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Hazards Evaluation of Neuroangiographic Procedures

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The history of radiation protection in medicine has progressed through several distinct patterns prompted by observed or suspected biologic effects. The two preceding papers (1, 2) focus on what has in the past few years developed into an area of major concern. Radiographic and fluoroscopic imaging equipment dedicated to neuroangiography and progress in the tactile skill of neuroradiologists have resulted in ever-increasing radiation exposures of patients and personnel. These papers present useful data to a new, yet expanding base of information regarding exposure and dose accompanying neuroangiographic procedures. However, they both fall short of the mark of providing useful information on dose reduction.

Within a year of the discovery of x-rays in November 1895 there were reports of radiation injury. These would be identified today as *deterministic* responses. A deterministic response to radiation is one that exhibits a severity that is dose dependent and follows a threshold-type dose response relationship (3). Classically, deterministic responses in radiation medicine are those of epilation, erythema, and other superficial responses. During the first 2 decades of this century, the principal hazards of exposure to medical radiation were electrocution and acute responses of superficial tissues. The literature is replete with individual reports of such injuries and also several excellent review articles (4–7). The focus during this period was on the patient, although some early radiation pioneers were injured or died as a consequence of their application of this new modality.

By the middle 1920s, it was clear that x-ray operators were subject to severe harmful effects of their occupation. Some early pioneers had suggested restriction of radiation exposure, but it was not until 1925 that a measure of radiation intensity, the roentgen, was officially adopted. Immediately after this adoption, an occupational dose limit of 15 R/y was proposed by the newly formed International Commission on Radiation Protection. In 1932, the US Advisory Committee on X-ray and Radium Protection—the forerunner to the National Commission on Radiation Protection and Measurements—was formed and adopted similar dose limits. This stretch of radiation protection activity was directed principally toward reducing occupational radiation exposure.

After World War II and the introduction of the atomic age, there was a flurry of activity resulting in an even more formal recognition of radiation protection practices and in the development of the specific discipline of radiation biology. The focus shifted from deterministic to *stochastic* effects. Stochastic effects are those that exhibit no dose threshold and whose incidence is related to the dose rather than the severity of the response. Principal examples of stochastic effects are radiation-induced malignant disease and genetic mutations.

During the 1950s and 1960s, radiobiologic investigations of the late effects of low-dose irradiation in animals were abundant. At the same time, human epidemiologic studies of a number of population groups, as shown in Table 1, flooded the literature, suggesting that even the smallest radiation exposure was accompanied by a finite risk of premature death. The focus of this activity among the responsible scientific bodies remained with the radiation worker, resulting in more precision in specifying occupational dose limits and a generalized lowering of those limits. Table 2 is a brief summary of this activity, shown graphically in Figure 1.

Diagnostic radiologic practice over the last 10 years or so has become more aggressive, and now even therapeutic via angiointerven-

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TABLE 1: Human populations in which radiation effects have been observed

Population	Principal Effect
American radiologists	Leukemia
Atomic bomb survivors	Cancer
Radiation accident victims	Acute lethality
Marshall Islanders	Thyroid cancer
Uranium miners	Lung cancer
Radium watch-dial painters	Bone cancer
^{131}I patients	Thyroid cancer
Children treated for enlarged thymus	Thyroid cancer
Ankylosing spondylitis patients	Leukemia
Thorotrast patients	Liver cancer
Fetuses irradiated in utero	Childhood cancer
Volunteer convicts	Sterility
Cyclotron workers	Cataracts

tional techniques. Current applications of digital fluoroscopy, digital subtraction angiography, and high-dose-rate fluoroscopy have increased the radiation load to the patient significantly. This of course increases proportionately the radiation exposure to the operator.

Anecdotal reports of superficial responses in patients during cardiac, abdominal angiointerventional, and neuroangiointerventional procedures are increasing in frequency. Clearly, this is because of the aggressively increasing use of equipment and techniques on behalf of the patient. Generally, these procedures require more fluoroscopy time and longer angiographic and cineradiographic runs with equipment designed for routine operation at higher radiation outputs (8).

These papers by Bergeron et al (1) and Kuwayama et al (2) that appear in this issue of *AJNR* provide useful information on patient dose and occupational exposure for several procedures. Knowing whether these procedures are totally representative will have to wait until the compilation of time and technique data from many institutions is available. Clearly, patient dose and therefore operator exposure are exceptionally sensitive to the x-ray apparatus used and the skill exhibited by an individual physician.

I found both papers deficient in that neither attempted to correlate output exposure measurements as one would obtain in a routine medical physics survey of the imaging equipment and the patient doses measured per procedure. In normal practice, a medical physicist would be asked to use the results of a routine radiation control survey to estimate patient or organ dose. We who engage in such evaluations

TABLE 2: Historical review of the maximum permissible dose for occupational exposure

Year	Recommendation	Approximate Daily Dose, mrem	Recommender
1902	Dose limited by fogging of a photographic plate after 7-minute contact exposure	10,000	Rollins
1921	General methods to reduce exposure	1000	British X-ray and Radium Protection Committee
1925	"It is entirely safe if an operator does not receive every thirty days a dose exceeding 1/100 of an erythema dose."	200	Mutscheller
1925	10% of a skin erythema dose	200	Sievert
1926	1 skin erythema dose per 90 000 working hours	40	Dutch Board of Health
1928	0.00028 of a skin erythema dose per day	175	Barclay and Cox
1928	0.001 of a skin erythema dose per month	150	Kaye
1931	Limit exposure to 0.2 R per day	200	US Advisory Committee on X-Ray and Radium Protection
1932	0.001 of a skin erythema dose per month	30	Failla
1936	0.1 R per day	100	US Advisory Committee on X-ray and Radium Protection
1941	0.02 R per day	20	Taylor
1943	200 mR per day is acceptable	200	Patterson
1959	5 rem per year, 5 (N-18) rem accumulated	20	National Council on Radiation Protection and Measurements
1987	50 mSv per year, 10 × N mSv accumulated	20	National Council on Radiation Protection and Measurements
1991	20 mSv per year	8	International Commission on Radiation Protection

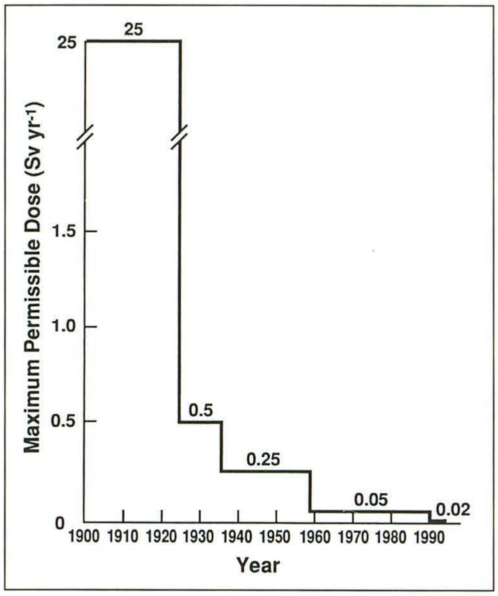

Fig 1. Maximum permissible dose values over the past 90 years.

know that, depending on the image receptor and the generator used, entrance skin exposure per frame or per minute can vary by up to an order of magnitude from one facility to another.

I think it is incorrect to use the concept of effective dose equivalent or effective dose to patients as Bergeron et al (1) have done. These concepts enunciated most recently by both the National Commission on Radiation Protection and Measurements (9) and the International Commission on Radiological Protection (3) were not intended for patient risk evaluation. They are occupational exposure concepts intended to be applied on a populationwide basis, rather than to an individual patient. The effect of introducing tissue weighting factors into the effective dose equivalent formulation is to increase our occupational dose limits, even though our annual dose limit (5 rem, 50 mSv) remains the same.

The recommendation by Kuwayama et al (2) suggesting that protective lenswear is appropriate in neuroangiography is incorrect. The concern over radiation-induced cataracts first appeared after lenticular exposure to neutrons during high-energy physics experiments. This activity in the late 1940s and 1950s almost wiped out a generation of high-energy physicists, yet the doses were extremely high, as was the radiation linear energy transfer. We now know that radiation-induced cataracts, a deterministic response, exhibit a dose threshold to x-rays of approximately 1000 rad (10 Gy) because of the temporal distribution of the radiation (10). Essentially it is not possible for an angiographer to receive such a dose. Our experience, measuring the response of collar-mounted radiation monitors worn by eight busy neuroangiographers during 1993, showed a range of 10 to 1320 mR with an average of 260 mR. Even though I suspect the faithfulness of these neuroradiologists in wearing their monitors, this can be taken as a reasonable approximation of dose to lens. If that is the case, one infers that the average neuroangiographer would have to work perhaps hundreds of years just to reach the dose threshold. My advice to such physicians is that if they are concerned about radiation dose to the eyes, go ahead and wear the protective lenses, but do not expect the hospital to provide them, because they are unnecessary.

I was disappointed that neither paper made suggestions for reduction of what can be a high patient dose and operator exposure. I suggest that each angiointerventional suite maintain a separate log containing technique data for each patient procedure. The technique data should include estimates of fluoroscopy time and radiographic exposures, along with the presumed kilovolts (peak), milliamperes, and milliamperes per second. With these data available, a medical physicist can easily estimate patient dose and, by applying a factor of 10^{-3}, operator exposure. I have found these data particularly valuable when demonstrating that some nonradiologically trained physicians (eg, orthopedists, cardiologists, and urologists) engage excessively in radiologic procedures. By identifying the physicians, some measure of oversight can be brought to their abuse of radiation-emitting apparatus. We must remember that as operators of x-ray equipment we are agents of the hospital and, should there be an untoward effect, the hospital assumes the principal risk.

The description of the equipment used in these procedures was incomplete, but I suspect that neither used pulse-progressive fluoroscopy. As the papers reported, it is not uncommon for fluoroscopic times to exceed 60 minutes. Consequently, entrance skin doses of several hundred rads are possible. Application of pulse-progressive fluoroscopy with freeze-frame imaging will reduce entrance skin exposure by at least a factor of 10. Anyone responsible for equipping a neuroangiographic suite must give high priority to this newer generation of equipment.

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