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Comparative anatomy of the accessory ciliary ganglion in mammals

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Summary. The orbits of 13 mammalian species (pig, sika deer, domestic sheep, horse, cat, fox, racoon dog, marten, rat, rabbit, crab-eating macaque, japanese macaque and man) were stained with silver nitrate and dissected under a dissecting microscope with special attention to the presence and location of the accessory ciliary ganglion. Some preparations were stained with thionin and examined as whole-mounts in a transmission microscope. The accessory ciliary ganglion was present in all 13 species, although the number and degree of development varied greatly from species to species. The accessory ciliary ganglion could be readily differentiated from the main ciliary ganglion in the following respects: it was located on the short ciliary nerve, and it had no root derived directly from the inferior trunk of the oculomotor nerve and it never attaches to this nerve. In many species, ganglion cells were also scattered in the short ciliary nerves in the stained whole preparations. In a few species, there were one or more small ganglia on the nerve to the inferior oblique muscle.

Key words: Ciliary ganglion – Parasympathetic ganglia – Oculomotor nerve – Autonomic ganglion – Eye innervation

Introduction

Since Lecco (1906) first described the presence of an accessory ciliary ganglion on the short ciliary nerve, the presence of the ganglion has been reported by several researchers in the cat, dog, formosan macaque and rhesus monkey (Imai 1935a, b, 1936; Christensen 1936; Grimes and von Sallmann 1960; Kuchiiwa et al. 1988a). However, detailed reports on the orbital nerves in other species are too few to determine whether the ganglion is generally present in all mammalian species including man. In the excellent textbooks on the autonomic and peripheral nervous system, a detailed description of the ganglion is not given either (Gabella 1976a, b).

Recent anatomical studies indicate that the accessory ciliary ganglion of the cat is parasympathetic in nature, and it has a postulated separate function of mediating pupillary constriction in association with convergence and accommodation of the eyes (Kuchiiwa et al. 1988a, b). If this suggestion is correct, an accessory ganglion can be expected in all or most mammalian species, and the ganglia would have common morphological characteristics.

This paper reports on a comparative study of the accessory ciliary ganglion in 13 mammalian species.

Materials and methods

Both orbits of individuals of 13 mammalian species in six orders were dissected with special attention to the presence and location of the accessory ciliary ganglion; the distribution of scattered ganglion cells or small groups of ganglion cells in the short ciliary nerves or in other branches of the oculomotor nerve was examined in stained whole-mount preparations.

The materials used were obtained from four pigs (*Sus scrofa*), one sika deer (*Cervus nippon*), two domestic sheep (*Ovis aries*), three horses (*Equus caballus*), five cats (*Felis domestica*), two foxes (*Vulpes vulpes*), two raccoon dogs (*Nyctereutes procyonoides*), five martens (*Martes melampus*), three rats (*Rattus norvegicus albus*), five rabbits (*Oryctolagus cuniculus*), three crab-eating macaques (*Macaca irus*), two Japanese macaques (*Macaca fuscata*) and two men (*Homo sapiens*); the animals had been used for food or fur, or used in other experimental studies (Kuchiiwa et al. 1984, 1985); the human orbits were obtained from stock teaching laboratory preparations.

Each of the orbital tissues examined was prepared in the following general manner. The complete orbital content was removed and fixed with 10% formalin, then dissected under a dissecting microscope. In many cases a part of extraocular muscles were resected without damage to the underlying nerves, and the preparation was then stained with 0.5% silver nitrate solution as described by Christensen (1936) to facilitate observation of fine nerve connections. In most cases, after completion of the dissection, the

Abbreviations: *II*, optic nerve; *III*, oculomotor nerve; *IV*, trochlear nerve; *V*, trigeminal nerve; *VI*, abducens nerve; *ACG*, accessory ciliary ganglion; *CB*, communicating branch from the long ciliary or nasociliary nerve; *CG*, ciliary ganglion; *Io*, branch to the inferior oblique muscle; *IoG*, ganglion on the nerve to the inferior oblique muscle; *IR*, inferior rectus muscle; *Ir*, branch to the inferior rectus muscle; *LCN*, long ciliary nerve; *LP*, levator muscle of the palpebra; *LR*, lateral rectus muscle; *Lr*, branch to the lateral rectus muscle; *Mr*, branch to the medial rectus muscle; *Mx*, branch from the maxillary nerve; *NCN*, nasociliary nerve; *SCN*, short ciliary nerve; *SCNl*, lateral branch of the short ciliary nerve; *SCNm*, medial branch of the short ciliary nerve; *SO*, superior oblique muscle; *SR*, superior rectus muscle; *Sr*, branch to the superior rectus muscle; *Sym*, sympathetic nerve; *TG*, trigeminal ganglion

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accessory and the main ciliary ganglia were removed together with their roots and the short ciliary nerves. These nervous tissues were stained with a thionin solution containing sodium acetate trihydrate, 2.72 g; distilled water, 1000 ml; sufficient glacial acetic acid to adjust pH to 3.8 (approximately 4.8 ml), and thionin, 2.5 g, in order to determine, with the aid of a transmission microscope, the distribution of the ganglion cells.

Results

The number and the course of the short ciliary nerves, and their connections with the fifth nerve varied considerably, not only from species to species but also from individual to individual, and so did the location, number and size of the accessory ciliary ganglia. The variation tended to be conspicuous in animals with a multiple pattern of the short ciliary nerves, such as primates and artiodactyla. In contrast, in animals with simple nerve patterns, such as carnivores and the lagomorphs, the variation was minimal.

Pig

The ciliary ganglion was connected to the nerve for the inferior oblique muscle by several short roots and gave off a lateral and a medial group of the short ciliary nerves (Fig. 1A). Communicating branches from the nasociliary nerve joined the main ciliary ganglion, while another fine branch fused with one of the lateral short ciliary nerves about 20 mm distal to the main ganglion. At the point of fusion there was a prominent accessory ganglion. Another small ganglion often appeared on one of the lateral branches distal or proximal to this ganglion. A large branch of the maxillary nerve entered the orbit through the inferior orbital fissure, divided into many fine branches, and joined the main ganglion and the nerve to the inferior oblique muscle. Near the points of fusion, there were also a few small ganglia on the nerve to the inferior oblique muscle.

Sika deer

The ciliary ganglion was connected to the branch for the inferior oblique muscle by large motor roots of varying lengths and gave rise to a thick lateral and a finer medial short ciliary nerve (Fig. 1B). Several accessory ciliary ganglia were located on both branches a short distance from the eyeball. The most prominent of them was located on the lateral branch about 15 mm from the main ganglion and gave off a number of postganglionic nerves which branched further into many filaments. The communicating branches from the nasociliary nerve fused with the accessory ciliary ganglion and the lateral short ciliary nerves rather than with the main ganglion. The communicating branch from the maxillary nerve frequently divided into several finer branches, which then joined the ciliary ganglion and the nerve for the inferior oblique muscle in a fan-like arrangement.

Domestic sheep

The ciliary ganglion was characterized by lobulate appearance (Fig. 1C). A number of its roots were derived from the origin of the nerve for the inferior oblique muscle, and they anastomosed into a single heavy branch before entering the ganglion. The main ganglion gave off five to eight short ciliary nerves which bifurcated repeatedly. The communicating branches from the nasociliary nerve did not join the main ganglion but fused with the short ciliary nerves not far from the eyeball. Many accessory ciliary ganglia were located at these points of bifurcation and fusion. A thick branch from the maxillary nerve bifurcated before joining the main ganglion and the nerve for the inferior oblique muscle.

Horse

The root of the ciliary ganglion derived from the nerve for the inferior oblique muscle, and was 7–8 mm in length (Fig. 1D). The ciliary ganglion gave off a single short ciliary nerve which bifurcated into two branches just proximal to the accessory ciliary ganglion; the medial branch entered the accessory ganglion, while the lateral one passed by it and directly entered the eyeball close to the ora serrata in the inferior surface of the eyeball. The accessory ganglion was located outside the retractor bulbi about 5 mm distal to the main ganglion and gave off two postganglionic branches which did not enter the inside of the cone of the retractor bulbi but ascended to the superior surface of the eyeball and penetrated the sclera near the ora serrata. There was no connection between the communicating branches from the long ciliary nerve and the accessory or main ciliary ganglion. The branch from the maxillary nerve bifurcated into two communicating branches which joined the main and the accessory ciliary ganglia.

Cat

The anatomy of the ciliary nerves of the cat has been described previously, and the findings of the present study were in good agreement with those observations (Lecco 1906; Imai 1935b; Christensen 1936; Grimes and von Sallmann 1960; Kuchiiwa et al. 1988a). The ciliary ganglion was fastened to the main trunk of the oculomotor nerve or was connected by a very short root (Fig. 2A). It gave rise to a thick lateral and a finer medial short ciliary nerves. One or two fine communicating branches from the long ciliary nerve were fused with the lateral branch about 3–4 mm from the main ganglion; at this point of fusion there was a single prominent accessory ciliary ganglion. In the carnivora examined, there were no branches of the maxillary nerve coming into the orbit.

Fox

The ciliary ganglion was well developed, 2 mm in its longest diameter, and lay on the oculomotor nerve just at the junction of the branches supplying the inferior oblique muscle and the medial rectus muscle (Fig. 2B). There were between three and six short ciliary nerves, which often fused with each other immediately after emerging from the ganglion. There were two accessory ciliary ganglia on the short ciliary nerves. One was prominent, 1 mm in diameter, situated about 6 mm from the main ganglion. The other, much smaller but discernible in the silver-impregnated preparations, was located 2 mm more peripherally. Each ganglion gave off many fine short postganglionic branches which entered the eyeball. The communicating branch, separated

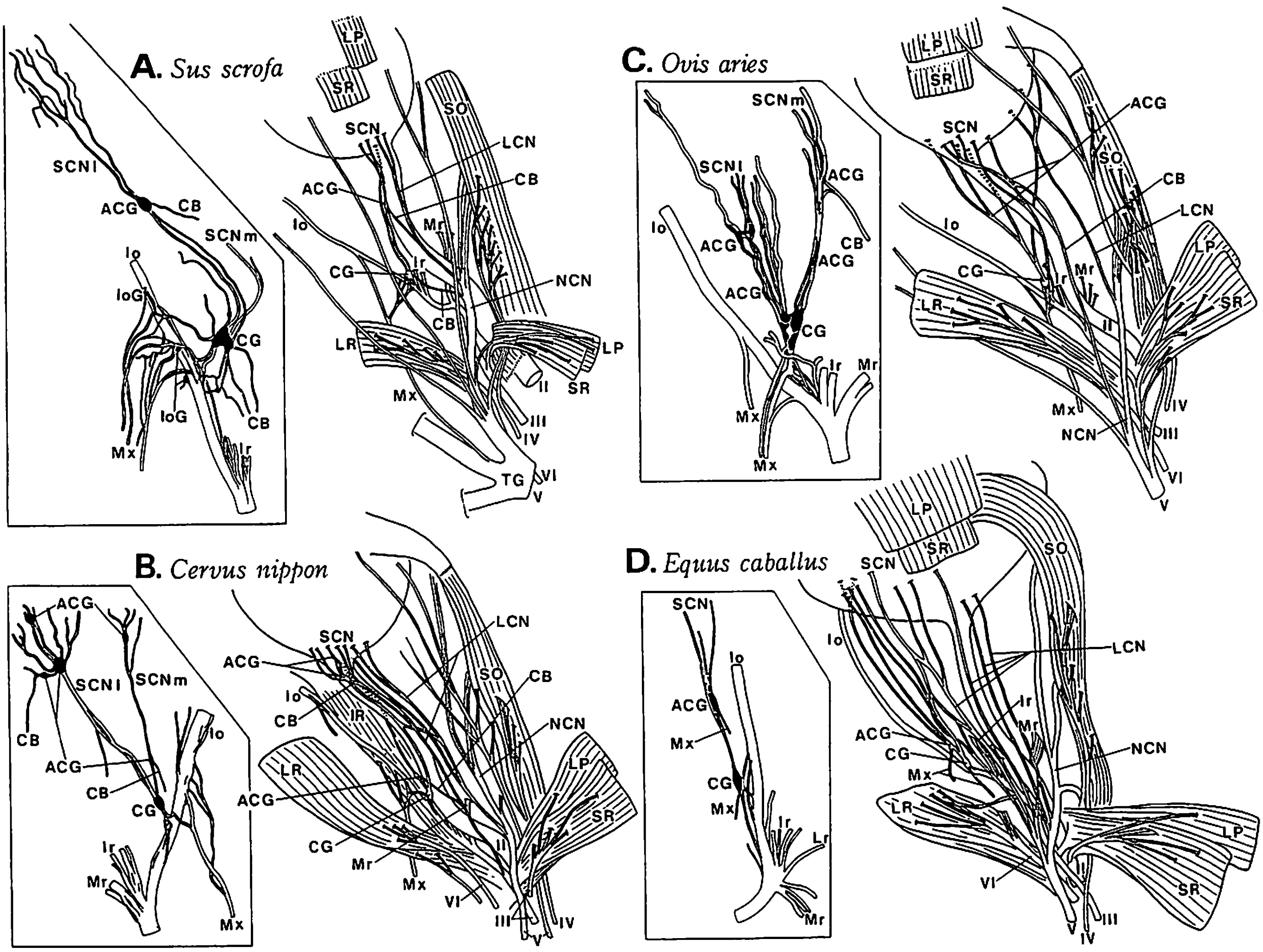

Fig. 1A–D.

Figs. 1–3. A series of drawings of dissections of orbital nerves showing the course of the cranial nerves and the locations of the accessory ciliary ganglia. Left orbits, view from above with the globe at the top. Insets: drawings made from the preparations of the untwisted and flattened oculomotor nerves indicating the sites of the accessory and the main ciliary ganglia (filled areas) and the clusters of the ganglion cells (dots). **1. A** Pig. **B** Sika deer. **C** Domestic sheep. **D** Horse. **2. A** Cat. **B** Fox. **C** Racoon dog. **D** Marten. **3. A** Rat. **B** Rabbit. **C** Crab-eating macaque. **D** Japanese macaque

from the nasociliary nerve, joined each accessory ganglion but not the main ganglion.

Raccoon dog

The ciliary ganglion was well developed, attached directly to the main trunk of the oculomotor nerve or connected by a very short root (Fig. 2C). There were two main short ciliary nerves: the lateral nerve was a thick trunk which coursed along the lateral aspect of the optic nerve and divided into two branches before entering the eye. The medial nerve was finer and divided into two branches immediately upon emerging from the ganglion. The accessory ciliary ganglion was single, prominent, 1 mm in diameter, readily discernible in the non-stained materials, and located on the lateral branch about 4 mm from the main ganglion. The communicating branch from the long ciliary nerve bifurcated into two or three finer branches which joined the accessory ganglion and the short ciliary nerve in a fan-like arrangement. The main ciliary ganglion did not join the branch from the long ciliary nerve.

Marten

The ciliary ganglion of the marten was very large, ovoid, 1.5 mm in its longest diameter (Fig. 2D). It was attached to the oculomotor nerve just at the origin of the branch supplying the inferior oblique muscle, and gave rise to two short ciliary nerves. There was no accessory ciliary ganglion visible to the naked eye, but in stained preparations a cluster of ganglion cells always appeared on the lateral branch at the point of fusion with the communicating branch of the nasociliary nerve, about 3–4 mm peripheral to the main ganglion. Besides, scattered ganglion cells were found at the point of bifurcation of the lateral short ciliary nerve.

Rat

The location of the ciliary ganglion of this animal was peculiar. It was situated at the origin of the nerve running to

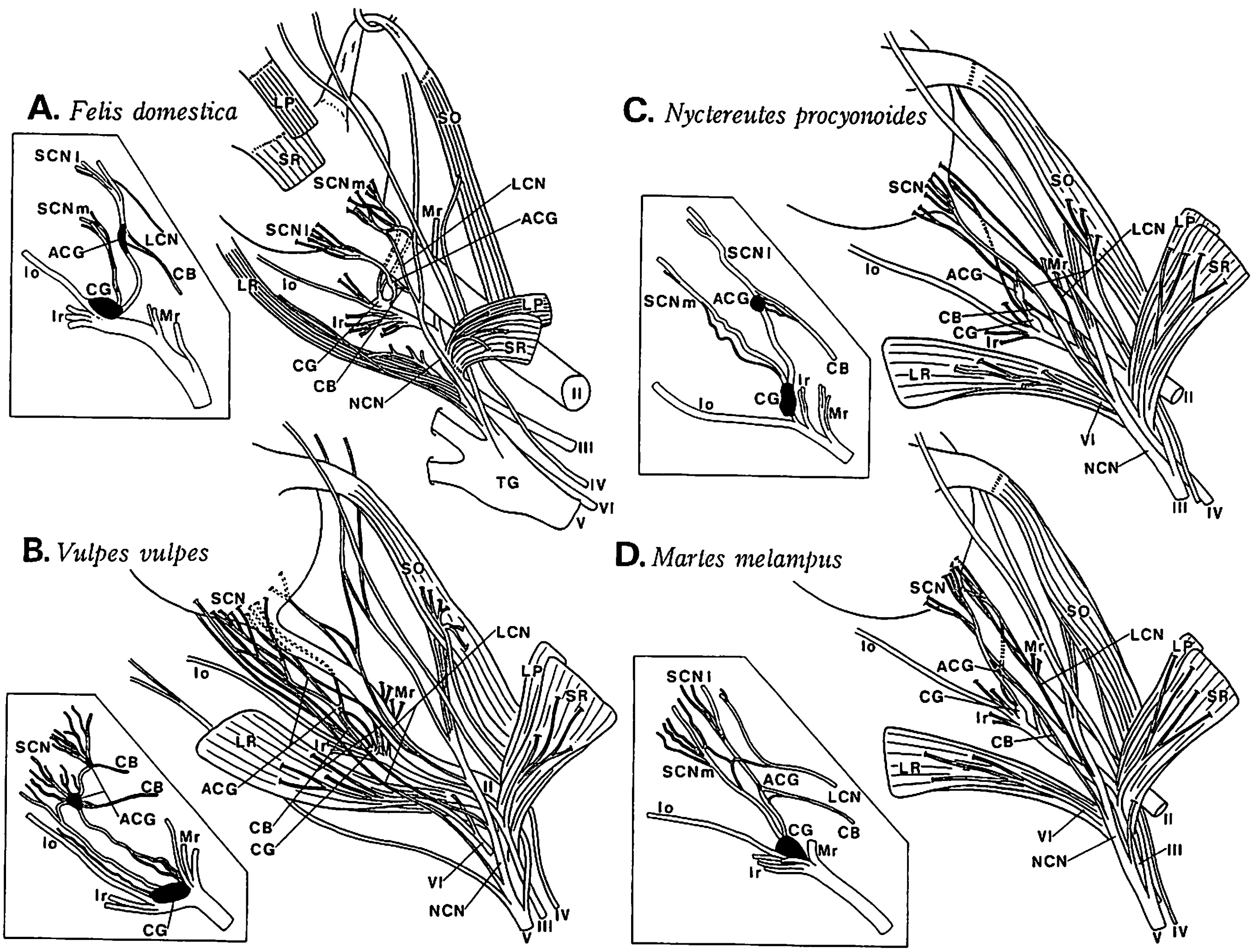

Fig. 2A–D. (For legend see p. 201)

the medial rectus muscle (Fig. 3A). There were two groups of short ciliary nerves. The lateral nerves were divided into several fine branches that entered the eyeball lateral to the optic nerve. The medial ones bifurcated into fine filaments, which fused with branches from the long ciliary nerve and with sympathetic roots originated in a plexus around branches of the ophthalmic artery, and then formed a plexus surrounding the optic nerve. The accessory ciliary ganglia, five to ten in number, were located at the points of bifurcations and fusions of the medial nerve group. Another small ganglion was observed on the nerve for the inferior rectus muscle. A branch of the maxillary nerve ran anteriorly along the optic nerve and entered the eyeball.

Rabbit

The ciliary ganglion of the rabbit was also peculiar (Fig. 3B). It was located medial to the optic nerve, and was attached to the third nerve trunk close to the origin of the nerve for the medial rectus muscle. There was a single short ciliary nerve. Two poorly developed accessory ciliary ganglia were always situated on the short ciliary nerve at the points of the fusion with fine communicating branches from the long ciliary nerve. In the stained materials there was also a cluster of ganglion cells on the oculomotor nerve at the junction of the branches supplying the inferior rectus and the long branch to the inferior oblique muscle. In most of the mammals examined, this point was close to a portion where the main ciliary ganglion was located or was connected by one or more roots. No root was derived from these ganglion cells. There were no branches of the maxillary nerve coming into the orbit.

Crab-eating macaque

The ciliary ganglion was attached directly to the main trunk of the oculomotor nerve just at the origin of the branches for the inferior oblique muscle (Fig. 3C). The fifth nerve connections were occasionally multiple. In three specimens, a lateral group of the short ciliary nerves was anastomosed 1–2 mm from the main ganglion, and fused with a thick branch from the nasociliary nerve; at this point of fusion there was a prominent accessory ganglion. In these preparations, there were no communicating branch from the ophthalmic nerve to the main ganglion. In other specimens, the communicating branches consisted of three to five rather fine branches; one of these entered the main ganglion, the others joined the postganglionic branches. The accessory ganglion was located at, or close to one or two of these

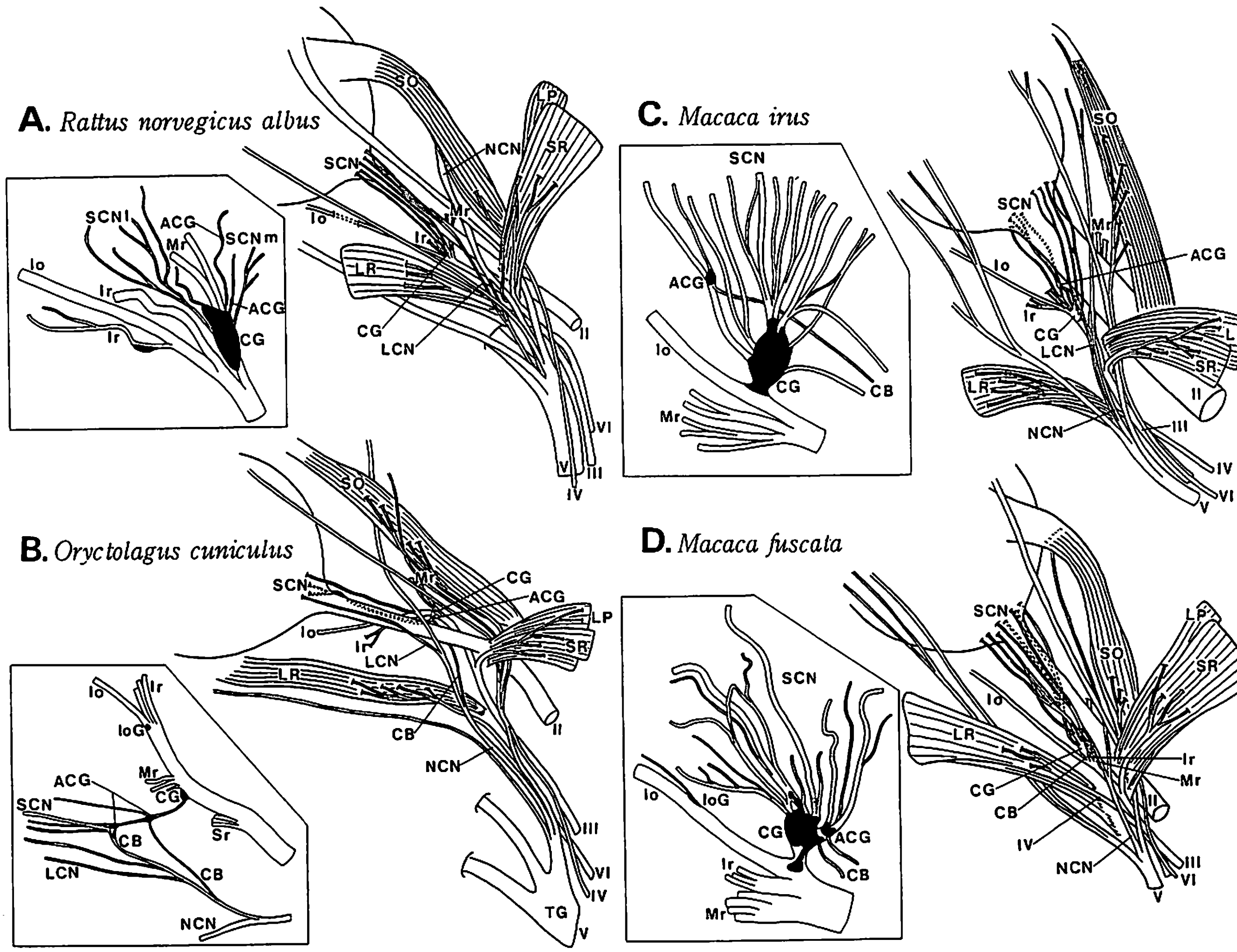

Fig. 3A–D. (For legend see p. 201)

fusions. In the primates, including this species, there were no branches of the maxillary nerve coming into the orbit.

Japanese macaque

The ciliary ganglion lay on the ventro-lateral surface of the optic nerve and was attached to the origin of the nerve supplying the inferior oblique muscle, or was connected to it by a very short root (Fig. 3D). Generally it was a rounded body, approximately 1.5 mm in diameter. Many short ciliary nerves emerged from the ganglion at the border facing the eye ball, the number varying from animal to animal. One of the communicating branches from the long ciliary nerves joined the main ganglion and the other one of the short ciliary nerves, a very short distance from the main ganglion. In the stained whole-mount preparations, there was a small accessory ganglion on the short ciliary nerve at the point of the fusion, and another small ganglion on the nerve for the inferior oblique muscle.

Man

Dissection of the human preparations was undertaken only for comparison, since the anatomy of the ciliary nerves in man is well known (Wolff 1968; Sinnreich and Nathan

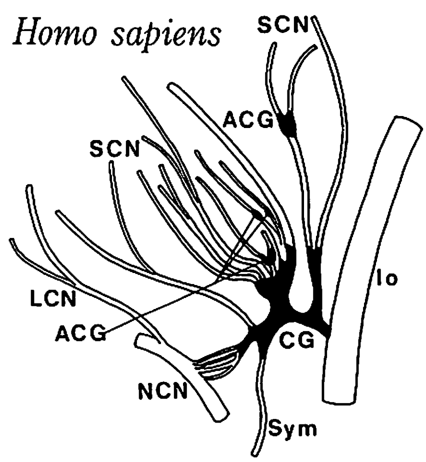

Fig. 4. Drawing of the preparation of the flattened short ciliary nerves of the man indicating the sites of the accessory ciliary ganglia. Right orbit, dorsal view

1981). The ciliary ganglion of man was attached directly to the nerve for the inferior oblique muscle or was connected by a motor root (Fig. 4). It gave off six to ten short ciliary nerves. Ganglion cells were also distributed into the sensory root and the motor root, and both roots gave off short ciliary nerves. There were several small ganglia on the short ciliary nerves 0.5–2.5 mm from the main ganglion. The communicating branches from the nasociliary nerve were not fused with the accessory ciliary ganglia but joined the main ciliary ganglion.

Discussion

An accessory ciliary ganglion can be clearly distinguished from the main ganglion in the following respects: it is located on the short ciliary nerve, it never has a root derived directly from the inferior trunk of the oculomotor nerve and it is never attached to this nerve.

In previous studies an accessory ciliary ganglion had been demonstrated only in the cat, the dog, the formosan macaque and the rhesus monkey (Imai 1935a, b, 1936; Christensen 1936; Grimes and von Sallmann 1960; Kuchiiwa et al. 1988a). In the rabbit, Grimes and von Sallmann (1960) found a single ganglion in only one of 20 silver-impregnated whole-mount preparations. In the present study, however, we found double ganglia in all 10 rabbit preparations. This discrepancy may be the result of the very small size of the ganglia which makes them difficult to find in silver-impregnated preparations.

The accessory ciliary ganglion in many species examined bulged out from the short ciliary nerve so that it could be identified readily in non-stained or silver-impregnated materials, except in the marten, the rat, the rabbit and in primates, whose ganglia were poorly developed and required further microscopic observation. Although the number and degree of development varied greatly from species to species, examination of the whole-mount preparations revealed the presence of an accessory ciliary ganglion in all 13 species. It is therefore probable that the accessory ciliary ganglion is common to all or most mammalian species.

The ciliary ganglion of man is known to have three roots: sensory, sympathetic, and motor; the findings in the present study indicate that this mode of connection is rather exceptional. In most species the fifth nerve is fused with the short ciliary nerve, and very frequently the accessory ciliary ganglion is located at the point of fusion. Thus, the ganglion is joined by nerve fibers which bypass the main ganglion.

In the cat, the origin of the preganglionic fibers of the accessory ciliary ganglion is extremely restricted to the midsagittal plane of the rostral midbrain unlike those of the main ganglion, and the preganglionic fibers leave the midbrain by way of the oculomotor nerve and then pass through and/or bypass the main ganglion to terminate in the accessory ganglion (Kuchiiwa et al. 1988b). It has been strongly suggested that, on fluorescence microscopical and histological grounds, the accessory ciliary ganglion must be parasympathetic in nature (Kuchiiwa et al. 1988a), and the communicating branch between the fifth nerve and the accessory ganglion contains finely myelinated fibers postulated to be parasympathetic (Christensen 1936; Tobari 1971). The postganglionic fibers were considered to be distributed to the intrinsic eye structures close to the anterior and/or posterior chamber of the eye, since the injection of horseradish peroxidase into the posterior chamber resulted in the labeling of almost all these ganglion cells (Kuchiiwa et al. 1988a).

After extirpating the ciliary ganglion in monkeys, Foerster et al. (1936) found that although the pupil reactions to light in the operated eye were lost, the pupil reaction to convergence and accommodation was retained. This experiment showed that there must be two efferent pathways for pupillary contraction, one subserving the light reflex which passes through the ciliary ganglion; the other concerned in the contraction of the pupil that accompanies the convergence and accommodation, mediated in some other ganglion, and running to the sphincter muscle by some other route. As the experimental extirpation of the main ganglion can be performed without damaging the accessory ganglion and the communicating branches to it, it is possible that the accessory ciliary ganglion may be a station for the convergence-accommodation synkinetic contraction.

Axenfeld (1907) described in man the presence of ganglion cells in the ciliary nerves close to the eye and in the episclera and named them episcleral ciliary ganglia. The cells were found both singly and in clusters of up to 30. Such arrangement of the ganglion cells were observed along the length of the short ciliary nerves, hence, it is conceivable that they are nothing more than the accessory ciliary ganglia located just near to the sclera or in the scleral canals.

The ganglion located on the nerve to the inferior oblique muscle has been reported in the formosan macaque (Imai 1935), but apparently in no other animals. In this paper we report the presence of a similar ganglion in the pig, the rabbit and the japanese macaque. It is conceivable that the ganglion is present only in some species, since we could not confirm its presence in other mammalian orbits. The functional significance of this ganglion is obscure.

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