Clinical Aspects of Nonionizing Radiation

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Abstract—Various types of human injury attributable to nonionizing radiations are presented. Because of the unique combination afforded by the optical qualities of the eye and by the differential diagnostic features of resultant ocular pathology, an ophthalmological examination frequently can provide the signature indicating whether visible or invisible radiations produced the injury. For example, visible radiations principally result in various forms of macular photoretinitis and retinal burn or detachment or chorioretinal melanomata; whereas, invisible radiations principally produce thermal types of cataract or uveitis. Other systemic injuries and effects are also discussed. A rationale is submitted in support of a new concept, elastic membrane fatigue, as an etiological factor for otherwise inexplicable findings, such as the increased incidence of cardiovascular disease, which parallels the increased ambient levels of electronic smog found in urban environments.

Introduction

ALL REGIONS of the electromagnetic radiation spectrum can produce serious human injury. However, when the term "radiation bio-effect" is used, usually attention is focused disproportionately on that region of the spectrum characteristically associated with ionizing phenomena. Although any ionizing effect, such as carcinogenesis, could also result from an unusual intensity-duration function among the so-called nonionizing irradiations, e.g., obviously by the stripping of electrons in a megapulse of laser radiation [1] or obscurely by prolonged exposure to infrared radiation as in the Kangri cancer [2], nevertheless the chief concern in this paper lies with a discussion of other injuries more related to wavelength specificity. Aside from some specialized wavelength specific effects and acute radiation reactions, all can produce burns following a massive exposure. However, a burn is not the usual form of injury encountered in occupational environments where ordinarily delayed effects occur following chronic subthreshold exposures.

Radiant energy can produce injury to all of the tissues of the eye. Further, the eye serves as a unique organ in which to determine the associated hazards because 1) the radiations frequently leave a signature of injury, 2) forme fruste stages of tissue injury can be detected, 3) the susceptible ocular tissue serves as a cumulative dosimeter, 4) the ocular tissues can be examined *in vivo*, 5) physiological fluctuations and sampling techniques do not alter the findings, and 6) the findings can be documented [3]. For these reasons, our principal concern will be centered on the ophthalmic effects of nonionizing radiations. However, because of the obviously unique optical properties of the eye, it is necessary to divide the nonionizing portion of the spectrum into visible and invisible regions.

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Visible Radiations

Because of the well-known danger to the eye of retinal burn as a consequence of exposure to intense light, a resurgence in concern for health safety accompanied the advent of optical masers. Although laser beams can produce skin burns, that is not as important in the relative hazard scale as ocular injury because the eye's refractive system can enhance the incident energy density by more than four orders of magnitude while focusing light onto the retina. With direct illumination by a laser beam, the retina can be imploded, resulting in complete loss of vision [4]. At lesser intensities, a retinal burn can be produced and this may lead to partial blindness—the extent of the visual loss being dependent upon the specific portion of the retina injured.

Aside from direct exposure to laser beams, there are other concerns regarding environments containing all types of high-intensity light sources. With the expanded use of intense broad-band electrooptical devices, a disturbing pattern of ocular abnormalities, whose full significance cannot yet be evaluated, is evolving [5]. Based on performing more than 10 000 eye examinations as part of a medical surveillance program for individuals working in research and development laboratories using high-intensity light sources, the results can be described in two parts. The first is confined to the macular region of the retina and the second can occur anywhere in the posterior segment of the eye.

The macula is a highly specialized portion of the retina which provides discrimination of fine detail and its function is measured in terms of visual acuity. Characteristically, the macula has a homogeneous red-orange appearance, measures about 2.0 mm in diameter, and contains a central depression known as the fovea. Occasionally the macula has a blackish hue, thereby appearing hyperpigmented, and rarely, minute areas of depigmentation about 50-100μ in diameter can be identified in this region. Because these findings occur without any apparent or measurable interference with the visual function, they have not been considered to be abnormal in the past and little attention has been paid to them by ophthalmologists. However, among the group who work in occupational environments containing high-intensity light sources, the findings of generalized hyperpigmentation of the macula and small areas of depigmentation within the macular region have each been found to be ten times more prevalent than in the general population. For this reason, each of these two findings expresses a different but not necessarily unrelated threshold for photic injury. As such, both can be considered forme fruste stages of *macular photoretinitis*. More advanced stages have been seen where the clinical findings cannot be differentiated from central serous retinopathy, macular cyst, or foveo-macular retinitis, all of which are usually associated with partial loss of

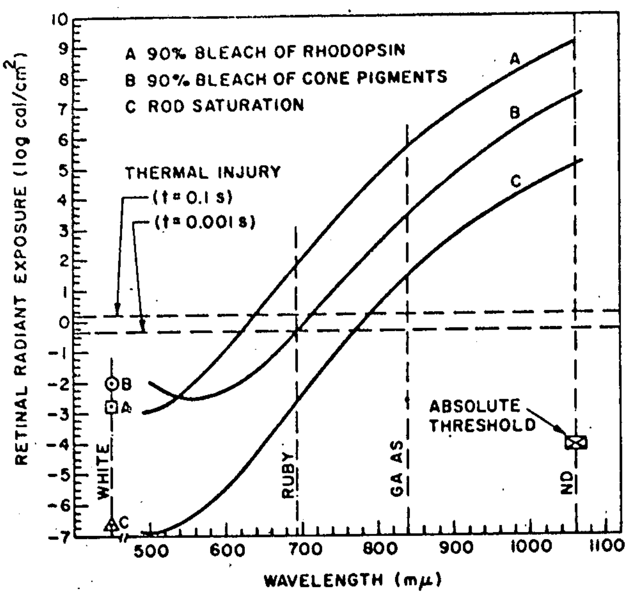

Fig. 1.

vision and occur rarely in the general population, but have also been found in the sample group with greater incidence than anticipated.

Other findings which occur in the posterior segment of the eye are of more immediate concern and can be classified as retinal burn and melanomata, each being present in 1 percent of this population.

Retinal burn is the predictable consequence of overt ocular exposure. Most of these cases present a history of accidental irradiation. It is not unusual for the individual to indicate the axial direction of exposure corresponding to the retinal area exhibiting chorio-retinal coagulation. Although it is not surprising to find this condition existent among employees working with high-intensity light sources, nevertheless, an incidence of 1 percent must be considered excessive.

Melanomata (pigmented masses) occurred covertly without specific relationship to known exposure. More commonly it appeared to originate in the pigment epithelium of the retina where it can be considered to be an area of focal hyperpigmentation. Less commonly it appeared to lie in the adjacent choroid resembling a choroidal nevus or freckle. This abnormality, which has been produced experimentally in the monkey retina [6], is suggestive of an abiotic effect. The long-term prognosis must be guarded.

Visual and retinal effects are also produced in the near infrared or paravisible region of the spectrum. An example of this is presented in Fig. 1: a graph indicating retinal radiant exposure for 90 percent bleach of visual pigments, rod saturation, and absolute threshold for the dark adapted eye plotted as a function of wavelength [7]. Also plotted in dashed lines are two thresholds for thermal injury, each based on exposure duration, and retinal radiant exposures required to bleach the visual pigments with monochromatic laser frequencies. Clearly, the neodymium laser source intercepts demonstrate that retinal burns are produced before significant visual effects occur. Formerly, this type of information would have been of pragmatic interest only for a limited number of vision physiology researchers. Now, however, because of the expanded usage of high-intensity infrared luminaries in conjunction with frequency converters and image intensifiers, e.g., as covert viewing systems for military, paramilitary, riot control, and crime detection purposes, the danger of ocular injury has been extended to large segments of the unsuspecting population.

With ultraviolet radiation, the hazard is different because these radiations, having less depth of penetration, are absorbed more preferentially near the body's surface. Thus ultraviolet produces its principal effects on the skin, surface mucous membranes such as the conjunctiva, and the outermost layers of the cornea. An acute injury of the skin, photodermatitis, resembles sunburn; a chronic exposure can induce skin cancers. When the eye is exposed both the cornea and conjunctiva are injured and this is termed kerato-conjunctivitis. In the acute form, whether produced, for example, by a welder's arc or by a sun lamp, it is seldom misdiagnosed. However, the chronic form of ultraviolet kerato-conjunctivitis by and large remains undiagnosed and the patient goes through life believing himself to be particularly photosensitive, avoiding high ambient levels of illumination, and wearing tinted or filter eyeglasses constantly.

Invisible Radiations

The invisible nonionizing radiations induce heat stress. Generally, the shorter the wavelength, the more efficiently this energy is absorbed and the more obviously the induced thermal burden upsets the body's thermoregulatory mechanism. Where water absorption peaks, e.g., at the carbon dioxide laser emission, the effect may be principally on the surface tissues. However, for most other frequencies, the depth of penetration would be related generally to wavelength so that infrared radiation is absorbed mostly in the superficial tissues, microwaves are absorbed over a greater depth into the body, and longer radiowaves penetrate more deeply.

Two tissues, the testicle and the eye, are located near the body surface and both are particularly sensitive to thermal insult. In the case of the testicle, the principal effect believed to occur is a temporary reduction of the sperm count [8]. However, other more serious effects such as congenital anomalies in offspring [9] and testicular malignancy [10] cannot be ruled out as possible consequences.

Regarding the eye, the principal effect is thermal cataract. Unfortunately, this is a serious sequela because frequently the true nature of this type of cataract is not recognized. The causal relationship may be unsuspected because exposures usually occur covertly and a long latency, measurable in years, frequently exists before the effects become apparent. Moreover, its surgical removal is more difficult than other types of cataract and is associated with a higher risk of complications. The reasons for this may be appreciated by reviewing the difference between thermal and all other types of cataract.

The lens is a transparent biconvex tissue enclosed in a thin transparent capsule and situated in the anterior segment of the eye immediately behind the iris. The capsule, a few microns thick, normally cannot be detected by the routine slit-lamp examination. Occasionally, in some people exposed to heat-producing radiation, observable opacification subsequently develops in the capsule. When this occurs, it can be the earliest evidence of thermal injury.

The lens substance itself is situated within the capsule and is composed primarily of cells, namely epithelial cells and lens fibers. The lens substance is also normally in a state of optical transparency, but because of its mass and relucency, it can be visualized by slit-lamp examination. Any loss of transparency is termed opacification. When opacification results in a measurable reduction of visual capability, this is recognized in the clinical context as a cataract. Ordinarily, cataract formation takes place within the lens substance and does not involve the capsule.

The lens is an avascular tissue isolated from the rest of the body by its capsule. The capsule serves two functions. One is its action as a Donnan's membrane selectively permitting water and certain solutes to pass through for the metabolic needs of the lens substance. The other function of the capsule is due to its elasticity, whereby the shape of the lens can be altered for refraction purposes. The constant change in focal length of the lens, the method by which an image of regard is focused onto the retina, is mediated via the elasticity of the lens capsule.

For more than a century it has been known that radiations capable of heating the body could produce cataracts. Since 1907, industrial heat cataract has been recognized as a compensable occupational disease [11]. This condition was related at that time to chronic infrared radiation exposure and capsular opacification was a pathognomonic finding. Because of the health-safety measures taken to minimize chronic occupational exposure to infrared radiation, the incidence of capsular cataract was reduced markedly. It became so rare that most currently practicing ophthalmologists have had little experience with thermal cataract and fail to recognize the etiological significance of capsular opacification. Recently [12] microwaves have been found also to produce capsular cataract, and this has led to speculation concerning the basic mechanism.

With both infrared and microwave radiations, chronic environmental exposure is followed generally by a latency measured in years before the lens capsule findings become apparent. With infrared irradiation the anterior capsule is usually first involved, while with microwaves the posterior capsule usually is first involved. Perhaps this may be explained best in terms of intraocular thermodynamics. When the eye is heated with infrared radiation, a thermal gradient is established from the surface to the deeper structures so that across the lens the temperature is highest where it is closest to the surface, i.e., at the anterior capsule. On the other hand, when irradiated with microwaves, the entire eye is heated simultaneously. However, in this instance, the iris, located in front of the lens, serves as a heat sink thereby reversing the thermal gradient so that the posterior capsule would be at a higher temperature. Once initiated, the process of capsular opacification never regresses, although it may remain arrested for long periods of time. Eventually, however, the opacification becomes denser and spreads to encompass increasingly larger areas until the entire capsule becomes involved. Even at this stage, the visual acuity remains relatively unaffected unless cataractogenesis has begun in the lens substance secondary to failure of the selective permeability function of the lens capsule.

A rationale, based upon the elastic membrane function of the lens capsule, may be offered to explain the cataractogenesis which subsequently ensues. As the eye focusses during vision, the elastic lens capsule is constantly under the stress of relative stretch and relaxation. Normally after each stress from stretching there is complete recovery. However, following excessive irradiation, the elastic properties of the capsule may be altered. Eventually this would lead to a mechanical fatigue of the membrane. The net result appears to be an alteration of the membrane's composition exhibited by opacification and friability of the capsule. Then the capsule can no longer function well as a Donnan's membrane. Ultimately, this leads to opacification within the lens substance itself and results in the formation of a cataract. At the end stages, when the lens substance is also opaque, it is not possible to differentiate the cataract so formed from all other types of cataract which had evolved completely within the lens substance because it is no longer possible to identify the capsule after the lens substance has lost its transparency.

When the exposure to nonionizing radiation produces the described pathognomonic capsulopathy, it should be considered the primary etiologic causal agent. In addition, such exposure can also serve a contributory role for other types of cataract, e.g., senile, metabolic, or hereditary, which are confined to the lens substance. In these cases, the irradiation acts by accelerating the time duration, i.e., the aging. In other words, where the anticipated time for natural evolution of cataractogenesis ordinarily might take years, following irradiation the time sequence for change would be reduced to months. Here, the irradiation would not produce a mixed type of cataract but instead it would merely hasten the end result.

Needless to say, when exposures are massive the effects are evident immediately. In addition to hydrops of the lens (a rapidly fulminating cataract), all the other ocular tissues including principally the cornea, iris, ciliary body, choroid, and retina also exhibit immediate evidence of burn. What is not generally recognized is that these tissues can also be injured covertly at lesser exposure dosages. Thus keratitis, uveitis (inflammation of the iris, ciliary body, and/or choroid), and retinitis can all result from exposure to nonionizing radiation. As a consequence, secondary glaucoma can also become manifest as a late sequela.

Less understood than the ocular, testicular, or neoplastic relationships are the other organ and tissue effects produced by irradiation. Perhaps a rationale for these can be presented best by the analogy of elastic membrane fatigue described above for the lens capsule because some organs, many tissues, and even on a microscopic level, most individual cell walls exhibit such a function. For example, currently there is no acceptable explanation for the delayed cardiac effects occasionally seen following nonionizing radiation exposures. However, the lining of the heart and its major blood vessels are contained within an internal elastic membrane. The cardiovascular elastic membrane, like the lens capsule elastic membrane, is constantly under the stress of relative stretch and relaxation as it helps to sustain the hydraulic pressure of the circulatory system. Here again after each stress from stretching there is complete recovery. However, following excessive irradiation, the elasticity of this membrane could also eventually undergo mechanical fatigue and this would ultimately lead to degredation of the elastic membrane's integrity and result in cardiovascular disease. There is much to support this concept because one of the best known delayed appearing radiation effects is premature aging, which occurs concomitantly with a reduction in tissue elasticity. Certainly all cardiovascular disease cannot be explained in this simplistic fashion and other predisposing factors must also exist; nevertheless, it is interesting to note that a gross parallel could be drawn between the increased incidence of coronary artery disease and myocardial infarction in urban centers and the increased ambient levels of electronic smog in these environments.

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Short Communications

Contactless Nerve Stimulating Transducer

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Abstract—Stimulation of nervous tissue by means of an induced electric field produced by a contactless device is described. The unit is unique because it lends itself to surgical implantation.

Recently, the development of an inductive device for contactless stimulation of nervous tissue was reported by Maass and Asa in the June 1970 issue of the IEEE TRANSACTIONS ON MAGNETICS. Effective utilization of this device has been hampered because of the tissue damage resulting from the high temperatures generated by the device. Such a device would also have a more promising future if it could be surgically implanted.

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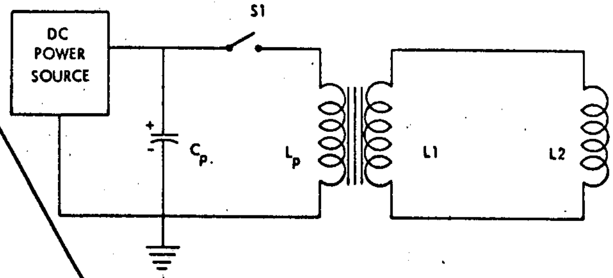

Fig. 1.

Successful stimulation of the sciatic nerve of a 29-lb mongrel dog with such a contactless nerve stimulator, which operates at temperatures compatible with living tissue, was successfully accomplished on July 16, 1971. Fig. 1 shows a simplified electrical schematic of this device. S_1 is a silicon-controlled rectifier controlled by circuitry that coordinates the charging and discharging of the capacitor C_p. C_p is a 500×10^{-6}-F discharge capacitor and L_p is a 20-turn coil 2.54×10^{-2} m in diameter with an inductance equal to 28.6×10^{-6} H. L_1 is a 6-turn fessor and Chairman of the Department of Electrical Engineering, Adjunct Professor in the Department of Surgery (Biomedical Engineering), and Supervisor of the program in Biomedical Engineering.

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Dr. Zaret is a member of the American Medical Association, the Association for Research in Ophthalmology, the Aerospace Medical Association, the American Academy of Ophthalmology and Otolaryngology, the Pan American Medical Association, the American Institute of Physics, and the Optical Society of America. He is also a Diplomate of the American Board of Ophthalmology and a Fellow of the American College of Surgeons.