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Glimpsing Nature's Eye Guardians: A Comparative Analysis of the Nictitating Membrane in Birds and Mammals

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ABSTRACT

This review examines the nictitating membrane, a specialized third eyelid present in various animal groups, and its relation to the plica semilunaris. It highlights the distinctive features of the nictitating membrane in birds, its sophisticated neuro-muscular mechanism, and its protective role in maintaining vision.

Keywords: Nictitating Membrane, Plica Intercipiens, Cartilage Intercipiens

Introduction

The nictitating membrane [from the Latin word *nictare*, which means blink] is a transparent or translucent third eyelid present in some animals that can be drawn across the eye from the medial canthus to protect and moisten the eye while maintaining vision [1, 2]. The tailless amphibians, certain reptiles, birds, and sharks possess complete nictitating membranes but many mammals have a small, vestigial portion of the nictitating membrane located in the corner of the eye. Some mammals, such as cats, beavers, and polar bears, have fully developed nictitating membranes [3]. The nictitating membrane is often called a third eyelid or haw, it may be referred to in scientific terminology as the *plica semilunaris*, *membrana nictitans*, or *palpebra tertia* [4]. Certainly, the nictitating membrane has a special mechanism to protect the eyes from foreign objects is crucial for maintaining vision in all land animals [5]. When foreign bodies enter the eye, they can immediately disrupt vision, and if not removed promptly, can lead to permanent damage. Therefore, the sensitive nature of the cornea serves as a threatening signal for the urgent need to remove these foreign bodies [6]. Different animals have varying protective adaptations based on their habitats and the importance of their vision. This includes crawling, burrowing animals, mammals, and birds. The birds have the most acute need for protection due to their high-speed flights. Birds have a unique protective structure called the "nictitating membrane," which swiftly moves over the cornea to remove any debris [7]. The nictitating membrane is also related with the plica semilunaris in mammals, including humans. which is supposed to be a vestigial structure representing the third eyelid that is present in birds and mammals [8, 9].

Methodology

This review discussed the comparative analysis of the nictitating membrane in birds and mammals. This study focused on nictitating membrane changes across land animals, depending on their habitat and requirements. The review was conducted through a detailed study of the previous literature by using databanks, including Google Scholar [http://www.scholar.google.com/ [accessed on 27 October 2023], Science Direct [http://www.sciencedirect.com/ [accessed on 28 October 2023] Scirus [http://www.scirus.com/ [accessed on 29 October 2023] and PubMed [http://www.ncbi.nlm.nih.gov/pubmed [accessed on 30 October 2023].

Anatomical Characteristics of Nictitating Membrane in Mammals and Birds

Bird's Nictitating Membrane Anatomy and its Neuro-Muscular Mechanism

The nictitating membrane in birds has been well studied and is identified to have an advanced neuro-muscular mechanism. The nictitating membrane is triangular-shaped and situated adjacent to the inner canthus. It is almost transparent, allowing for unimpeded vision and protect the eye by covering its significant portion. The movements of the membrane are resembling to a pendulum-like swing and rapidly clearing the eye. The upper angle of the nictitating membrane remains immovable or fixed while the lower angle is loosely attached and allowing its independent and free movement [9, 10]. The pyramidalis muscle attached to its lower angle, facilitate the function of the nictitating membrane. This muscle wraps around the eye to make sure that the membrane stays in contact with the cornea during its motion. The quadratus muscle works in coincidence with the pyramidalis and prevent it from putting pressure on the optic nerve [9, 11]. The quadratus muscle also helps pyramidalis muscle to move in right direction and ensuring constant motion irrespective of the position of eye. Furthermore, the depressor palpebrae inferioris muscle prevents the lower lid from being pulled outward during the membrane's movement and helps maintain its uniform application to the eye's front. The nerves that control these muscles are derived from the 3rd and 6th cranial nerves [9]. This in-depth knowledge about the nictitating membrane in birds serves as a basis for making its physiological comparisons with mammals.

Mammalian Nictitating Membrane Anatomy

Superficially, the structure in mammals appears similar to the nictitating membrane in birds. However, it is a crescent-shaped fold of the conjunctiva at the inner corner of the eye, with a rigid, cartilaginous base [12]. While it is described as sweeping over the eye as the eyelids close, it seems unlikely to move very far, possibly due to its rigid structure. Unlike the nictitating membrane in birds, it lacks the necessary muscular apparatus for independent movement [9]. Dissections of various mammalian orbits, including those of calves, sheep, rabbits, and cats, have revealed no specialized mechanism for moving the membrane. In some cases, a few scattered bundles of unstriped muscle fibers have been observed, but they do not constitute a proper muscular apparatus. Structurally, the nictitating membrane in mammals is more complex, involving a cartilage that has evaginated the conjunctiva. This cartilage, referred to as the intercepting cartilage, serves the purpose of picking up particles from the eye's surface [13]. The intercepting cartilage is shaped like a pickaxe, with a stout, flattened handle and a long, thin blade that stretches vertically across the cornea. It forms a "squeegee" at the inner side of the orbit, allowing the eyeball to roll under it. Additionally, the Harderian gland, typically situated at the back of the orbit in birds, is found within the substance of the intercepting membrane in mammals. Its secretion is thick and sticky, while the usual lachrymal gland is located in the upper and outer part of the orbit, producing a serous secretion [9].

Histological Characteristics of Nictitating Membrane in Mammals and Birds

Birds

The nictitating membrane is primarily composed of fibrous tissue, with most bundles oriented longitudinally, some intersecting at right angles. While it is said to retract due to its elasticity, the amount of elastic tissue in it is not excessive, although clearly visible in picro-carmine sections[14]. The conjunctival covering consists of stratified epithelium, notably heaped up on the palpebral surface, especially near the free edge where it forms the distinctive pectinate ridge. The membrane lacks glandular tissue, with the duct of the Harderian gland opening into the deep internal fornix [9].

Mammals

The microscopic structure of the nictitating membrane reveals a hyaline cartilage with abundant cells, apparently small and without distinct grouping. The Harderian gland, primarily a typical alveolar serous gland, exhibits a peculiar portion near its inner or anterior end. This area consists of round or oval alveoli lined by cubical epithelium, containing a homogeneous colloidal-like substance [15]. Some alveoli contain cell debris, giving the impression of cells undergoing a colloidal change, resembling an adenomatous goiter. The nictitating membrane's substance, apart from the gland and cartilage, is comprised of compact areolar tissue [16, 17]. The palpebral surface of the membrane is lined with a stratified epithelium set on small papillae, while the ocular aspect is covered by a single or double layer of somewhat flattened cells[17].

The Physiological Role of the Mammalian Plica Semilunaris

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The function of the plica and cartilage in mammals can be understood by observing how the eye naturally removes foreign bodies. For instance, during a dust storm, the eyes tend to collect dust at the inner canthus, near the caruncula lachrymalis, without causing any irritation or harm. The plica semilunaris, despite being considered a vestigial structure, plays a significant role here, with an underlying conjunctival fornix providing ample space for the collected matter [18, 19]. When a foreign body comes into contact with the eye, two mechanisms are triggered. Firstly, excessive tear secretion helps to lift the object off the eye's surface, while the closure of the eyelids creates a basin-like area to bathe the eye, aiding in moving lighter objects forward. The action of the orbicularis palpebrarum then sweeps the tears and foreign matter toward the inner side of the eye, diverting them across the caruncular region [9]. This area contains glands similar to sebaceous glands, where the foreign body is eventually eliminated. Observations suggest that when there's a foreign body in the eye, the eye repeatedly turns inwards, attempting to use the plica to direct the object toward the caruncular region [20]. For example, an eyelash might be carried inward by tears and the action of the orbicularis, slip under the plica semilunaris, and eventually be guided out and transferred to the skin at the inner canthus [21].

Hence, the terms "PLICA INTERCIPIENS" and "CARTILAGO INTERCIPIENS" have been proposed to better describe these structures. It seems that the most effective way to handle a foreign body in the eye is to close the lids and allow this natural process to take place [9].

This mechanism is tailored to the specific needs of different species: birds require the quickest possible method, while mammals can afford to prioritize thoroughness over speed.

Morphology of the Nictitating Membrane and Cartilage

The reviewer has not yet studied how the membranes and cartilage develop in mammals. So, it's too early to be sure about their structure. However, they likely differ from birds due to their unique nerve and muscle setup. But, there's no doubt that the bird's nictitating membrane is similar to a part of the lower eyelid in certain amphibians like frogs and newts.

The following considerations are suggestive:

The bird's upper eyelid is short and stiff, moving with the eye and unable to move independently [2]. The lower lid is broader, moves freely on its own, and has a transparent upper part. To close the eye, the lower lid covers three-quarters of the eyeball, while the eye itself turns down, bringing the upper lid along, and allowing the lids to meet [9, 21]. This lower eyelid is similar to the nictitating membrane in transparency and its position, as well as its muscular and nervous mechanisms.

1. When the lower lid is not in use, its transparent upper part slides down between the ocular conjunctiva and the palpebral, resembling the bird's nictitating membrane [22]. The lower lid of the frog can be divided into an inner transparent nictitating part and an outer opaque skin-covered lid part. In the bird, both parts of the developing lid grow equally, forming a separate nictitating membrane under a distinct and movable lower lid. The previous study suggests that the nictitating part might be the primary lid, with the lower lid developing as a secondary outgrowth from it [23]. Despite the nictitating membrane of the bird being at the internal canthus, it can be compared with that of the frog by slightly rotating the frog's lower lid. This change in position could be associated with the development of a frontal brain region and the orbit's roof [21].
2. The lower eyelid of the frog is raised by a tendon attached to its outer corner, passing through the fibers of the pterygoid muscle and connecting to a muscle from the outer side of the sclerotic [24]. This muscle is part of the choanal muscle, closely associated with the optic nerve and the external rectus and controlled by the sixth nerve [23]. Similarly, in birds, the muscles of the nictitating membrane surround the optic nerve and the back of the eyeball, linked with the external rectus, and controlled by the sixth nerve. If we consider that eye muscles represent three pre-otic head segments, the frog's lower lid elevator is akin to the bird's pyramidalis muscle [25]. Additionally, the frog has a depressor palpebrae inferioris, corresponding to the fibrous sling and depressor muscle of the bird, both controlled by the third nerve and belonging to the first head segment [25].

Neuro-muscular apparatus in the Mammal

We have noticed that the Anatomy and physiology of the eyelid in mammals differ from those of birds. Although the mammal has a distinct retractor bulbi muscle similar to the choanal muscle in frogs and the two muscles in the bird's nictitating membrane, it does not appear to be connected to or related to the eyelid fold. This retractor bulbi muscle in mammals is a thick muscular cone around the outer side of the optic nerve, closely associated with the external rectus and controlled by the 6th nerve [26]. This suggests the presence of two distinct mechanisms: one controlled by the 3rd nerve for the eyelid and another controlled by the 6th nerve for the nictitating membrane [27]. In frogs, both mechanisms are associated with the lower lid, while in birds, they relate to the lower lid and the nictitating membrane separately [9]. In mammals, both mechanisms exist, but the one controlled by the 6th nerve doesn't seem to be linked to the eyelid fold.

Conclusion

The plica in mammals, including humans, is structurally and functionally distinct from the nictitating membrane in birds. Hence, the term "nictitating membrane" should be replaced with "plica intercipiens," and its cartilage should be termed "cartilage intercipiens." There is a likelihood that the plica in mammals differs morphologically from the nictitating membrane. However, a detailed ontogenetic study of mammalian structures is necessary before a definitive conclusion can be drawn

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