor visceral nuclei were found to enter the trigeminal root, indicating that all oculomotor preganglionic fibers emerge from the brain stem through the oculomotor root, and that a small part of them then enter the trigeminal trunk at some peripheral point. Under the dissecting microscope, however, no obvious communicating branches between the oculomotor and the trigeminal nerve were found in por-

tions proximal to the ACG (Kuchiiwa et al., 1989; Kuchiiwa, 1990). Since the oculomotor trunk makes contact with the origin of the ophthalmic nerve trunk, and both trunks are wrapped together by a connective tissue capsule, it is considered that some of the preganglionic nerve fibers of the ACG leave the oculomotor trunk to join the trigeminal trunk at this point of contact.

Since extirpation of the CG destroys light reflex and accommodation but not pupillary near reflex, it may be possible that the pupillary near reflex fibers relay not only in the CG but also in the more peripherally situated ACG, at least in part, by way of the communicating branch from the long ciliary nerve.

Nathan and Turner (1942) collected records of 10 cases in humans where an orbital injury had given rise to an Argyll-Robertson pupil. The ACG cells of humans occur in association with the short ciliary nerves both singly and in clusters. They are situated episclerally, sclerally, and intraocularly as well as intraorbitally (Givner, 1939; Castro-Correia, 1967; Kuchiiwa et al., 1989). (Of these, the ganglia just proximal to the sclera or in the scleral canals are known as the episcleral ganglia of Axenfeld (1907), and these have been considered most likely to be pathways for axons mediating pupillary near reflex (Nathan and Turner, 1942)). In man, over one hundred intraocular ACG cells were found in each eyeball (unpublished). Since these cells are considered to be more resistant to intraorbital trauma, the peripheral Argyll-Robertson pupil may occur after injuries to the orbit.

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