

# CURRENT TOPICS in review

## Risk-benefit considerations in pedodontic radiology

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### Abstract

*The principal risk to the pediatric patient from diagnostic radiologic procedures is cancer induction, while diagnostic yield resulting in improved patient care is the principal benefit. It is imperative that high yield criteria be established for the radiologic examination of the pedodontic patient. Epidemiologic studies on human populations exposed to ionizing radiation are presented which indicate that at extremely low doses a linear or quadratic relationship exists between increasing radiation dose and increasing cancer induction. Animal and in vitro laboratory studies are discussed which support this concept, and which suggest that dose fractionation and interactions of low-level radiation with other environmental agents may enhance carcinogenesis. The most efficient means of dose reduction is through the appropriate use of radiographs only when there is a predicted diagnostic yield which is expected to impact on the patient's treatment. Determination of the appropriate radiologic examination is made following the completion of a thorough history and clinical examination. Screening with radiographs is shown to be an inappropriate, low-yield procedure with an unfavorable risk-benefit ratio. Specific clinical indications for radiologic examinations are presented and discussed. While there are specific indications for panoramic radiographs, it is a specialized radiologic technique and its widespread use in pedodontics as a screening and diagnostic tool is questioned. A variety of technical methods to reduce patient exposure are discussed including the use of beam-guiding film-holding field-size-limiting devices.*

### Introduction

There has recently been considerable discussion in the public media regarding possible risks of cancer induction in humans from exposure to low-level ioniz-

ing radiation. The incident at Three Mile Island in Pennsylvania during the spring of 1979 has focused attention on nuclear power plants as a source of such radiation. Unfortunately, this has deflected public awareness from the increasing use of dental and medical diagnostic X-rays as a significant source of ionizing radiation (see Tables 1 and 2). It is estimated that 90 percent of the total man-made radiation dose to which the population of the United States is exposed is from medical and dental uses of radiation.<sup>1</sup>

Nearly every practicing dentist has some instrument for taking radiographs in his or her office. Dentists are generally taught to rely heavily on X-ray films to confirm or supplement their clinical examination. However, every X-ray exposure carries with it a risk to the patient, and such risk considerations are even more critical in the radiologic examination of the young patient. It has been established that children are significantly more susceptible to radiation-induced carcinogenesis than adults.<sup>2,3</sup>

It is clear that the dentist who treats children must be especially careful in his or her utilization of diagnostic radiology. This paper will attempt to briefly review the biological basis for considering low-level X-radiation as a carcinogen and suggest ways of maximizing clinical diagnostic radiologic utilization while minimizing patient exposure.

### Radiobiological Considerations

#### Review of Terms

An understanding of certain radiologic terms is essential to the discussion. Table 3 lists a number of these terms and the definitions which we will use. (A more comprehensive discussion of these and related terms may be found in government publications<sup>4,5,6</sup>

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and radiologic textbooks.<sup>7,8,9</sup>) Since dental radiology employs low kilovoltage X rays, the numerical values of roentgens (R), rads and rems are very similar and essentially interchangeable. For the sake of uniformity, we have elected to use the term roentgen in its abbreviated form "R" throughout our discussion. Table 4 presents some approximate skin entry doses for commonly encountered diagnostic and therapeutic radiological procedures. More detailed dosimetric measurements may be found in recent publications of Bengtsson<sup>10</sup> and Danforth and Gibbs.<sup>11</sup>

### The Dose-Response Relationship

Following the atomic bombings of Hiroshima and Nagasaki at the end of World War II, the major population risk from low-level radiation exposure was perceived as non-lethal genetic damage which could be carried and perhaps amplified through subsequent generations. Subsequent studies of atomic bomb survivors and numerous genetic studies on animals showed less dramatic genetic effects than had been predicted and resulted in a reappraisal of relative patient risks from low-level exposures.<sup>2,6,12</sup> In recent years, somatic damage and primarily cancer induction to the exposed individual has become the primary concern of agencies establishing risk estimates and safety guidelines.<sup>4,5,13</sup> There has been a recent revival of interest in genetic effects and new data and analytic techniques appear to be leading towards new and more accurate genetic risk estimates to the population from low-level radiation exposures. Based on the 1977 UNSCEAR report,<sup>6</sup> Danforth and Gibbs<sup>11</sup> have calculated the risk of inducing a non-lethal, transmittable mutation with a harmful clinical effect to be 30 cases/billion full-mouth radiographic examinations of 16-22 films each. This type of analysis is relatively new and theoretical. The facts that exposures to organs at cancer risk—bone marrow, thyroid gland, salivary gland—are considerably greater than to the gonads in dental radiographic procedures, and that quantitative risk estimates for carcinogenesis are orders of magnitude greater than for genetic damage support carcinogenesis as the principal radiation risk to be considered for dental patients.

The degree of risk of cancer induction in humans following exposures to diagnostic levels of X-radiation is a highly controversial area. In the initial years following the identification of carcinogenesis as a major population risk following radiation exposure, arguments centered on the presence or absence of a "threshold dose"; in other words, a particular dose below which there would be no risk of cancer induction. However, epidemiologic studies of human populations exposed to ionizing radiation following atomic bomb blasts, occupational exposures in nuclear reactor

**Table 1. Sources of significant radiation exposures to the population**

Source	Whole Body Exposure (mrem/year)
Natural radiation	102
Man-made radiation	
Medical and dental diagnostic	73
Weapons testing fallout	4
Occupational exposures and nuclear power generation	<1

*Source:* National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation. Considerations of health benefit-cost analysis for activities involving ionizing radiation exposure and alternatives. Washington, D.C. 1977.<sup>53</sup>

**Table 2. Distribution of medical and dental X-ray examinations in the year 1970**

Body Area Type of Examination	Number (Million)
Chest (Thorax)	65
Upper abdomen	15
Lower abdomen	17
Upper extremities	10
Lower extremities	12
Head, neck and other	10
Gastrointestinal series	6.6
Barium enema	3.5
All other fluoroscopic examinations	2.5
<b>DENTAL RADIOGRAPHY</b>	<b>68</b>

*From:* USPHS. Population exposure to X-rays. U.S. 1970. Food and Drug Administration, DHEW Publication (FDA) 73-8047, DHEW, Washington, D.C., 1973.<sup>93</sup>

plants, and diagnostic or therapeutic medical radiology have shown that, at least for the majority of tumors, there is probably no threshold dose.<sup>2,14,15,16</sup> Present day arguments tend to be concerned more with the shape of the cancer induction dose-response curve at low radiation doses: whether it is linear, quadratic, or "convex upwards" for a particular tumor or group of tumors.

Figure 1 shows four possible dose-response curves for cancer incidence vs. increasing radiation dose. At moderate (50-500R) to high dose levels (above 500R), there is a substantial amount of data on exposed human populations, and these data support a linear relationship between increasing radiation dose and increasing incidences of a variety of cancers.<sup>2,6,13,15</sup> At extremely high doses, the incidence of

**Table 3. Review of terms**

Term	Definition
absorbed dose:	The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad.
exposure:	The measure of the ionization produced in air by X-radiation. The unit of exposure is the roentgen.
roentgen (R):	The unit of exposure in air. The exposure required to produce $2.58 \times 10^4$ coulomb of charge in 1 kg of air.
rad:	The unit of absorbed dose which is equal to 100 ergs per gram.
rem:	Rad corrected for the relative biological effectiveness (RBE) of the type of radiation employed. For diagnostic X-rays, $rem = rad = R$ .
gray (Gy):	The new international unit of absorbed dose. One Gy is equivalent to 100 rads.
threshold dose:	The minimum absorbed dose that will produce a detectable degree of any given effect.
skin entry dose:	A term frequently encountered in dental literature describing the total absorbed dose to the skin in the area of exposure.
marrow dose:	A term frequently encountered in dental literature describing the total absorbed dose to the bone marrow in the area of exposure.
dose-rate:	The interval of time in which a given radiation exposure or exposures is made. Technically, dose-rate refers to the speed at which a given dose is delivered, and is expressed as rads per unit time.
integral absorbed dose:	Absorbed dose corrected for the amount of tissue irradiated, expressed in gram-rads. This is often referred to as "total skin entry dose".

cancer declines as cell killing, rather than sub-lethal malignant alteration, becomes the predominant manifestation of radiation damage.

The dose-response curve for radiation carcinogenesis in the diagnostic range is unclear and may assume one of several shapes. At present, the most widely used model is the linear hypothesis (line "A"), which simply extrapolates the linear relationship at higher doses through the origin. This model, used by both national and international radiation protection agencies as the most likely model, implies a finite carcinogenic risk with any radiation exposure no matter how small. The U.S. National Academy of Science Committee on the Biologic Effects of Ionizing Radiation stated in 1972 that this is a conservative estimate.<sup>2</sup> The same committee stated in 1979 that this relationship is no longer considered to be conservative and that risks from low-level exposures may be greater than previously calculated.<sup>13</sup> A minority report of this Committee suggested that some of the new risk estimates might be excessive.<sup>13</sup>

The "threshold" hypothesis represented by line "B" states that there is a certain dose below which there is no risk of cancer induction. Although some tumors

may ultimately be shown to fit this model, the bulk of present data suggests that this model is not applicable to radiation induction of most human tumors.<sup>13,15</sup>

One of several possible "quadratic" responses is represented by line "C" as a model which incorporates cell killing and cell repair. Although this curve also implies a finite risk with any exposure, it is more flexible and biologically oriented than the linear hypothesis, and may ultimately become the model of choice for human tumors.<sup>15</sup>

Line "D" is the "convex upward" curve, and its shape implies that radiation is more efficient as a carcinogen at lower doses than at higher doses. Although the implications of such a curve are disturbing, recent data on exposed human populations as well as *in vivo* and *in vitro* laboratory studies have suggested that this curve may describe the induction of some cancers by low dose radiation.<sup>15,17,18</sup>

The discussion of the shape of the dose-response curve for radiation carcinogenesis at low doses leads to two conclusions. First, no single dose response curve will describe the induction of all tumors. The shapes of the curves may be determined by numerous modifying factors including type of tumor, type of

**Table 4. Some typical skin entry exposures in radiology**

Type of examination	Dose (mR)	Reference
Single molar periapical film (long, lined, open ended cone)		
Paralleling technique: 70 kVp	600*	a
90 kVp	310*	a
Paralleling technique with beam-guiding device: 70 kVp**	264*	a
90 kVp	210*	a
National average, U.S., 1970, per intraoral film	910*	USFDA 1973 <sup>93</sup>
National average, U.S., 1978, per intraoral film	500*	(NEXT)
Panoramic film		
Conventional film-screen combination	4500-6000*	Reiskin 1977 <sup>84</sup>
Rare earth film-screen combination	1000-3000*	Reiskin 1977 <sup>84</sup>
Lateral cephalometric film		
Conventional film-screen combination	103*	a
Rare earth film-screen combination	5-20*	a
Chest X-ray	30-50	ICRP NO. 16 <sup>5</sup>
Radiotherapy—curative	6,000,000	Rubin 1978 <sup>94</sup>

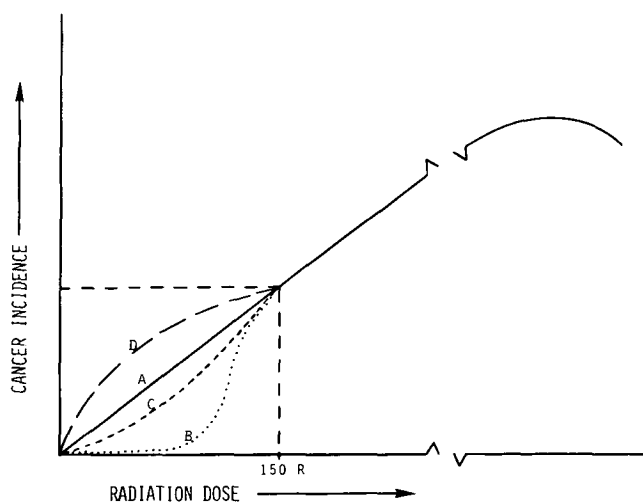
\*Total exposure to patient

\*\*With samarium filtration

a. Determined at the University of Connecticut Health Center, School of Dental Medicine, Division of Oral Radiology using LiF thermoluminescent dosimetry.

**Table 5. Radiogenic cancer risks for selected human tissues**

Organ	Age at irradiation (years)	Risk (excess cases of cancer per 10 <sup>6</sup> persons per rad per year)	Reference
Bone marrow (leukemia)	in utero	5.1	BEIR 1972 <sup>2</sup>
	0-9	5.3	BEIR 1972 <sup>2</sup>
	10-21	2.2	BEIR 1972 <sup>2</sup>
	adults	0.4-1.0	BEIR 1979 <sup>13</sup>
Breast (female)			
—“A” Bomb survivors	34	2.5	McGregor 1977 <sup>27</sup>
—Fluoroscopy series			
—Nova Scotia	26	8.4	Shore 1977 <sup>29</sup>
—Massachusetts	25	6.2	Boice 1978 <sup>30</sup>
—Mastitis patients	adults	6.0	BEIR 1972 <sup>2</sup>
Thyroid			
	0-30	1.6-9.3	Brown 1976 <sup>15</sup>
	30+	2.0	BEIR 1979 <sup>13</sup>



**Figure 1.** This figure shows a generalized dose-response showing the increase in cancer incidence with increasing radiation dose. Four possible shapes for this curve at doses below 150R are shown: A = linear response, B = threshold response, C = quadratic response, and D = convex upwards response. A detailed discussion is found in the text.

radiation, dose-rate of exposures, age of the exposed population, ability of irradiated cells to repair, and the presence of radiation modifying agents. Second, the predicted risks from low-level radiation exposures have increased as new data have become available. With almost every published comprehensive report on induction of cancer in humans by radiation, international and national radiation protection agencies have subsequently become more conservative in their recommendations and guidelines concerning radiation exposure.

## Studies of Low-level Radiation

### Human Studies

Radiation carcinogenesis at low doses may be studied epidemiologically in human populations, or in the laboratory in animal populations or cell cultures which have been exposed to ionizing radiation. Laboratory studies are used to generate qualitative information on the possible mechanisms by which radiation induces cancer, while quantitative risk estimation is based on human epidemiological studies.

There are numerous ways of expressing radiation risk to human populations. We have chosen a widely used term for our discussion: excess cases of cancer above expected incidence per  $10^6$  persons exposed per rad per year ( $N \times 10^6$  man-rad-years). Risk estimates for radiation induced cancer in organs which are particularly sensitive to such effects and which

may be exposed during a dental X-ray examination are shown in Table 5. This table has been compiled from a variety of sources and is quite general in nature. The risk of induction of leukemia is clearly greater in children than in adults. Breast and thyroid risks are for wider age cohorts and may be greater for children than young adults. According to presently accepted data, the incidence of tumors in these three organs falls within the radiation risk range predicted by the linear hypothesis.

A new risk estimate term recently used in some dental X-ray risk discussions is the "increase in lifetime cancer cases above the expected per million full-mouth radiographic examinations consisting of fourteen to twenty-two films."<sup>10,11</sup> Analyzing data from the 1977 UNSCEAR report and the 1972 BEIR report, and assuming a linear dose response, Danforth and Gibbs have calculated risk estimates for cancer induction in a variety of tissues exposed during dental examinations.<sup>11</sup> They estimated that lifetime cancer risk estimates per million full-mouth radiographic series (16-22 films) and per million panoramic + two bitewing film examination are as follows:

	FMX	Panoramic + BWX
Salivary gland	1-3	1.3-2.6
Thyroid gland	4-11	3-10
Brain	0.2-1	0.2-1
Leukemia	0.2-0.4	0.14-0.26
All cancers	6-17	5-14

These estimates are similar to those recently reported by Bengtsson.<sup>10</sup>

The massive effort which has been and is being utilized in an attempt to determine accurate risk assessments for the population illustrates the difficulty in interpreting the results of human population studies. There are several specific problems in human radiogenic cancer risk estimation which must be considered:

1. Radiogenic cancers are indistinguishable from other cancers.<sup>19,20</sup> They have no identifying biochemical, histopathological, or pathophysiological features which distinguish them as being radiation-induced.
2. The latent period for tumor induction is usually quite long, ranging on average from 10 to 35 years depending on tumor type. However, it is shorter (2-10 years) for induction of leukemia.<sup>13,16</sup>
3. There may be human sub-populations particularly sensitive or insensitive to induction of cancer by low-level radiation.<sup>21</sup>
4. There may be a variety of synergistic, additive, or inhibitory interactions amongst low-level radiation and other known or suspected noxious environmental agents such as chemical carcinogens,

oncogenic viruses, tumor promoters and mutagens.<sup>22,23</sup>

5. The effects of splitting up the radiation exposure into several smaller exposures over many years on the carcinogenicity of the radiation are not well defined.<sup>18,24,25</sup>
6. Most risk estimates are expressed in terms of whole body exposure. Most diagnostic radiological procedures are partial body exposures. Presently, there are no data to support or deny the concept that irradiating one-tenth of the body results in one-tenth of the cancer risk of irradiating the entire body.
7. Most low-risk estimates are derived by extrapolating the results of populations exposed to doses in the moderate-to-high dose range (50-500R), as there are few control studies of populations exposed to low doses. A mechanistic biological basis for such extrapolations remains to be established.

The effect of delivering a lifetime radiation dose as multiple small exposures at varying time intervals, referred to as "fractionating the dose," upon the carcinogenic potential of that radiation dose is of critical interest to the pedodontist. The practice of repeated radiologic exposures at frequent intervals during childhood and young adulthood could be considered as fractionation of a moderate (greater than 50R) radiation dose. For example, based on the national average of 500 mR skin entry dose per intraoral film in the U.S. in 1978,<sup>26</sup> a 20-film series taken every five years from childhood through 60 years of age would deliver, through repeated low-dose exposures, a total exposure to the patient of approximately 120R.

In a recent review, Brown presented data which suggested that the fractionation of X-ray doses and the reduction of the dose per fraction increases the carcinogenicity of x- and gamma-radiation in both human female breast and human bone marrow tissues.<sup>15</sup> Table 5 shows that in atomic bomb survivors who received an acute gamma ray and neutron exposure, the risk estimate for breast cancer induction was 2.5 (excess cancer above the expected incidence).<sup>27</sup> Mastitis patients receiving fractionated X-ray exposures at a high dose per fraction had a risk estimate of 8.3.<sup>28</sup> Fluoroscopy patients receiving fractionated X-rays at a low dose per fraction had a risk estimate of 6.2-8.4.<sup>29,30</sup>

A similar observation can be made for leukemia induction in humans. Atomic bomb survivors, victims of an acute gamma ray exposure, had a leukemia risk estimate of 0.5 excess cancer beyond the expected incidence. Ankylosing spondylitic<sup>31</sup> and mastitis<sup>28</sup> patients who received fractionated therapeutic X-ray

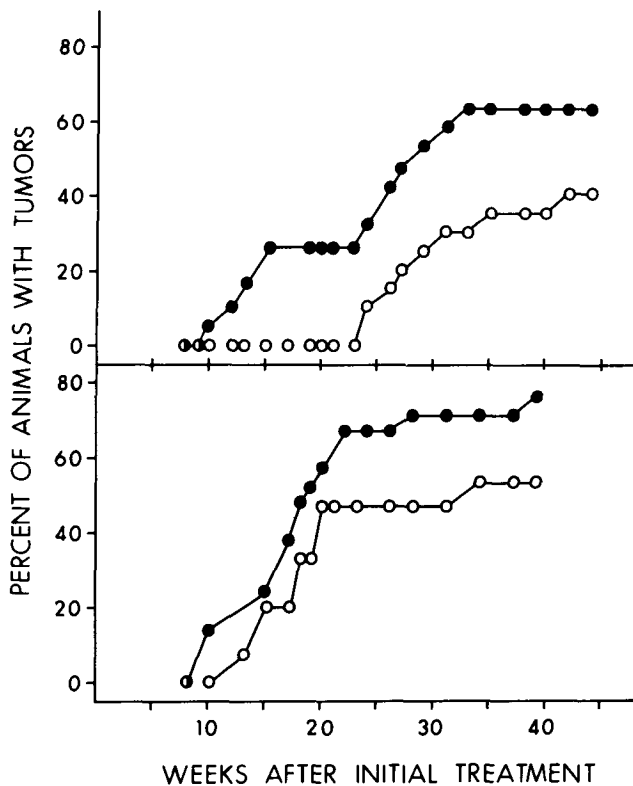
treatments, ranging from 275R to 2750R, have respective leukemia risk estimates of 0.5 and 2.4.

These leukemia and breast cancer data suggest increasing efficiency of radiation to induce cancer with fractionation. It is interesting to consider the analogy between the effects of fractionation on leukemia and breast cancer induction in these studies, and the overall cancer risk to patients repeatedly exposed to dental X-ray exams, particularly during childhood and young adulthood.

A controversial suggestion concerning induction of leukemia in children was made by Bross and Nataraian in their 1973 Tristate Study.<sup>21</sup> This was a retrospective matched case/control study which examined a large group of children with leukemia and analyzed similarities and contrasts in their medical and radiation exposure histories with their cohorts. They found at least two population sub-groups: one group with and the other group without leukemia associated with exposure to low level radiation, such as diagnostic X-rays in utero. It was concluded that not only are children more susceptible to radiation carcinogenesis than adults, but that within the population of children there may be sub-groups "orders of magnitude more sensitive" than the total population of children. However, serious questions regarding the validity of the statistical methodology and sensitive sub-population concept have recently appeared.<sup>13</sup>

There have been several papers analyzing carcinogenesis in workers at the Hanford Nuclear Power Plant in Richland, Washington, some of which have claimed substantially greater leukemia risks in adults from low level radiation than those shown in Table 5.<sup>21,32</sup> However, these data have been the subject of considerable debate in the literature,<sup>33,34,35</sup> are based on extremely complex statistical analyses, and thus have not been presented in this discussion.

Most data on radiation cancer induction in humans appears to fall within the predicted linear models, thus indicating a small but definite increased cancer risk with any radiation exposure, no matter how small. Additionally, there is evidence that there is a greater cancer induction risk for children than for adults due to the greater proliferative activity in growing tissues. This is clearly shown in the leukemia and thyroid data of Table 4. Human population studies have tended to support conservative (linear as opposed to threshold) estimates of risk, and estimates of risks have increased as new data have become available. (Such increased risk estimates are evidenced by the growing estimates for radiogenic thyroid carcinoma induction from the Modan<sup>36</sup> study, which had a risk estimate of 6.1 in 1973<sup>37</sup> but has recently been revised upwards to 10.9.<sup>15</sup>) Although the reality of risk from low-level exposures appears clear from human studies, the lack of



**Figure 2.** Induction of tumors in hamster cheek pouch epithelium by DMBA and DMBA + repeated low-level head-and-neck X-ray exposures. Two separate, identical studies are shown above and below. o = groups treated only with DMBA; • = groups treated with DMBA + X-radiation. There were significantly greater tumor incidences in both DMBA + X-radiation groups—radiation only controls had no detectable pathology. (Courtesy of A. G. Lurie, *Radiation Research*, Ref. 41.)

understanding of the possible mechanisms of induction of cancer by low-level radiation makes it difficult, if not impossible, to quantitate or predict this risk accurately. It is through laboratory studies that we can begin to understand such mechanisms, as well as the qualitative aspects of low-level radiogenic carcinogenesis and risk estimation.

### Experimental Studies

Cancer has been induced in almost every organ of experimental animals by exposures to ionizing radiation.<sup>20</sup> The long latent period and the non-specificity of most low-dose radiogenic cancers in humans are likewise features of many radiogenic cancers in animals.<sup>20,25</sup> These biologic features make experimentation difficult and tedious due to the large sample sizes and long study periods which must be used to generate meaningful data. Additionally, almost all radia-

tion carcinogenesis studies in animals have been conducted with sizable radiation exposures (hundreds to thousands of R), and generally have employed single exposures rather than repeated exposures to smaller radiation doses. The problems in interpreting animal studies—the lack of direct data at low doses, the prevalence of data obtained from single exposures, and the necessity of extrapolating the shape of the dose-response curve at low doses from the data at high doses—are the same problems as those found in interpreting human studies.

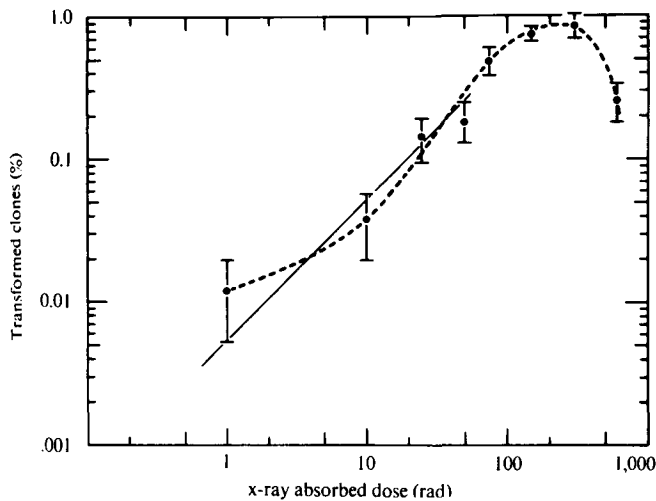
An analysis by Shellabarger of data taken from the 1972 United Nations report<sup>6</sup> on induction of a variety of tumors in a variety of animal systems demonstrated that no uniform conclusions could be reached on the dose-response characteristics for these tumors.<sup>25</sup> The doses at which the increases in incidences became detectable, at which the maximum incidences were reached and at which the declines in incidence began, as well as the shapes of the radiation dose-response curves, varied from one system to another. He stated, "Just as it seems likely to many that there will be no single cancer cure, it seems equally likely that no single dose response relationship will describe radiation carcinogenesis."

A study of the effects of fractionating the dose on the induction of tumors in animal systems has provided results which differ somewhat from those discussed earlier for human breast cancer and leukemia. The incidence of some tumors induced in experimental animals by X- and gamma radiation is lower when the total dose is delivered using greater numbers of exposures at a lower dose per exposure, than when the total dose is delivered as a single exposure, or as a reduced number of exposures at a higher dose per exposure.<sup>25</sup>

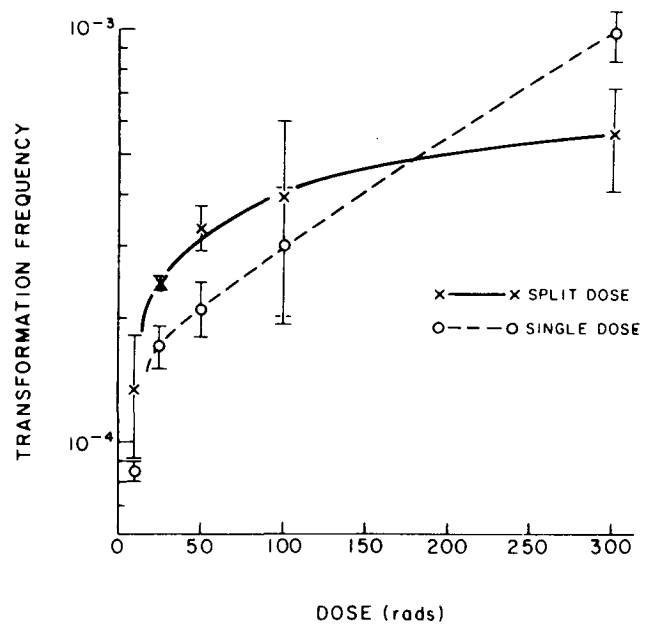
### Interactions

Exposure to radiation is rarely, if ever, the only exposure to a carcinogen that a human will receive. Realistically, humans are repeatedly exposed, either singly or concurrently, to a variety of known or suspected environmental carcinogens, including hydrocarbons and nitrosamines in the atmosphere and the diet, oncogenic viruses, and heavy metals. Thus, potential interactions between these agents and diagnostic X-ray exposures is an important theoretical consideration when discussing human low-level radiation risk.

Possible low-level radiation interactions with other carcinogenic agents has been addressed in animal studies. In 1938, Maltron showed enhancement of benzpyrene carcinogenesis in skin by beta irradiation.<sup>38</sup> The first clear demonstration of enhancement of chemical carcinogenesis by low-level x-radiation



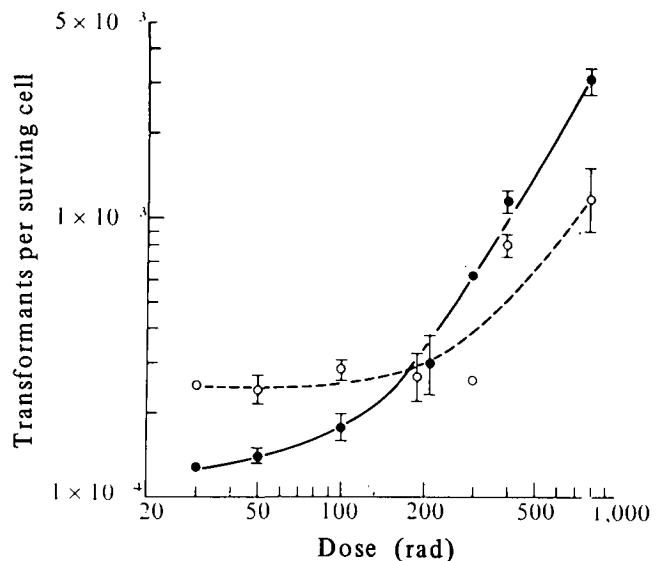
**Figure 3.** Malignant transformation in cultured hamster embryo cells vs. single radiation doses from 1R through 600R. Note the significant malignant transformation following a 1R exposure and the linear or quadratic shape of the curve in the low dose range. (Courtesy of C. Borek and E. J. Hall, *Nature*, Ref. 42.)



**Figure 4.** Frequencies of malignant transformation induced in cultural A31-11 mouse BALB/3T3 embryo cells by single (o) and split (x) X-radiation exposures. In split-dose studies, 2 equal fractions were separated by a five-hour interval. Note the greater efficiency of split doses below 150R in causing transformation. (Courtesy of J. B. Little, *Cancer Research*, Ref. 17.)

came in 1957 when Bock and Moore observed carcinogenesis in the skin of dogs exposed to cigarette smoke condensate plus small X-ray doses.<sup>39</sup> Neither agent induced tumors when used alone. Other studies have shown enhancement of urethan leukemogenesis in mice by moderate dose single and split x-ray exposures,<sup>23</sup> and enhancement of chemical carcinogenesis in rat liver and stomach by moderate doses of x- or neutron radiation.<sup>40</sup>

Recent studies in our laboratory have shown enhancement of DMBA (a potent epithelial hydrocarbon carcinogen derived from benzpyrene) carcinogenesis in hamster cheek pouch and lingual epithelium by concurrent repeated exposures to low level X-radiation.<sup>22,41</sup> Figure 2 shows the results of two representative studies in hamster cheek pouch. Animals received either repeated applications of low concentrations of DMBA, one head and neck exposure to 20R X rays once a week for 17 consecutive weeks, or simultaneous treatment with both agents. In all studies conducted during the past four years, animals receiving treatment with both agents have had more tumors, larger tumors, and possibly a reduction in the tumor induction period than animals receiving only DMBA treatments. Animals receiving only irradiation treatments have had no detectable changes. These studies, as well as those cited previously employing higher doses, strongly indicate that radiation can significantly enhance the induction of tumors by other agents at dose levels which alone do not produce readily detectable biological effects.



**Figure 5.** Frequencies of malignant transformation induced in cultured C3H 10T $\frac{1}{2}$  mouse embryo cells by single (•) and split (o) X-radiation exposures. As in Fig. 4, split doses were separated by five hours and were more effective in causing transformation than single exposures at doses below about 150R. (Courtesy of R. Miller and E. J. Hall, *Nature*, Ref. 18.)

### In Vitro Studies

In 1973, Borek and Hall demonstrated malignant



transformation\* in cultured hamster embryo cells with X-ray doses as low as 1R.<sup>42</sup> The incidence of malignant transformation versus radiation dose found by these investigators is shown in Figure 3. Since this initial demonstration *in vitro* of low dose X-ray induced malignant transformation, the same findings have been made in a variety of cultured mammalian cells.<sup>17,18</sup> These studies have examined both the dose responses of malignant transformation in the low dose range and the differences in malignant transformation frequencies between single and split X-ray exposures. Malignant transformation has been induced in most of these cell lines with radiation doses in the one to twenty R range.<sup>17,43</sup> At total doses below 15R, splitting the total dose into two equal fractions separated by five hours induces a higher frequency of malignant transformation than does the single dose.<sup>18,24</sup> This increased efficiency of transformation induction by split low-dose radiation exposures is shown in Figures 4 and 5. Elkind and Han have proposed that this increased effectiveness of radiation dose-splitting in inducing malignant transformation may relate to different repair mechanisms for sub-lethal and lethal radiation damage.<sup>44</sup> The finding of the greater effectiveness of splitting doses in the low dose range on transforming cultured mammalian cells, as well as possible similar results of *in vivo* radiation-chemical interaction studies again suggests serious implications on the dental clinical utilization of diagnostic X rays.

Cellular changes, other than malignant transformation, which are associated with carcinogenesis have been observed both in cell cultures and in animals exposed to low levels of ionizing radiation. These changes include chromosome non-dysjunction in the fetuses of mice whose parents were exposed to 5R total body radiation prior to copulation,<sup>45</sup> increases in chromosome and chromatid aberrations in Syrian hamster cheek pouch epithelium following X-ray exposures smaller than 5R,<sup>46</sup> in fresh and cultured human lymphocytes following X-ray exposures smaller than 6R,<sup>47,48,49</sup> and altered cytokinetic activity in a variety of tissues following *in vivo* exposures to tritiated thymidine or low-level X-radiation.<sup>50,51,52</sup>

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\*Malignant transformation is a term which generally refers to alterations in the structure and function of cells in culture which correspond to similar types of changes in human and animal cancer cells *in vivo*. These changes include: reversion to a more primitive cell morphology, loss of contact inhibition of cellular proliferation, accumulation of cells in transformed clones, and increased nuclear/cytoplasmic ratio. Additionally, a clone of transformed cells will result in a clinical tumor when placed into the appropriate tissue of the animal of its origin. For a more detailed discussion, see the recent review by Borek.<sup>42</sup>

## Summary of Studies on Low-Level Radiation Carcinogenesis

There is an abundance of epidemiologic and laboratory data indicating that induction of cancer, enhancement of cancer induction by other agents, and cellular changes associated with the induction of cancer have been caused by exposure to low levels of X-radiation. Although the dose levels and dose rates vary widely among these studies, many of them fall within the ranges encountered in diagnostic dental and medical radiology. Many of these studies indicate that children are more susceptible, perhaps considerably more so, than are adults to low-level radiation carcinogenesis. Clinicians employing radiographic examinations of children must do so with the utmost consideration of their patient's biologic risk and with a sound clinical rationale for taking such films.

## Maximizing Diagnostic Yield While Minimizing Radiation Risk in Pedodontic Practice

### Introduction

Every properly positioned, exposed, and processed dental radiograph contains diagnostic information. In view of the population risk from low-dose exposures, "possession of diagnostic information" is not, of itself, an adequate justification for taking radiographs on a patient. It is our position that every diagnostic x-ray examination must have an anticipated information content, either positive or negative, which will result in improved care for that patient.

There are several national and international agencies that review human and laboratory radiobiologic data, establish guidelines for human risk estimates, and/or establish radiation safety and protection standards. The most notable of these groups are: the International Commission on Radiation Protection (ICRP), the National Commission on Radiation Protection and Measurement (NCRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the Bureau of Radiological Health (BRH), and the National Academy of Sciences Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR).

Statements of some of these organizations which affect the practice of radiology in dentistry are as follows:

1. The 1972 Committee on the Biological Effects of Ionizing Radiation (BEIR) stated that, "No exposure to ionizing radiation should be permitted without the expectation of a commensurate benefit. Medical radiation exposure can and should be reduced considerably by limiting its use to clin-

**Table 6. Clinical situations for which radiographs may be indicated**

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History of pain
Evidence of swelling
Positive neurologic findings in face and jaws
Trauma to teeth, jaws and/or lips
Mobility of teeth
Unexplained bleeding
Deep periodontal pocketing
Fistula formation
Unexplained sensitivity of teeth
Evaluation of sinus condition
Unusual eruption of teeth
Unusual spacing or migration of teeth
Lack of response to conventional dental treatment
Unusual tooth morphology, calcification or color
Evaluation of growth abnormalities
Altered occlusal relationships
Aid in diagnosis of systemic disease
Assessment of dental involvement in established systemic disease
Familial history of dental anomalies
Post-operative evaluation
Others

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ically indicated procedures utilizing efficient exposure techniques and optimal operation of radiation equipment.”<sup>2</sup>

2. The National Committee on Radiation Protection and Measurements (NCRP) has recommended that, “Exposure which fulfills no useful purpose should be reduced to an absolute minimum . . . a major effort is justified to assure that the radiation field does not extend beyond the area of the X-ray film or fluoroscopic screen or significantly beyond the region to be examined.”<sup>4</sup>
3. The Food and Drug Administration (FDA) has proposed regulations which will mandate quality assurance programs in any diagnostic radiology facility (including the private dental office) to reduce the radiation exposure burden to the American population. The commissioner of the FDA stated that such regulations are necessary because “. . . data from several sources indicate that many diagnostic radiology facilities are producing poor quality images and giving unnecessary patient radiation exposure.”<sup>54</sup> As of the date of the submission of this paper, no final action had been taken in this area.

In addition, the American Dental Association Council on Dental Materials, Instruments, and Equipment has recommended that, “The decision to use diagnostic radiography rests on professional judgment of its ne-

cessity for the benefit of the total health of the patient. This decision having been made, it then becomes the duty of the dental professional to produce a maximum yield of information per unit of X-ray exposure.”<sup>55</sup>

The interest of state and federal governments in the examination and possible future regulation of all aspects of the diagnostic radiological sciences has steadily increased during recent years. Areas being considered by such agencies as the President’s Interagency Task Force on Ionizing Radiation, Congressional Hearings on ionizing radiation, the Commissioner of the FDA, and a number of state legislative committees and regulatory agencies include machine performance, film characteristics, operator training and licensing, professional and auxiliary education, quality assurance programs, and facility licensing and inspection programs. Eight states have instituted specific radiologic licensing examinations for dentists separate from their State Dental Board Examinations. Several other states are considering similar action.

How does the practicing dentist meet such radiation safety and practice criteria while maintaining the level of diagnostic radiology needed for excellence in clinical practice? We feel that these needs are met in two ways: (1) the establishment of high diagnostic yield criteria to be used in the determination of the need for films; and (2) the execution of such examinations incorporating techniques which maximize the diagnostic yield while minimizing radiation exposure for every film.

#### **Suggested Criteria for Radiologic Examination of Children and Adolescents**

We shall define high yield criteria as those clinical or historical findings for which radiographic examinations are likely to provide confirming or clarifying information. These radiographic examinations should have a high probability of affecting the diagnosis and treatment of a problem which, if left untreated, poses a potential health hazard greater than that associated with the radiographic exposure.

Historically, dentists have used radiographic examinations for a variety of documentary and screening purposes. Documentary purposes include films taken for insurance company post-treatment verification, teaching files, slide collections, patient education, completeness of records, “making sure everything is OK,” and the evaluation of marginal adaptation of restorations. Such purposes rarely provide a benefit to the patient, and we disapprove of such practices because they expose patients to a radiation risk without a commensurate or greater benefit.

A screening examination is one in which specific diagnostic procedures are performed in a population

specifically at risk with a view towards discovering occult disease of a life-threatening nature which would be otherwise undetected. Such a population may be that of an entire country, an entire city, or the private practice patients of an individual dentist. For a screening procedure to be effective, positive findings *must* be followed by appropriate treatment. If the screening procedure entails risk to the population, then the benefits accrued from the discovery and treatment of occult disease must outweigh this risk.

The only radiographic screening procedures presently employed, to our knowledge, are mammography in post-menopausal women, where there is an established and significant risk-benefit ratio in favor of the patient,<sup>56,57</sup> and radiographic screening for diseases of the jaws in dentistry where a risk-benefit ratio has never been established and is likely to be quite unfavorable for the patient population being screened. Although there are diseases which are unique to the jaws, the incidences of serious diseases of the jaws have not been demonstrated to be greater than those involving the general skeleton. A total body skeletal radiographic survey for the detection of occult disease in the absence of clinical findings is not practiced anywhere in the world. In addition, often-cited examples of such diseases of the jaws are cysts, abnormally formed teeth, odontogenic neoplasia or cancer. The only diseases in such a list with expected serious consequences are cancers and aggressive odontogenic neoplasms of the jaws, both of which are exceedingly rare in the pediatric age group. When such lesions do occur, they almost always have presenting clinical signs and symptoms which in the absence of any radiographic examination would be suggestive of an abnormality requiring further evaluation.

The rational use of radiology in pedodontics requires definition of clinical and historical criteria which are likely to require a radiologic examination to allow a practitioner to proceed with the best possible treatment: *high yield criteria*. Table 6 lists a variety of positive clinical and historical findings which are likely to require radiographic examination. Many of the clinical situations listed in this table are obvious. For example, the dentist to whom a pedodontic patient presents with a history of pain, evidence of swelling, or after traumatic injury, must have the benefit of radiologic examination available in order to carry out the best treatment. However, some of the situations listed in this table require discussion.

Fistula formation in the pediatric age group is usually indicative of a localized furcational or periapical infection of dental origin. Radiographic examination is necessary, but one should be selective in the number and types of films used. Each film should have an indication based on the clinical situation;

there is no reason to simply order a "full-mouth series." The same holds true for the evaluation of unusual eruption of teeth. For example, a seven-year old presents with erupting maxillary permanent lateral incisors but only one erupting permanent central incisor. Consideration of the absence or displacement of the unerupted incisor must be made, and an individual periapical or occlusal film is the indicated radiographic examination. Another situation which the pedodontist is faced with is the evaluation of the medically exceptional child. A dental radiographic examination may be helpful in the diagnosis of systemic disease; however, the taking of numerous radiographs in a patient with an established systemic disease but no clinical evidence of dental involvement to "see what's going on" is not an indicated procedure because it exposes the patient to a radiation dose without having a significant potential benefit to that patient.

Whenever diagnostic radiology is to be utilized, the practicing dentist should make an intelligent decision of which radiographs will provide the information needed at the lowest radiation exposure possible. There may be times when the decision should be that no radiographs are indicated. Although we do not ascribe to broad rules to dictate which radiographs to take for which problems, there are certain common situations in pedodontics which require discussion.

### **Common Clinical Indications for Radiology**

Five clinical situations which the pedodontist is commonly confronted with in which radiographs are usually indicated for a thorough evaluation are: (1) detection of congenital dental anomalies in the mixed dentition in patients undergoing comprehensive dental care; (2) detection of interproximal carious lesions; (3) third molar evaluation; (4) infection; and, (5) trauma. Each of these indications for radiographic examination requires a consideration of the risk-benefit ratio. These situations and examination rationales are shown in Table 7.

1. *Detection of congenital dental anomalies.* The comprehensive dental care of the pedodontic patient includes the management of the dentition in a way that permits the most harmonious occlusal relationships to develop. The dentist must be able to anticipate any condition which may complicate the treatment plan. The mixed dentition space analysis is often used to detect potential problems which may be developing as the occlusal pattern is established. Undiagnosed congenital anomalies of tooth number, size, shape and location have a potential impact on the successful management of the developing dentition. Such pathology generally is detectable only with radiographs.<sup>58</sup>

Various authors have investigated the incidence of

congenital dental anomalies in children.<sup>59,60</sup> The conditions most frequently observed are missing, supernumerary, fused and peg-shaped teeth. It has been shown that approximately one child in fifteen will present with at least one of these four anomalies.<sup>59</sup> This relatively high incidence of positive findings which will affect the pedodontist's treatment plan suggests a favorable risk-benefit ratio for the patient. It is our opinion that the goal of successful guidance of the developing dentition with the least radiographic risk can be attained by performing one appropriate intraoral radiographic examination at the optimal age for detecting and evaluating such problems: early in the mixed dentition, six to eight years of age. The six film intraoral radiographic examination consisting of two occlusal films and four posterior periapical films demonstrates all areas of the jaws which contain succedaneous teeth. Such an examination results in a minimal radiation exposure,\* and thus is the radiologic examination of choice in detecting congenital dental anomalies in the mixed dentition. MacRae *et al.*, in a study of 456 children aged six to eight years, demonstrated the maximum yield in the detection of congenital dental anomalies using an eight film survey (two occlusal films, two bitewing films, and four periapical films) when compared with a three-film survey (one maxillary occlusal film and two bitewing films) in which 22 percent of the anomalies were not detected, or two posterior bitewing films alone in which 61 percent of the anomalies were not detected.<sup>61</sup> There are reports of surveys of a similar nature incorporating panoramic radiography,<sup>62,63</sup> a practice we strongly discourage, which we will discuss in a subsequent section. The six film intraoral radiographic examination will reveal the presence of any developmental anomaly in the tooth-bearing areas of the jaws. In patients with positive findings, further radiographic evaluation as dictated by the findings and clinical needs may be indicated to better define the problem.

2. *Detection of interproximal carious lesions.* One of the most frequent indications for radiographic examination of the pedodontic patient is the evaluation of carious involvement of the interproximal surfaces of the posterior teeth. Unfortunately, this procedure is routinely performed on almost all patients at intervals usually varying from six to twelve months. Such routine examinations need to be performed only on those patients for whom it is clinically indicated. The fre-

quency of such examinations should be dictated by considerations of caries activity, the degree of spacing between the posterior teeth and clinical examination. When such radiographic examinations are performed, the largest film possible should be employed to allow monitoring of the development and eruption of the permanent premolars without an appreciable increase in the patient's radiation exposure.

3. *Third Molar Pathology.* A constant problem in dentistry is the management of the impacted third molar. A majority of dentigerous cysts are associated with these teeth, and are most often seen in adolescence and young adulthood.<sup>64,65</sup> Additionally, odontogenic neoplasms and occasional carcinomas associated with odontogenic tissues are most frequently found in the mandibular third molar/ramus region.<sup>64,66,67</sup> Considering that most people have third molars and that they are often treated between the ages of 14 and 17,<sup>68</sup> there is a substantial benefit in radiographic examination for the presence, position, morphology and possible associated pathology of these teeth during these years. Four periapical films constitute the radiographic examination of choice in the initial evaluation of maxillary and mandibular third molars. These films provide the maximum detail, provide sufficient coverage of third molar development, and deliver the minimum radiation dose to the patient. Cases of unusual position or development of the third molars may require additional films for the visualization necessary to adequately plan treatment. Examples of such films may be a cross-sectional occlusal film to determine buccal-lingual position of a mandibular third molar or a lateral oblique projection for the examination of a posteriorly positioned tooth or associated pathology.

4. *Infections of dental origin.* We feel that infection of odontogenic origin is the most common pathologic condition of potentially serious consequences to the patient encountered in dentistry. The risk of treating a known or suspected infection without knowledge of the severity and/or extent of the condition is considerable, as the potential sequelae include osteomyelitis, localized spread of the infectious process, bacteremia and others. The benefits from a thorough radiologic examination are obvious and outweigh the small radiation risk involved. Since most infections in the jaws arise from teeth and are confined to periapical structures, single periapical films of the tooth or involved area are usually sufficient to demonstrate their nature and extent. If the films, clinical findings, or history suggest further bony involvement of the mandible, the lateral oblique projection is the film of choice. Right angle views are always necessary for the complete evaluation of such a condition, and the P-A mandible and cross-sectional occlusal projections may help to demonstrate buccal-lingual cortical plate expansion.

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\*Based on the 1978 NEXT data, the total exposure to the patient from the six films would be approximately 300mR. Using optimal techniques which are available today and will be discussed at a later time, the exposure to the patient would be reduced to approximately 900-1200mR.<sup>26</sup>

**Table 7. Common clinical situations requiring radiology and suggested radiographic examinations in pedodontics**

Indications	Radiographic Examination	Time of Examination
1. Detection of congenital dental anomalies in patients undergoing comprehensive dental care	Six film examination (four posterior periapicals and two occlusals)	Once between the ages of six and eight years
2. Detection of carious lesions on interproximal surfaces of posterior teeth	Bitewings with largest film possible allowed by patient anatomy	As infrequently as is indicated by clinical examination, caries activity and spacing of teeth
3. Third molar evaluation	Periapical films to establish presence, position, morphology and possible associated pathology of third molars. Additional radiographs may be required to establish unusual position or pathology as noted on periapical films	Once between the ages of fourteen and seventeen
4. Infection:		
a. Dental involvement suspected	Periapical films to establish nature and extent of dental involvement	
b. Mandibular involvement suspected	Lateral oblique projection, occlusal projection, P-A mandibular projection	As clinically indicated
c. Maxillary sinus involvement suspected	Water's projection, lateral sinus projection, molar periapical films	
d. Maxillary involvement suspected	Usually complex radiographic techniques beyond the capabilities of most private dental offices are necessary	
5. Trauma to the teeth and supporting structures:		
a. Suspected fractures of teeth and the supporting alveolus	One isometric periapical and one eccentric (25°-40°) periapical with further views as indicated	
b. Suspected mandibular fractures	Obtain right angle views, lateral oblique projection, occlusal projection, P-A mandible projection (panoramic projection)	As soon as possible after injury as complications such as swelling impair the ability to perform an adequate radiographic examination
c. Suspected maxillary and other midface fractures	Usually complex radiographic techniques beyond the capabilities of most private dental offices are necessary	

Extensive osseous involvement of the maxilla is rare and requires films usually beyond the capacity of the dental office. Infections of the maxillary sinus are best demonstrated by the molar periapical film, and the lateral sinus and Water's projections.

5. *Trauma.* The pedodontic patient who presents with localized trauma to the teeth and jaws requires a thorough historical and clinical evaluation. The potential complications of undiagnosed or improperly diagnosed traumatic injuries are numerous, and since most are osseous or dental in nature, such complications may be obviated by an appropriate and thorough radiographic examination of the likely areas of injury.<sup>69,70,71</sup> As with infection, therefore, the obvious substantial benefit which results from the complete demonstration of the injuries via radiographic examination leading to appropriate treatment outweighs the radiation risk.

Andreasen has discussed the need for multiple radiographic views in the examination of suspected fractured teeth.<sup>72</sup> From an optical point of view, a two-film examination consisting of one standard and one eccentric periapical film, with the tube head rotated and the film in the standard position, of the traumatized tooth usually will demonstrate the presence or absence of a fracture of the root. If a fracture is documented, or if the clinical evidence is not consistent with the radiographic findings, further radiographs may be necessary. For example, if there is clinical evidence that the root apex of a maxillary incisor tooth has been displaced into or through the buccal plate, the lateral view using an extraorally placed periapical or occlusal film has been suggested.<sup>72</sup> However, as this technique does not necessarily demonstrate collimation requirements and as it is an extraoral film, it may violate both federal and state regulations. Alternatives are intraoral placement of dental films in the buccal vestibule or use of an extraoral cassette. If the clinical evidence suggests a root fracture which is not demonstrated on initial radiographic examination, further eccentric periapical films may be indicated.

Fractures of the mandible and midface usually present with compelling historical and/or clinical findings. These patients will generally be treated by an oral surgeon or hospital-based dental service. The diagnostic work-up usually will involve a radiographic examination, thus the most prudent course with such a patient in a private office is referral without radiographs, since any films would most likely be duplicated at the time of treatment at the surgeon's office or in the hospital.

For those practitioners who are involved in the care of facial and mandibular fractures, the following general principles apply to the radiographic examination of such traumatized patients. In the case of suspected

mandibular fractures, right angle views are essential to adequately demonstrate the existence of a fracture and the nature of any displacement. The lateral oblique projection demonstrates the mandibular body and ramus, and the open mouth Towne projection demonstrates the condylar head and neck, while the P-A mandible, right angle mandibular occlusal, and/or submentovertex projections demonstrate the body, ramus and symphysis in right angle projections. There have been recent preliminary studies conducted at the Vanderbilt University Medical Center which suggest that the panoramic projection may be a particularly high yield procedure when used to confirm the presence of a clinically suspected fracture.\* Radiographic examination of fractures of the midface and cranial bones may be complex and dictated by the clinical situation.

*Follow-up of Infection and Trauma.* Radiographs can be effective means of following osseous response to therapy after trauma and/or infection. Keeping in mind the requirement that there must be a 30 percent to 60 percent alteration in the mineral content of the tissue to result in a detectable radiographic change,<sup>73</sup> an adequate time interval should be allowed before taking follow-up films. For example, just as there may be no radiographic evidence of an acute osteomyelitis in an obviously clinically ill patient until three weeks after onset of the disease, a healing mandible with previous widespread chronic osteomyelitis may still present radiographically as seriously diseased for several weeks after positive response to therapy. In order to reduce the number of follow-up films, every effort must be made to duplicate as closely as possible the patient positioning and exposure factors used in the original examination. This, of course, requires thorough quality control and record keeping at all times.

### **Extraoral Curved Surface Panoramic Radiography**

The current popularity and misunderstanding of extraoral panoramic radiology in pedodontic practice requires discussion. Following the introduction of extraoral panoramic machines into the United States in the early 1960s, its supposed virtues of low dose, ease of operation, patient education capabilities, patient comfort, and high diagnostic content were extolled, and there has been subsequent widespread use of this procedure for a variety of clinical situations.<sup>74,75,76,77</sup> It is our contention that although there are specific clinical indications for an extraoral panoramic film, the vast majority of panoramic radiographs taken in the United States today are inappropriate, unnecessary, and potentially inaccurate and confusing. Extraoral

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\*S. J. Gibbs, Department of Radiology, Vanderbilt University, Nashville, Tennessee 37232, personal communication.

panoramic radiology substantially adds to the population radiation burden with little if any concomitant benefit to the patients.

The extraoral panoramic film is a tomogram—an optical slice which intentionally blurs structures in front and in back of the part of the object being examined. Although tomographic units used in medical radiology can be operated in such a way as to finely control the areas being demonstrated or blurred, the panoramic unit produces a film with fixed cut thicknesses and limited flexibility in patient positioning. Variations in patient positions and anatomic configurations result in a lack of precise control over the anatomic areas in focus on the film. Objects in and about the jaws, not in the plane of focus of the cut, may be partially or completely absent in the resultant film. This applies to objects as large as impacted teeth.<sup>78</sup> Additionally, there are inherent distortion artifacts frequently observed in a variety of areas.<sup>79,80,81</sup>

There are several articles dealing with relative dosimetry of panoramic and conventional intraoral radiography, and these studies have explained patient exposures and/or absorbed doses in a variety of ways including: local skin entry dose, total skin entry dose, integral absorbed dose, marrow absorbed dose, thyroid dose, and most recently marrow equivalent dose. In most of these studies, skin and marrow doses from the panoramic films have been lower than a conventional full-mouth intraoral radiographic examination due to the dose reducing quality of film/screen combinations.<sup>82,83</sup> Recent studies have indicated that the use of the new extremely high speed rare earth imaging systems can result in a substantial dose reduction beyond current levels.<sup>84</sup>

It must be remembered that there are centers of rotation in the patient's head which receive greater exposures in extraoral panoramic radiography than in intraoral radiography, most notably thyroid, salivary gland and pharyngeal-lymphoid regions.<sup>85</sup> Recent Monte Carlo dosimetric studies suggest that the increased lifetime cancer risk per million persons for a single panoramic film is quite similar to that from a collimated, 16-22 film full-mouth series.<sup>10,11</sup> The exposure to the thyroid gland is of particular concern in taking panoramic films in the pediatric age group. As discussed earlier, the thyroid gland in children is a particularly sensitive organ to low-level radiation carcinogenesis. Myers *et al.*<sup>82</sup> have recently discussed the necessity of shielding the thyroid gland, especially in children, during panoramic and cephalometric radiographic procedures. In their discussion, they pointed out the more superior anatomic position of this gland in the child, thus placing it closer to the primary beam field than in the adult.

Perhaps the single greatest excess contribution to

the patient radiation exposure from panoramic radiography occurs when suspected positive findings on panoramic films generally require additional plain films\* to be taken. These films are needed to clearly demonstrate and define suspicious positive findings which are poorly shown on the panoramic film due to its inherent distortion. The plain films usually could have been ordered at the outset if a thorough and thoughtful clinical and historical evaluation were obtained, and would have demonstrated the pathology without the need for the panoramic film. Additionally, panoramic artifacts in the midline and molar regions often suggest the presence of pathology and require plain films which reveal nothing more than normal anatomy. The patient has been unnecessarily exposed twice. Artifacts which may be suggestive of cystic or neoplastic disease are lucencies in the mandibular midline, maxillary antral and tuberosity regions and the mandibular molar-ramus region. A more extensive discussion of such artifacts may be found in a recent publication by Reiskin.<sup>81</sup>

The panoramic radiograph is often used as a population screening device. Even if there were a favorable risk-benefit ratio from radiologic screening for serious occult dental disease, the panoramic film would be a poor choice since it neither demonstrates the entire dental and osseous content of the jaws nor possesses adequate sharpness and definition. It is rarely possible to arrive at a secure radiographic diagnosis based on this film alone. Screening for dental disease using a panoramic film is comparable to screening for lung cancer with a random cut tomogram in one plane of the lungs.

There are several reasons cited in the literature for taking panoramic radiographs on children. These include the relative rate of success of the examination, patient comfort, ease and speed of the examination, and the usefulness of the film as a patient education aid.<sup>62,75,77,86</sup> Clearly, these reasons for taking panoramic films are not related to the clinical needs of the patient. They do not contribute appreciably to anything but the convenience of the dentist and the radiation exposure of the patient. Although one could argue that the higher yield of diagnostic quality films is valid, this shows a lack of adequate technique in performing conventional high yield radiologic examinations, since techniques are available to do so.

While the majority of pediatric panoramic examinations appear to be inappropriate and unnecessary, there are certainly indications for the taking of such films. They are particularly useful for patients in

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\*"Plain films" are films in which all structures between the radiation source and the film appear in focus on the film. All intraoral films are plain films.

whom conventional radiology cannot be performed. Such patients would include: those in intermaxillary fixation; some post-trauma patients; patients who are not able to tolerate films or instruments in their mouths; and perhaps, those with suspected mandibular fractures. As with all other forms of tomography, the panoramic projection is a specialized examination which has a place in clinical dentistry when well defined clinical criteria and judicious use result in a favorable risk-benefit ratio.

### Techniques for Minimizing Patient Exposure

Thus far, we have discussed the rationale for decision making in pedodontic radiology based on consideration of the individual needs of each patient. This is the manner in which the greatest reduction in the pediatric population radiation exposure in dentistry can be accomplished.

The means of reducing the radiation dose to the absolute minimum is through the use of state-of-the-art technique and equipment. Bengtsson in a recent review of maxillofacial aspects of radiation protection discussed the strong influence of technical factors on the radiation dose to the patient.<sup>10</sup> He stated that examiners not particularly interested in the radiation dose easily give more than twice the dose given by examiners strongly interested in patient radiation protection.

There are numerous publications in the dental literature which discuss radiological techniques and equipment for use in pedodontics which will result in significant patient dose reduction.<sup>87,88,89,90,91</sup> We shall limit our discussion to a brief review of these techniques and consideration of beam-guiding, field-size-limiting, film-holding devices.

1. *Variable voltage equipment* allows the use of the highest possible kVp for the desired clinical result, thus reducing the exposure of the skin and superficial structures. A recently developed alternative to the variable kilovoltage machine is the fixed 70 kVp machine with samarium filtration and small focal spot size which permits higher contrast radiology than 80 to 90 kVp units while delivering a significantly reduced radiation dose to the patient.<sup>81</sup>

2. *Fast speed film* (speed group "D") combined with high milliamperage machines allow the minimal exposure time with a reduction in exposure and motion distortion.

3. *Wrap-around leaded aprons and thyroid shields* substantially reduce exposures to critical body sites and alleviate patient concern regarding gonadal exposure.

4. *Optimal processing chemistry* eliminates the need for overexposing and underdeveloping films which

only adds to the patient's radiation burden and results in poor film quality.

5. A *daily quality assurance program* for optimal machine and processing chemistry performance should be instituted in every pedodontic office. Deterioration of machine or chemistry performance can result in increased patient exposure in a variety of ways.

6. *Use of double film packs* allows an original radiographic record to be sent to another practitioner while permitting an identical set to be maintained in the office and provides insurance against loss of one set.

7. *The use of beam-guiding, field-size-limiting, film-holding instruments* for intraoral radiology is probably the most significant advantage in patient dose reduction, film quality improvement, and attainment of consistently successful films in recent decades. Federal regulations state that for medical diagnostic radiology, the beam size must not exceed the receptor size. Although intraoral dental radiology is not included in these regulations, the technology to restrict the incident beam to the size of the film is readily available in the market. Such devices have been shown to dramatically reduce radiation doses to marrow, thyroid, and other tissues outside of the area being examined.<sup>92</sup> This is accomplished not only by restricting the beam size to that of the receptor but by the incorporation of a metal shield behind the X-ray films, on some of these devices, which absorbs that part of the primary beam passing through the film packet. Additionally, such devices improve film quality by reducing incident scatter and maximizing projection geometric relationships between teeth, alveolar bone, and the primary beam.<sup>92</sup> These devices reduce the number of retakes by allowing precise positioning of the films and permit sequential films of the same area to be taken using the same projection geometry throughout the prolonged treatment period. Every pedodontist should have such instruments in his or her office.

### Summary

The risk of cancer induction in children by exposure to low-level X-radiation demands the thoughtful use of diagnostic radiology in pedodontics. The possible relationships between decreasing radiation dose and cancer induction are discussed, and human, animal and cell culture studies of radiation carcinogenesis and malignant transformation are presented to clarify and explore these low-level radiation risk concepts.

The concept of high yield criteria to determine the need for radiographs is presented and the applications of such criteria to pediatric patients with caries, trauma, infection, third molar and congenital abnormalities are discussed. Screening and panoramic radio-



graphic examinations are also considered. Techniques for reducing patient exposures to an absolute minimum are presented.

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