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Fluoroscopy:

Radiation Protection of the Eye

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Fluoroscopy: Radiation Protection of the Eye

Bryant Furlow, BA

Visual system tissues, particularly the lens of the eye, are extremely vulnerable to the harmful effects of ionizing radiation. There is no well-established "safe" level of radiation exposure for the eyes. With the expanding use of fluoroscopy and fluoroscopy-guided interventional procedures, radiation doses to patients have increased dramatically. Radiation dose management is crucial to protect the eyes of patients and health care personnel who perform fluoroscopic exams.

Dosimetric monitoring and dose minimization practices — including planning, careful selection of fluoroscopy imaging modes, the proper use of protective equipment and shielding, effective quality assurance and quality control programs, and adequate operator training — all play important roles in protecting the eyes of patients and health care personnel.

After studying the information presented, the reader should be able to:

- Describe the functional anatomy of the eye.
- Explain how ionizing radiation can disrupt the structure, physiology and function of visual system tissues.
- Discuss different types of visual system diseases and disorders and their relation to ionizing radiation exposure.
- Discuss changing views about dose thresholds for radiation cataract formation.
- Identify how staff positions with respect to the fluoroscopy unit and patient can affect dose.
- Describe strategies for minimizing patient and staff radiation doses during fluoroscopic procedures.
- Explain why fluoroscopic radiation dose to the eye lens is a major occupational exposure concern and how the threat of chronic exposure can be mitigated.
- Describe sentinel event thresholds requiring postfluoroscopic monitoring for radiation injury.

Fluoroscopy and other imaging modalities have revolutionized modern medicine, providing physicians with invaluable anatomical and physiological information about their patients. The range of fluoroscopic examinations, particularly fluoroscopy-guided interventional procedures, has proliferated over the past 20 years. Because of prolonged examination times and other factors, patient radiation doses and the incidence of serious radiation injury from fluoroscopy also have increased.[1] For example, interventional fluoroscopy for transcatheter embolization involves patient radiation doses of up to 100 mSv, an amount that is 1,000 times the dose delivered by a typical chest radiograph.[2]

Visual system tissues, particularly the lenses, are very vulnerable to damage caused by ionizing radiation and, therefore, are of particular concern to patients and health care personnel. Fluoroscopy not only can expose the eyes of patients to varying doses of ionizing radiation, but also the eyes of surgeons, radiologists, radiologist assistants (RAs), radiologic technologists and other personnel who are involved in these procedures. Fluoroscopic radiation doses are subject to the type of examination, target tissue, exam duration, and the radiation protection practices and specific equipment used.[1]

Ionizing radiation is not the only potential medical imaging hazard to the visual system. In fact, animal experiments suggest that ultrasound energy can cause free radical damage to the endothelial cells of the cornea.[3] However, ionizing radiation is a well-established threat to visual system integrity and health, and the higher radiation doses associated with fluoroscopy must be considered when planning and performing procedures.

This article describes the anatomy and physiology of the eye, the biological effects of ionizing radiation on the eye and the implications of radiation pathobiology for radiation protection of the eyes. The article also discusses the risks posed by long-term exposure to low-dose scatter radiation to the eyes of health care professionals.

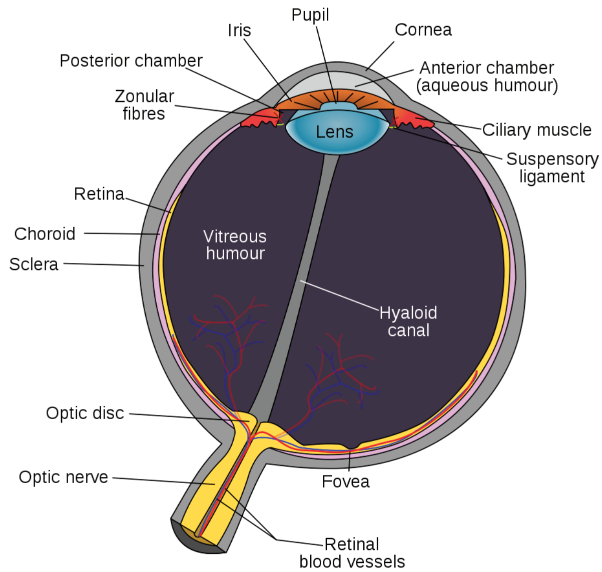

Figure 1. *Gross anatomy of the eye. (Used with permission from Wiki Commons, http://commons.wikimedia.org).*

History

Ophthalmology evolved over the centuries from folk cures and quackery to a systematic, scientific field of medicine and surgery. The first published description of eye anatomy, Benvenuto Grassi's *De Oculis,* appeared in 1474, at which time ophthalmology was a primitive medical endeavor. Eye medicine was the dubious province of barbers, who also practiced crude dentistry and general surgery.[4] Physician Leonhart Fuch's 1539 text *Alle Kranckheyt der Augen (All Illnesses of the Eyes)* was an early scientific text on ophthalmology; it systematically described the eye's anatomy, pathologies and treatments.[4]

Surgeon Jacques Daviel explained the surgical removal of cataracts in 1753, and by 1817 a 2-volume ophthal-mology textbook was published, marking the early origins of ophthalmology as a distinct field of medicine.[4] In 1820, partly in response to an epidemic of trachoma bacterial infections of the eye, Benjamin Travers wrote the first English-language ophthalmology text, *A Synopsis of the Diseases of the Eye.* By 1900, ophthal-mology was a well-established medical field.

Functional Anatomy of the Eye

The human eye is frequently described as the "window to the soul" or, less poetically, compared to a simple camera with respect to its ability to capture images. Simply put, light enters the eye through a refracting cornea; the cornea redirects light to the retina, where photon energy is converted into an electrochemical signal that is transmitted to the brain. The components of the eye reduce light scatter, improve focus and control the aperture through which light enters the overall structure. In reality, the eye is a much more complex and dynamic structure than George Eastman's Kodak machine or even, arguably, contemporary magnetic resonance (MR) and computed tomography (CT) scanners.

We understand the gross anatomy and overall function of the eye reasonably well (see **Figure 1**); however, we know little about the biology, genetics and pathobiologies of the eye's protein structures and immunological defenses. The molecular biology of ocular surfaces, cell membranes and mucosal secretions, not to mention the intricate neurobiology of the visual pathway, also are not well known.[5-8]

In the most general terms, the eye consists of 3 primary tissue layers. The protective outer layer of the eyeball, or globe, is the tunica fibrosa, a tissue rich in collagen and elastins.[9] The tunica vasculosa, more commonly referred to as the uvea (from the Latin *uva,* or grape), is the middle layer of the eye orb. As the term *vasculosa* suggests, this layer contains the eye's vasculature, as well as its pigmented iris.[9] The innermost primary layer of the eye is the tunica nervosa, named for the optic nerve and the fact that it originates as an outgrowth of the developing fetal brain.

Early in prenatal development, the embryo's anterior neuroectodermal tissue layer folds into the optic cup and eventually the eyeball. Neuroectodermal tissue also forms the neural crest and tube, an early developmental phase of the central nervous system.[9] The tunica fibrosa contains the corneal tissues and sclera, for example, and the tunica nervosa contains the retina and lens.

Radiologic imaging in and around the eyes, and even imaging of other parts of the body, can expose visual system tissues to ionizing radiation. Thus, it is important to understand the structure, physiology and function of the eye's major anatomical subsystems.

The Orbit and Eyelids

The eyes do not function in isolation from adjacent tissues. The eyelids, for example, shield the eyes from particulate matter and intense light levels, but these complex flaps also are anatomically contiguous with, and functionally related to, adjacent skin, bone and muscular structures of the face. A complex network of nerves and musculature known as the superficial musculoaponeurotic system coordinates muscular contractions of the eyelids, eyes, lips, nostrils and nose, and forehead.[10] This musculature attaches to larger muscle systems such as the zygomatic muscles, and to facial and orbital bone structures, including the zygomatic arch.

The eyelids protect the ocular surfaces, and even seemingly small problems in the development of these muscular flaps can cause corneal disorders. Blinking, or the rapid opening and closing of the eyelids, is categorized into spontaneous, reflexive and voluntary behaviors. Reflexive blinking is controlled by relatively simple, local nerve pathways and is triggered by touch, sound, bright light or irritation of the ocular surface.[10]

Eyelid width grows by 10% during adolescence and early adulthood, and then contracts by 10% after the mid-30s, so that the eyes appear larger or wider during reproductive years than they do in childhood or late adulthood. The eyelid margin is home to musculature, conjunctiva and glands. Although eyelids basically open and close, the force, speed and frequency of these movements are under both autonomic and voluntary control.[10]

The eyelids close and blink chiefly through contraction of the orbicularis oculi muscle, which also contributes to facial expressions. In addition, eyelid closure involves contraction of the levator palpebrae superioris muscle, also known as the upper lid's "chief reactor" muscle. The upper eyelids and eyeball share attachments to the superior rectus muscle, so that movement of the upper eyelid and globe are coordinated, particularly when looking upward.[10]

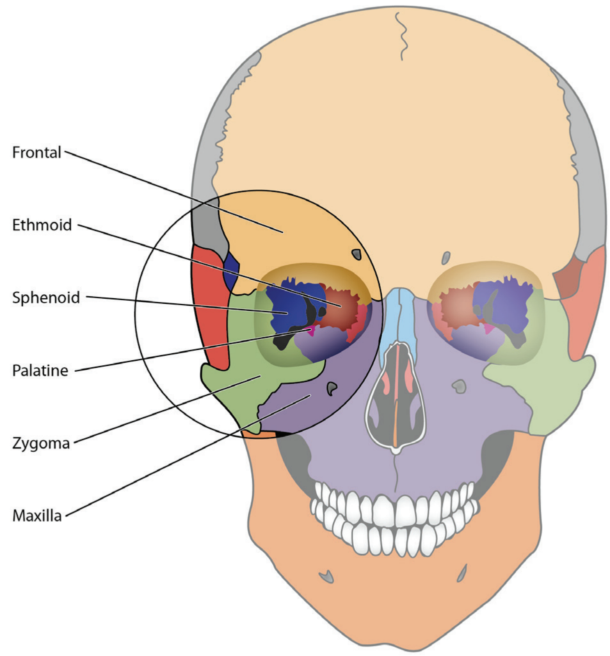

Figure 2. *The bony orbit.*

The bony orbit, which supports and protects the soft tissues of the globe, is composed of 7 bones — the sphenoid, frontal, ethmoid, maxillary, zygomatic, palatine and lacrimal bones. These bones articulate to create a roughly pyramidal structure with gaps to accommodate nerve bundles and vasculature (see **Figure 2**).[11] Bone composing the anterior (frontal) orbital rim is thicker to protect the eye from traumatic blows. The zygomatic (cheek) bone, which constitutes roughly the lower and outer quarter of the anterior orbital rim, is thicker than the rest of the orbit and is the orbit circumference's strongest component. The maxilla represents the inner and lower quarter of the anterior orbital rim and much of the triangular orbital floor, which is thin, poorly supported, and more prone to fracture than the rest of the orbit.[11] Blows to the lower anterior orbital rim can fracture the orbital floor, causing the eye to sink or recess into the orbit. This type of trauma can be accompanied by cheek neuropathy (numbness) and affected eyesight (double vision and, in some cases, blindness).[11,12] The optic canals carry the optic nerves and arterial vasculature. They meet behind the bony orbits, where the optic nerves cross contralaterally to the brain's visual cortex.[11]

An intact bony orbit cannot accommodate displacement of the eyeball back toward the skull, so dislocation of the eye within the orbit results in exophthalmos, or pushing of the eye forward through the anterior orbit. This protrusion can cause severe myopia and can be the result of inflammation, such as that associated with adult thyroid eye disease, or tumors, either benign or malignant. Postsurgical or radiation therapy-related exophthalmos involves the eye contralateral to the tissue that has undergone treatment.[11]

The extent of protrusion can be measured using an exophthalmometer, but the underlying cause of a protrusion cannot. Asymmetrical protrusion of the eyes, especially asymmetries exceeding 2 mm of difference, indicate orbital disease and globe displacement, and should be evaluated with diagnostic imaging examinations.[11]

Orbital connective tissue is nearly devoid of elastin, but spaces within this tissue are filled with adipose (fat) deposits and fatty acids.[11] The carotenoid content of fat in orbital connective tissue is up to 4 times that found in other body tissues. The reason for this excess is not known, but researchers speculate that the fat in orbital connective tissue is derived from the mesoderm like the body's other yellow adipose tissue.[13] Yellow-pigment, fat-soluble carotenoids such as beta-carotene bind free radical molecules that would otherwise damage cellular proteins and DNA. Free radicals are highly reactive molecules that can disrupt chemical bonds within proteins and DNA, causing mutations and structural abnormalities. [11]

The orbital blood system consists of complexly branching vascular trees. The ophthalmic arteries, which supply the globe and orbital tissues, arise from the internal carotid arteries. Each ophthalmic artery has a dozen major arterial branches, although there is considerable variation in arterial branching patterns and the precise course of arterial branches. Damage to retinal or choroidal vessels within the globe can cause ischemia and loss of sight.[11]

Orbital defenses against infection include the shielding provided by eyelids and the lubricating and cleansing effects of blinking. Because early dye studies failed to identify lymphatic vessels within the orbit, it was long assumed the eye lacked a lymphatic immune system defense. But enzyme histochemical studies in the 1990s revealed the presence of lymphatic capillaries within the optic nerve and lacrimal gland, strongly suggesting the existence of an orbital lymphatic pathway.[14-16]

The Ocular Surface

The transparent ocular surface broadly comprises 2 tissues: the corneal epithelium, composed largely of collagen fibers, and a clear mucous membrane covering the sclera (the white outer wall of the eyes).[17] The cornea serves 2 important functions for the visual system. First, corneal and scleral tissues encase and protect the globe of the eye; the cornea acts as a physical barrier, blocking potentially harmful particulate matter and pathogens that are not stopped by the eyelids. Second, the oval-shaped cornea refracts light and focuses it onto the retina, a key first step in the visual pathway.

Thanks to its complex molecular structure, the cornea is extraordinarily efficient at transmitting and refracting light, a crucially important factor in maintaining eyesight. Corneal tissues transmit more than 99% of visible light waves hitting the ocular surface.[17] The cornea contains no blood vessels that could potentially compromise the passage of light.

The cellular arrangement of corneal tissues also maintains transparency. An outer epithelium and inner endothelial cell layer sandwich membranes and stromal cells. Collagen fibers strengthen the extracellular matrix without scattering light.[17] The ocular surface sustains continual damage; therefore, the surfaces of the corneal epithelium and conjunctiva undergo constant cellular turnover. Supplied by stem cells, the cells of the corneal epithelium are entirely repopulated every 1 to 2 weeks.[10]

The following sections describe the layers of the ocular surface from the outer epithelial layer to the inner endothelium.

The Epithelium

The cornea's outermost layer is organized more precisely than epithelia in other organs, reflecting the need to maintain transparency and provide a physical barrier. The epithelium is composed of up to 7 well-ordered cell layers, with only the basement layer producing new cells