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SMOOTH MUSCLE OF THE PERIORBITA AND THE MECHANISM OF EXOPHTHALMOS

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DISCUSSION on the mechanism of exophthalmos is rendered unnecessarily difficult by doubt as to whether the experimental results obtained on the dog and other mammals may properly be expected in the case of human subjects. The work of MacCallum and Cornell (1904), Whitnall and Beattie (1933) and Code and Essex (1935) has shown that in the dog and cat exophthalmos may be produced by contraction of the periorbital membrane through stimulation of the cervical sympathetic nerve trunk at a point caudal to the superior cervical ganglion. To the smooth muscle of this membrane (or to the whole membrane) the name of "Müller's orbital muscle" has been applied (Müller 1858a, Whitnall 1932). The same name has also been given by the same writers to a muscle in the inferior orbital fissure in man. In Müller's article the muscles were said to be analogues. The human muscle has been illustrated by Whitnall. He points out that it cannot function like the muscle in lower animals owing to its different situation and size. The present writer has examined

the original works of Müller, Harling, Sappey and others as well as several text-books of animal anatomy but has been unable to find any illustrations of the minute anatomy of Müller's orbital muscle in the lower animals.

In this article histological preparations of the structure will be described and illustrated by photographs. Other photographs will show certain smooth muscle fibres which exist in the human periorbita. These were first described by D. S. Russell (1936) and, though less strongly developed, are similar in situation to Müller's orbital muscle of the lower animals.

Since Müller's article (1858a) is very short and rather inaccessible it seems worth while to give a complete translation of it.

" On the smooth muscle of the orbit in men and mammals."

" Preliminary communication by Heinrich Müller.

(1) " In man the inferior orbital fissure is filled with a greyish red mass. This consists of bundles of smooth muscle fibres which usually are equipped with elastic tendons.

(2) " In mammals there is a strongly developed muscular membrane connected with elastic laminae which is its more strongly developed analogue and which also consists of smooth muscle fibres (musculus orbitalis or membrana orbitalis of the author).

(3) " The third eyelid in mammals possesses in part smooth muscle continuous with the orbital muscle, in part striated muscle for drawing the lid forwards and backwards (the hare).

(4) " The orbital muscle is supplied with nerve bundles which consist almost entirely of fine or non-medullated (sympathetic) fibres. The nerves can be traced anatomically in part to the sphenopalatine ganglion.

(5) " The orbital muscle produces, by its contraction, the protrusion of the globe which has been observed in animals during the stimulation of the cervical sympathetic nerve. The same muscle acts as antagonist to the muscles which move the globe backwards in its cavity (M. retractor, orbicularis palpebrarum)."

Müller did not give any further details nor any illustrations of the orbital membrane. He died three years after the article was published. An obituary notice by Kölliker (1864) gives a list of his works.

Experimental Methods

It was decided to make sections through the whole orbital cavity of the cat and dog. The orbit was approached by removing most of the zygomatic arch and the coronoid process of the mandible. The muscles attached to them and to the ramus of the mandible

(temporalis, masseter, pterygoidei) were reflected downwards as far as possible (Fig. 3). Next a sagittal cut was made from the nose backwards in the middle line. To meet this a coronal cut was made through the maxilla and other bones in front of the orbit and a third cut was made parallel to the second but behind the orbit. The tissues were fixed in 4 per cent. formol saline and were decalcified with nitric acid. When decalcification was complete the mass was cut into blocks, usually with vertical faces at approximately right angles to the midline of the skull (coronal sections). The blocks were embedded in celloidin and sections were stained by haematoxylin and eosin, haematoxylin and van Gieson or by Mallory's phosphotungstic acid haematoxylin method. Sections were also prepared and stained by Weigert's elastic tissue stain.

Results

In the dog and cat only the medial wall, the anterior part of the floor and a small medial part of the roof of the orbit are formed by bone. The skull has an orbital fossa rather than an orbital cavity (Figs. 1 and 2). At the junction of the floor and medial wall of the orbit near the palato-orbito-sphenoidal suture, there is an almost horizontal antero-posterior ridge along which the periorbita is attached to the bone (Figs. 1 and 2). Above this ridge the skull is concave outwards, below it is convex outwards particularly in the dog. The lateral wall and the remaining part of the roof and floor are composed of periorbita (the periorbital membrane of H. Müller). This membrane is shown in Fig. 3. It resembles a hollow cone, having its apex attached to the bone round the optic foramen. Anteriorly it is attached to the lacrimal, frontal and zygomatic bones as well as to the fibrous orbital ligament which joins the two last-named bones. On dissection the membrane appears to be replaced medially by the periosteum of the frontal bone. Coronal microscopic sections suggest, however, that there is a layer of very loose areolar tissue between the fibro-muscular membrane and the true periosteum (see description of Fig. 6).

The orbital membrane of the dog includes three types of tissue: collagenous fibres, smooth muscle fibres and elastic fibres. The direction of all these fibres is mainly circular so that they are seen longitudinally in coronal sections of the orbit (Figs. 5-8). Elastic fibres, however, also run in other directions in several parts of the orbit and the amount of elastic tissue varies both absolutely and relatively to smooth muscle in different regions of the membrane.

DESCRIPTION OF FIGURES

All the figures except Figs. 5, 6 and 9 are untouched photographs. Figs. 5 and 6 are drawings based on photographs of sections. Fig. 9 is a sketch. The sections shown in Figs. 4, 7 and 8 were stained with haematoxylin and van Gieson; those shown in Figs. 10 and 11 with phosphotungstic acid haematoxylin.

Figures 7, 8, 10 and 11 are printed on art paper opposite page 264. The other figures appear in the text.

EXPLANATION OF FIGURES

ABBREVIATIONS

C.T.—Collagenous connective tissue.	PAL.SUP.—Upper eyelid.
E.T.—Elastic tissue.	P.INF.—Periorbita of floor.
G.Z.—Zygomatic (orbital) gland.	P.LAT.—" of lateral wall.
M.L.P.—Levator palpebrae superioris.	P.MED.—" of medial "
M.OB.INF.—Inferior oblique muscle.	P.SUP.—" of roof.
M.OB.SUP.—Superior " "	R.—Horizontal ridge of bone.
M.R.B.—Retractor bulbi.	T.—Tear through loose areolar tissue.
M.R.L.—Lateral rectus muscle.	TEC.OS.—Bony roof of orbit.
M.R.M.—Medial " "	1.—Plane 1.
M.S.M. or M.SM.—Smooth muscle	2.—" 2.
fibres.	3.—" of Fig. 5.
N.O.—Optic nerve.	5.—Region of Fig. 8
PAL.INF.—Lower eyelid.

FIG. 1.

Skull of a cat to show the orbital fossa and the ridge (R) to which is attached the membranous part of the floor of the orbit.

FIG. 2.

Skull of a dog to show the ridge (R) as in Fig. 1.

FIG. 3.

Dissection of the right orbit of a dog from the outer aspect to show the periorbital membrane (Müller's orbital muscle).

Coronal sections about 2 mms. behind the equator of the eyeball of the dog (Fig. 4, plane 1), show periorbita which is collagenous in the roof, fibro-muscular in the lateral wall, fibro-elastic in the floor and fibro-elastic in the lower 2 or 3 mms. of the medial wall. At the junction of the floor and medial wall it gives off a collagenous extension medialwards to the horizontal bony ridge. At the upper surface of the gland of the nictitating membrane the

FIG. 4.

Antero-posterior section through the orbit of a dog. The posterior pole of the eyeball has come forward during fixation. Smooth muscle of the periorbital membrane at P.INF.

periorbita becomes collagenous and blends with the fine fibres on the medial surface of the nictitating membrane.

A little further back (Fig. 4, plane 2), the roof is collagenous with strands of muscular and elastic tissue. The lateral wall is almost wholly muscular and is well developed. The floor from without inwards is in turn musculo-elastic, muscular and elastic again. The medial wall is elastic in its lower two-thirds and collagenous in its upper third.

Behind the globe (Fig. 4, plane 3 and Fig. 5) the roof is muscular except near its medial attachment to bone where it is chiefly elastic. The floor is muscular except for some elastic fibres in

its middle third. The junction of the two tissues is shown in Fig. 7. The medial wall below the level of the optic nerve is muscular. Above that level it has an elastic portion which is attached to the bone. In the same coronal section a concentric band of smooth muscle is present between the superior oblique muscle and the rectus medialis muscle (shown in Fig. 8).

FIG. 5.

Coronal section through the orbit of a dog at about plane 3 of Fig. 4, to show smooth muscle (M.S.M.) in the periorbital membrane (see text). There is a tear along the pointer line to M.R.B.

In the case of the cat the periorbital roof in this plane is muscular (Fig. 6) as is also most of the lateral wall and the lateral part of the floor. The middle part of the floor is elastic, but smooth muscle is found in the medial part of the floor and in the medial wall. It is attached to the medial bony wall of the orbit by extremely fine and loose connective tissue.

The sections show that a considerable amount of fatty tissue is enclosed in the periorbita (Figs. 4 to 6). The zygomatic or

FIG. 6.

Coronal section through the orbit of a cat behind the globe of the eye. At 6 a portion of fine areolar tissue has fallen out of the section. At 7 the areolar tissue was so fine that it could only be photographed if the negative was exposed to such a degree that all other details were lost.

orbital salivary gland may be seen in Fig. 6. The lacrimal gland is inside the periorbita; the zygomatic gland is outside it. Investing fascia of the extrinsic muscles of the eye can be seen in Figs. 4 to 6. It can easily be distinguished from the smooth muscle of the orbital membrane in the histological sections.

FIG. 7.

Region at left hand lower corner of Fig. 5 highly magnified to show junction of smooth muscle and elastic fibres.

FIG. 8.

Region M.S.M. 5 of Fig. 5 more highly magnified, showing typical smooth muscle fibres.

FIG. 10.

Human periorbital adjacent to the lateral rectus muscle, showing smooth muscle fibres as a dark band.

FIG. 11.

Human periorbital from the dorso-lateral angle, showing darkly staining smooth muscle fibres in the inner collagenous layer.

Discussion

MacCallum and Cornell (1904) exposed the periorbital membrane in dogs and observed its contraction on stimulation of the cervical sympathetic nerve trunk. They obtained a record of the protrusion of the globe. After the membrane had been divided, stimulation of the cervical sympathetic trunk no longer produced exophthalmos. The work of MacCallum and Cornell was confirmed and extended by Whitnall and Beattie (1933) and by Code and Essex (1935). The latter workers replaced the globe of the eye by a balloon and registered the increased pressure in the balloon when it was prevented from coming forward and the nerve was stimulated. They have also shown by a film (Code and Essex, 1936) that nervous excitation of the periorbital membrane produces a forward movement of the eyeball in the dog.

This proved immediate mechanism of proptosis in the lower animals has no obvious functional analogue in man. Müller himself (1858a) recognised that in animals the musculo-elastic membrane was "more strongly developed" than the muscle in the infra-orbital fissure which, unfortunately, shares with it the name of Müller's orbital muscle. Results obtained from lower animals cannot without care be applied to the immediate mechanism of proptosis in man. Indeed no mechanism suggested in man has so far been able to win general acceptance.

The present writer has tried to obtain and examine *post mortem* room specimens of orbits from "normal" human subjects as well as from patients suffering from Graves' disease (with or without exophthalmos) at the time of their death. Recently a series of such orbits has been described by D. S. Russell (1936). Dr. Russell has allowed the writer to examine the sections and to reproduce in this article Figs. 9, 10 and 11, none of which has been previously published though they have been demonstrated with the preparations from which they were made.

The series included six cases of Graves' disease and three normal controls. The specimens were prepared by chiselling away the roof of the orbit. To this the periorbita was only very lightly attached. It was exposed as a cone-shaped glistening membrane, closely enveloping the soft tissues of the orbit (Fig. 9). These tissues were then dissected away with the bony wall of the orbit, fixed, decalcified and embedded in paraffin. Coronal sections were made in planes 1 cm. and 2 to 3 cms. in front of the anterior end of the optic canal and were stained by various methods, of which Mallory's phosphotungstic acid haematoxylin method demonstrated the smooth muscle fibres most clearly. Weigert's resorcin fuchsin stain was used for elastic fibres.

Of the orbits examined only those from one of the patients who

FIG. 9.

Periorbital membrane in a human subject, exposed by removal of the bony roof of the right orbit.

had Graves' disease at the time of death showed any pathological features. The oculomotor muscles in this case contained "Lymphorrhages" (Friedenwald 1932, Naffziger and Jones 1932). Otherwise the orbits of those who had Graves' disease including exophthalmos at the time of death did not differ from the normals. They showed no hypertrophy of striped or smooth muscle. In sections stained by Mallory's method unstriped muscle was visible in all the orbits. It extended throughout a large part of the periorbita in the planes of the sections and was most abundant on the lateral aspect (Fig. 10). Here the fibres were continuous with the smooth muscle of the inferior orbital fissure. They were situated towards the inner part of the orbital sheath. They became less numerous as the dorsal aspect of the periorbita was reached and few were found medial to the frontal nerve. On the floor of the orbit muscle fibres passed in the periorbita from the inferior orbital fissure towards the medial wall but did not reach it. Here

the periorbita was closely applied to the ethmoid bones and resembled periosteum. On the roof and lateral aspects, however, the periorbita could be divided into three layers:—(1) an outer collagenous layer or periosteum proper, (2) a middle adipose layer, and (3) an inner dense collagenous layer. In this last layer were situated the smooth muscle fibres (Fig. 11). They were associated with numerous coarse and fine elastic fibres. Less conspicuous elastic fibres were also present in other parts of the periorbita which were devoid of muscle.

Much histological work on the human orbit has been concentrated on the front of the cavity and the structures that are attached to the eyeball itself. This may explain why the smooth muscle fibres in the posterior region have not hitherto been described. The drawings made from microscopical preparations and described in Hesser's (1914) article show occasional muscle fibres. Hesser regarded these as unimportant. In 1865 Harling noticed that the periorbital smooth muscle of the dog was less developed than that of the sheep. He wondered whether it was present in sufficient quantity to have a function. His question has been answered affirmatively and unequivocally. The same question may be asked to-day about the still smaller amount of smooth muscle which D. S. Russell has found in the periorbita of man. It may even be that differences in the development of smooth muscle in the two orbits of a patient may explain the puzzle of unilateral exophthalmos following thyroid medication (Brain 1936 and others).

The nomenclature of the smooth muscle in these different situations deserves some consideration. Müller described the musculo-elastic membrane of the lower animals as a more strongly developed analogue of the muscle in the inferior orbital fissure in man. One must agree with Whitnall (1932) when he says that, owing to its situation, Müller's orbital muscle in man could not increase the pressure behind the globe of the eye or otherwise produce exophthalmos. So identity of name hides a difference of function. If Müller's alternative name of "orbital membrane" were reserved for the structure in the lower animals and the name "orbital muscle" for the muscle in the region of the inferior orbital fissure in man a distinction would be suggested. Further, if the smooth muscle described by D. S. Russell is shown to have an important function, it will perhaps be named after its discoverer or be described as smooth muscle of the posterior periorbita.

Summary

(1) The whole orbital region was removed in one piece from the heads of dogs and cats. After fixation, decalcification and celloidin embedding, sections were stained by different methods.

(2) Sections at various planes show how smooth muscle and elastic tissue join with collagenous fibres to form the periorbital membrane known as Müller's orbital membrane or muscle. This is a funnel-shaped structure, having its apex round the optic foramen and attached in front to the orbital margin. In planes behind the eyeball it contains much smooth muscle. Its contraction increases pressure behind the globe and forces the globe forward. Its relations to the investing fascia of the extrinsic muscles of the eye and to the secreting glands of the orbital region are considered.

(3) Müller's orbital muscle in the lower animals is the final mechanism in them for proptosis. Müller's orbital muscle in man cannot by itself produce proptosis.

(4) Photomicrographs show smooth muscle behind the eyeball in the upper and outer periorbita of human subjects whether normal or suffering from Graves' disease. This muscle may be the functional analogue of the periorbital membrane of the lower animals and be a mechanism for the production of exophthalmos in man.

(5) The nomenclature of the smooth muscle in different situations is discussed.

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