Policy Statement on Thyroid Shielding During Diagnostic Medical and Dental Radiology

2013

American Thyroid Association

TABLE OF CONTENTS

EXECUTIVE SUMMARY 3

I. INTRODUCTION 5

II. MAMMOGRAPHY 7

III. CT SCANS AND OTHER DIAGNOSTIC RADIOGRAPHIC PROCEDURES 8

IV. DIAGNOSTIC DENTAL RADIOLOGY 10

V. SUPPLEMENTARY AND TECHNICAL MATERIAL 12

General Considerations 12

Dosimetry Related to Mammography and Measures to Protect the Thyroid 12

CT Scans and Other Diagnostic Radiographic Procedures 12

Diagnostic Dental Radiology 13

REFERENCES 17

Executive Summary

The thyroid, a small butterfly-shaped gland that impacts almost all of the body's metabolic processes, is among the most susceptible sites to radiation-induced cancer. The Incidence of cancer of the thyroid gland is increasing around the world. In the United States in particular, it is increasing faster than any other cancer, with more than 56,000 people likely to be diagnosed with thyroid cancer in 2012 alone (1).

Although the amount of radiation exposure from diagnostic radiology in the U.S. and elsewhere has been increasing dramatically, it is unlikely that radiation exposure is the predominant contributor to this trend. In a 2005 American Thyroid Association (ATA) brochure about thyroid cancer, the ATA states: "Routine X-ray exposure (e.g., dental X-rays, chest X-rays, mammograms) does not cause thyroid cancer." While scientific knowledge at the time supported this language for the one-time use of the modalities cited, the statement did not take into account repeated exposure over one's lifetime and, especially, the increasing use of computed tomography (CT), where the doses to the thyroid are larger.

In 2011 the ATA initiated a review of how to reduce the radiation dose to the thyroid during diagnostic radiography, with the aim of establishing a policy that would state its view on how the exposure of the thyroid to radiation should be minimized. The ATA's "Policy Statement on Thyroid Shielding During Diagnostic Medical and Dental Radiology" is the culmination of this effort.

The ATA's "Policy Statement" issues several key considerations based on a review of the literature.

1. The risk of thyroid cancer arising from radiation exposure is strongly dependent on age at exposure. This risk is greatest in children, increasing dramatically as the child's age at exposure decreases.

2. Risk of thyroid cancer for adults exposed to radiation is low, but not absent. It is only recently that a risk for exposure after the age of 15 has been observed.

3. Among children, the risk of thyroid cancer resulting from radiation exposure is reduced proportionately with the dose of radiation received, although this relationship may not continue down to the lowest doses.

In addition, the ATA's "Policy Statement" puts forth six key recommendations:

1. The ATA recommends that the necessity of all diagnostic x-rays be evaluated before they are performed. This must include the potential risks as well as the potential benefits to the patient. This must also include a consideration of the alternative methods for obtaining the same or related clinical information.

2. The ATA recommends that the patient or the patient's decision-maker are made aware of the potential risks and benefits to any diagnostic procedure in a manner that is understandable to them.

3. The ATA recommends that clinicians are adequately informed about the potential risks of radiation and the general principles of radiation dosimetry, especially as they relate to children and to the thyroid.

4. With regards to mammography, the ATA does not recommend thyroid shields for mammography due to a lack of data to substantiate their use and the extremely low amount of radiation that reaches the thyroid. Furthermore, any risk to the thyroid is much lower than the benefit of mammography.

5. With regards to CT scans and other diagnostic radiographies, the ATA recommends the use of thyroid shields when possible to protect the thyroid. These procedures may involve clinically relevant radiation doses to the thyroid, especially when more than one examination is performed, and the goal is to reduce thyroid exposure as much as feasible.

6. With regards to dental x-rays, the ATA recommends the reduction of thyroidal radiation exposure as much as possible without compromising the clinical goals of dental examinations. The ATA thus endorses the recommendations of the National Council on Radiation Protection & Measurements (NCRP) Report 145, Radiation Protection in Dentistry, 2003 (2). However, it urges a reconsideration of the less stringent requirement put forth for thyroid shielding in adults as compared to children. The ATA also recommends that efforts be made to encourage and monitor compliance with the American Dental Association (ADA) and NCRP guidelines and to reduce, as much as possible, the areas of ambiguity in them.

I. Introduction

The thyroid, a small butterfly-shaped gland that impacts almost all of the body's metabolic processes, is among the most susceptible sites to radiation-induced carcinogenesis. Risks of radiation exposure are thus of special concern to the American Thyroid Association (ATA).

The risk of thyroid cancer arising from radiation exposure is strongly dependent on age at exposure. This risk is greatest in children, increasing dramatically as the child's age at exposure decreases. Risk of thyroid cancer for adults exposed to radiation is low, but not absent. It is only recently that a risk for exposure after the age of 15 has been observed (3-5). Among children, the risk of thyroid cancer resulting from radiation exposure is reduced proportionately with the dose of radiation received, although this relationship may not continue down to the lowest doses. (6).

Thyroid cancer incidence is increasing throughout the world. In the U.S. in particular, it is increasing faster than any other cancer, with more than 56,000 people diagnosed with thyroid cancer in 2012 alone (1). Although it is unlikely that radiation exposure is the predominant contributor to this trend, an increase in the use of diagnostic x-rays, particularly computed tomography (CT), is widespread and necessitates the protection of the thyroid gland where possible to diminish thyroid cancer risk (7,8).

The ATA's key considerations are:

1. The risk of thyroid cancer arising from radiation exposure is strongly dependent on age at exposure. This risk is greatest in children, increasing dramatically as the child's age at exposure decreases.

2. Risk of thyroid cancer for adults exposed to radiation is low, but not absent. It is only recently that a risk for exposure after the age of 15 has been observed.

3. Among children and adults alike, the risk of thyroid cancer resulting from radiation exposure is reduced proportionately with the dose of radiation received.

In addition, the ATA makes six key recommendations:

1. The ATA recommends that the necessity of all diagnostic x-rays be evaluated before they are performed. This must include the potential risks as well as the potential benefits to the patient. This must also include a consideration of the alternative methods for obtaining the same or related clinical information.

2. The ATA recommends that the patient or the patient's decision-maker is made aware of the potential risks and benefits to any diagnostic procedure in a manner that is understandable to them.

3. The ATA recommends that clinicians are adequately informed about the potential risks of radiation and the general principles of radiation dosimetry, especially as they relate to children and to the thyroid.

4. With regards to mammography, the ATA does not recommend thyroid shields for mammography due to a lack of data to substantiate their use and the extremely low amount of radiation that reaches the thyroid. Furthermore, any risk to the thyroid is much lower than the benefit of mammography.

5. With regards to CT scans and other diagnostic radiographies, the ATA recommends the use of thyroid shields when possible to protect the thyroid. These procedures may involve clinically relevant radiation doses to the thyroid, especially when more than one examination is performed, and the goal is to reduce thyroid exposure as much as feasible.

6. With regards to dental x-rays, the ATA recommends the reduction of thyroidal radiation exposure as much as possible without compromising the clinical goals of dental examinations. The ATA thus endorses the recommendations of the National Council on Radiation Protection & Measurements (NCRP) Report 145, Radiation Protection in Dentistry, 2003 (2). However, it urges a reconsideration of the less stringent requirement put forth for thyroid shielding in adults as compared to children. The ATA also recommends that efforts be made to encourage and monitor compliance with the American Dental Association (ADA) and NCRP guidelines and to reduce, as much as possible, the areas of ambiguity in them.

These considerations and recommendations are supported in the sections to follow.

II. MAMMOGRAPHY

Mammography is used primarily in adult women for the early detection of breast cancer. The U.S. Preventive Services Task Force (USPSTF) recommends yearly mammograms starting at age 50 and continuing for as long as a woman is in good health. Mammography is also used, though much less frequently, as a diagnostic and screening tool in younger woman and in men. Mammography is never used in children.

Epidemiology

To date, no epidemiologic studies have been reported that investigate an association between mammography use and an increased risk of thyroid cancer. Given the small radiation dose to the thyroid likely to result from mammographic examinations, it is unlikely that a large enough study could be performed to confirm or exclude an association between mammography and thyroid cancer. Further, the dose is so small, that it would be exceedingly difficult to separate from other sources of radiation exposure to the thyroid.

Risk-Benefit Relationship

It is unknown whether mammography poses a risk to thyroid cancer. However, if indeed a risk exists, it is extremely low—much lower than the benefit of mammography. With respect to the risk-benefit relationship for using a thyroid collar during mammography, a statement by the American College of Radiology and the Society of Breast Imaging indicates that a thyroid collar could reduce the quality of the mammography images and result in "artifacts" (9). However, no data are given to substantiate or quantify this concern. Given the small dose to the thyroid, even if the collar further reduced this risk, the risk of a false-positive (including, but not limited to, the possible need to repeat the examination, anxiety, and additional unneeded tests, such as biopsies) would outweigh the benefit.

Guidelines and Statements from Professional Organizations and Regulatory Bodies

A joint statement by the American College of Radiology and the Society of Breast Imaging concluded that "…use of a thyroid shield during mammography is *not* [emphasis is in the original statement] recommended" (9).

ATA Conclusions

Data available at this time do not support the use of thyroid shields for mammography.

III. CT SCANS AND OTHER DIAGNOSTIC RADIOGRAPHIC PROCEDURES

Computed tomography (CT) scans and other diagnostic radiographs may be used to examine a variety of sites and for a wide variety of diagnostic indications.

Epidemiology

The use of CT scans and other diagnostic radiographic procedures has increased dramatically over the last several decades. In 2006, 377 million diagnostic and interventional radiologic examinations and 18 million nuclear medicine examinations were performed, representing a 10-fold increase since 1950 (10). A recent study demonstrated that the use of CT scans in emergency departments increased more than three-fold just between 1996 and 2007 (11), with approximately 72 million CT scans performed in the U.S. in 2007 (12). No epidemiologic studies to date have specifically examined associations between exposures to CT and other non-dental radiographic procedures and thyroid cancer.

Risk-Benefit Relationship

CT scans and other radiographic studies are of concern as a potential risk for thyroid cancer. CT scans typically employ much higher radiation doses than conventional X-ray, although thyroid radiation doses vary widely across different types of studies. They may be employed in individuals of any age, including children. However, when used appropriately, CT scans and other radiographic studies are of unquestionable benefit.

Guidelines and Statements from Professional Organizations and Regulatory Bodies

Adoption of the ALARA (As Low as Reasonably Attainable) principle, which is the basis for radiation protection, is critically important. The consortium of professional associations supporting the "Image Gently" campaign have as their goal the elimination of unnecessary radiation exposure in the practice of radiology, especially in children (13).

It is difficult to identify every instance where the thyroid gland is exposed to radiation in medical practice and prescribe exact methods to reduce the magnitude of the thyroid cancer risk. The following lists principles toward this end combining recommendations from the Image Gently Campaign and a recent review article (7, 13, 14):

Methods of reducing thyroid radiation exposure in children include:

- Use instrument adjustments specific for children. Scan only the indicated region.
- Scan once: multiphase scanning is usually not necessary in children. Scanning with and without contrast increases the dose two to three-fold, but rarely adds to the diagnostic information.
- Avoid overlapping fields, if possible, especially when cervical spine and chest CT scans are performed together
- Protect the thyroid from exposure with shielding, when possible.

- Institute policies, both procedural and educational, among radiologists and radiology departments to institute the above.
- Scan only when necessary. Increase the awareness of practicing pediatricians about the risks and benefits of radiological procedures and how to reduce the former without compromising the latter.
- Institute methods to explain the risk and benefits to patients in an accurate and understandable way.

ATA Conclusions

CT scans and other diagnostic radiographic procedures may involve clinically relevant radiation doses to the thyroid, and the goal is to reduce thyroid exposure as much as feasible. The thyroid should be protected from exposure with shielding when possible.

IV. DIAGNOSTIC DENTAL RADIOLOGY

Dental radiographs may be used to examine a variety of sites in the maxillofacial and cervical area and for a variety of diagnostic indications. Images may be captured on direct-exposure film, screen film, or digital receptors. A wide variety of instruments are used including conventional x-ray machines, panoramic scanners, and cone-beam computed tomography (CT) scanners (2).

Epidemiology

In 2006, there were 500 million bite-wing and full mouth survey images and 2.6 million panoramic and cephalometric procedures (15), representing the source of 2.5% of the total effective radiation dose from conventional radiographs and fluoroscopies in the U.S. in that year. In addition, between 1992 and 2006, the number of patients in the U.S. who underwent orthodontic therapy (i.e. typically requiring dental x-rays, and in some cases requiring dental CT scans) increased from 1.0 million to 1.6 million (16).

Attempts to study whether diagnostic dental x-rays are associated with risk of thyroid cancer based on self-reported information may be affected by selective recall. In case-control studies, people with cancer may be more likely to report prior dental x-rays than people with no cancer. No study to date has unequivocally established a relationship between x-ray exposure from dental radiography and the incidence of thyroid cancer, though the lack of documentation does not preclude the possibility of an actual risk. Although large epidemiologic studies of diagnostic x-rays in the future may be able to detect an associated risk for thyroid cancer, given the very low thyroid doses involved it is unlikely that a study could detect a risk isolated to dental x-rays.

Risk-Benefit Relationship

Three factors make dental x-rays a concern as a potential risk for thyroid cancer. First, in contrast to mammograms, they are used routinely in children and also in the treatment of prevalent dental conditions in children. Second, as noted above, the thyroid gland in children is especially sensitive to the effects of radiation. Third, a child's thyroid gland is closer to the target of the dental x-ray. There is little doubt that, when used appropriately, dental x-rays are of benefit.

Guidelines and Statements from Professional Organizations and Regulatory Bodies

Among the published guidelines about the practice of dental radiology, the NCRP Report No. 145 "Radiation Protection in Dentistry" is the most comprehensive and influential in the U.S. With respect to the thyroid, its key conclusion is as follows (2):

> "Thyroid shielding shall be provided for children, and should be provided for adults, when it will not interfere with the examination."

Ambiguity arises in this statement from the phrase "…when it will not interfere with the examination" (17). In addition, the rationale for distinguishing the recommendation for children and adults is not explicitly stated. Other guidelines are cited in the supplementary material.

ATA Conclusions

Although the thyroid doses associated with dental x-rays have not been shown to cause thyroid cancer, it is prudent to reduce thyroidal radiation exposure as much as possible without compromising the clinical goals of dental examinations. The ATA thus endorses the recommendations of NCRP-145. However, the ATA also urges a reconsideration of the less stringent requirement for thyroid shielding in adults as compared to children. Adult risk for radiation-induce thyroid cancer may be less, but still merits efforts to reduce it, given that the use of shielding is safe and readily available. The ATA also recommends that efforts be made to encourage and monitor compliance with the ADA and NCRP guidelines and to reduce, as much as possible, the areas of ambiguity in them.

V. SUPPLEMENTARY AND TECHNICAL MATERIAL

In this report mGy (milliGrays) is used as the measure of thyroid radiation dose. In many studies, doses are normalized for the entire body according to a procedure in which both the type of radiation and the radiosensitivities of the organs are taken into account, so a variety of different doses can be compared (e.g., a flight from New York to Paris with a dental x-ray examination), and are given at mSv (milliSieverts).

General Considerations

Until recently it was uncertain whether there is a risk for thyroid cancer after radiation exposure occurring after age 15. The risk for exposure after age 15 has now been reported in studies of survivors of the atomic bomb and in Chernobyl liquidator workers (4,5). The risk, if it confirmed, is clearly much smaller than for children, and it can be anticipated that further work will aim to confirm and substantiate the presence, magnitude and modifying factors of the thyroid cancer risk for adult exposure.

Epidemiologic evidence has provided strong evidence that thyroid doses as low as 100 mGy are associated with increased risk of thyroid cancer (18). Additional evidence extends this to about 50 mGy (19). For the purposes of public health planning, most experts and organizations assume that below 50 mGy the risks are reduced proportionately with the dose, but there is no direct evidence in this dose range (6).

Dosimetry Related to Mammography and Measures to Protect the Thyroid

Screen-film and digital mammography are widely used. The reported doses to the breasts for conventional two-views are 4.7 mGy for the former and 3.7 mGy for the latter. According to the American College of Radiology and the Society of Breast Imaging, the dose to the thyroid from mammogram consisting of two views of each breast could range up to 0.005 mGy (9), with the cumulative dose over 40 years of annual mammographic screening thus ranging up to 0.2 mGy. A further description of the data obtained by Sechopoulos et al., focusing on the potential thyroid dose from mammography, has been published (20). Based on the projected doses and generally accepted age-dependent risk coefficients (6), the authors estimate that annual screening mammograms from age 40 to 80 would increase the life-time risk of thyroid cancer by 1 in 17.8 million women. They also provide an example of a mammography examination where a thyroid collar results in a suboptimum image.

CT Scans and Other Diagnostic Radiographic Procedures

Clinically relevant doses of radiation can be involved in computed tomography scans, highlighting the importance of the ATA goal to reduce them. For example, in the emergency evaluation of patients injured by blunt trauma, CT is frequently used. One survey returned by 41 physician members of the American Society of Emergency Radiology indicated that most respondents (83%) overlapped study margins in the area of the thyroid when cervical spine and chest CT were obtained together (21). Another study of 197 pediatric blunt trauma patients, using dosimeters placed over the thyroid gland, found that 71% (141 patients) of thyroid glands had doses in the range of 10-90 mGy and 19% (38 patients) had doses greater than 50 mGy (22).

Diagnostic Dental Radiology

Epidemiology Studies

Studies from Los Angeles County suggest that epidemiologic methods could be used to identify the risk of cancer from dental x-rays. For example, a case-control study of 408 patients with benign (269) and malignant (139) parotid gland tumors and 408 neighborhood controls found an association between cancer and both cumulative radiation exposure and exposure before age 20 from full-mouth and panoramic dental x-ray examinations. Recognizing the possibility of selective recall in a study of this kind, the authors verified the dental records of a subset of the cases and controls. Thyroid cancer was not part of this study and it is likely that the doses for the examinations included in this study have decreased with technological advances (23, 24).

In Kuwait, 313 thyroid cancer cases were matched to an equal number of controls. Personal interviews were conducted and the consistency of the interviews (as opposed to the validity) was confirmed by follow-up phone interviews in a subset of the participants. Any dental x-ray versus no dental x-rays were associated with significantly increased risk of thyroid cancer (OR 2.1, 95% CI 1.4-3.1). Also, the number of dental x-rays reported was significantly associated with thyroid cancer (25). This study should be considered inconclusive. First, it depended completely on self-reporting of diagnostic x-rays, which is subject to recall bias. Second, the number of dental x-ray procedures was used as a surrogate for dose; cumulative doses to the thyroid in this study are not known. Third, other sources of radiation exposure were also obtained by self-reporting and were adjusted for; however, the procedure used to perform this adjustment was not described.

The potential for recall bias in case-control studies of diagnostic x-ray exposure has been carefully documented in two studies, one in Sweden and one in the U.S. and Sweden (26, 27). Studies in both countries found substantial lack of agreement between interview and medical records and potential evidence of bias, although largely non-differential.

Dosimetry and Measures to Protect the Thyroid

Radiation doses to the thyroid vary based on procedure (28).

- For a molar bitewing x-ray the estimated thyroid doses at ages 12 and 21 are 0.035 mGy and 0.032 mGy, respectively (28).
- The thyroid doses were 0.014-0.027 mGy and 0.035-0.054 mGy for the pediatric settings and 0.031-0.062 mGy and 0.037-0.049 mGy for adult settings for two digital panoramic systems (29). The thyroid dose was reduced by about 50% using pediatric settings for one type of unit, but not for the other. For digital panoramic dental x-rays, five units from different manufacturers resulted in the following doses to the thyroid: 0.029 mGy, 0.052 mGy, 0.025 mGy, 0.35.9 mGy and 0.010 mGy (30). Importantly, digital radiography has been noted for its potential to reduce radiation exposure. Appendix E, page 88 of NCRP Report 145 (2) states: “Sensitivity of digital receptors to x-radiation may result in exposure reductions greater than 50 percent compared to E-speed film. In many systems, however, the active area of the receptor is smaller than conventional film. Thus, more exposures may be required to image a specified region. In addition, most CCD receptors are thicker than conventional film, which may make intraoral positioning difficult and result in more retakes.”

- Cone beam CTs results in lower radiation exposure than conventional CT imaging. With three dental CBCT units, Ludlow et al. estimated thyroid doses for adults as 0.33 mGy, 0.77 mGy and 6.3 mGy (31). Noting that these doses are higher than for panoramic x-rays, the authors state that CBCT should not be used when panoramic x-rays would suffice. Theodorakou et al. estimated average thyroid doses for five different CBCT units of about 0.2 mGy for adolescents and 0.7 mGy for 10 year olds (32).
- There has been an increasing use of CT to image the lower third molars. Using an adult phantom, Ohman et al. estimate the dose to the thyroid as 1.5 mGy (33).
- At the University of Washington, before 1992 during one episode of orthodontic care the thyroid radiation dose was approximately 7 mGy, whereas after 1992 the average dose had decreased to 2.8 mGy (28).

In a survey of U.S. dental school practices published in 2002, only 48% usage of thyroid shields was reported (34).

Guidelines and Statements from Professional Organizations and Regulatory Bodies

There is generalized, but not complete, agreement about the use of thyroid shields among several comprehensive guidelines about the practice of dental radiology. The following are the relevant statements from each of these guidelines.

NCRP Report No. 145 "Radiation Protection in Dentistry" (2):

> 3.1 Protection of the Patient
> 1.1.9 Thyroid Collars
>
> "The thyroid gland, especially in children, is among the most sensitive organs to radiation-induced tumors, both benign and malignant (Appendix B). Even with optimum techniques, the primary dental x-ray beam may still pass near and occasionally through the gland. If the x-ray beam is properly collimated to the size of the image receptor or area of clinical interest, and exposure of the gland is still unavoidable, any attempt to shield the gland would interfere with the production of a clinically-useful image. However, in those occasional uncooperative patients for whom rectangular collimation and positive beam-receptor alignment cannot be achieved for intraoral radiographs, then thyroid shielding may reduce dose to the gland without interfering with image production (NRPB, 2001). Thyroid shielding *shall* (emphasis added) be provided for children, and *should* (emphasis added) be provided for adults, when it will not interfere with the examination."

The American Dental Association's 2006 publication "The Use of Dental Radiographs: Update and Recommendations" cites the NCRP report No.145 with respect to shielding the thyroid (35). Among its recommendations are:

> "Thyroid shielding with a leaded thyroid shield or collar is strongly recommended for children and pregnant women, as these patients may be especially susceptible to radiation effects."

Another recommendation in this publication is the use of panoramic radiographs for most new patients. The 2001 American Dental Association Council on Scientific Affairs guidelines state (36):

> "[Thyroid] collars should not be used with panoramic radiographs because they interfere with the primary beam."

A 2012 letter from the ADA responding to a query from the ATA states:

> "Regarding panoramic radiographic examinations...or other extra-oral imaging, the ADA recommendation 'whenever possible' applies. In most, if not all cases, use of the thyroid collar in these tests may obscure capturing some desired anatomical structures."

The European Commission guidelines on dental x-ray state [references in the original omitted] (37):

> 4.5.2 Thyroid Collar
>
> "The thyroid gland is one of the more radiosensitive organs in the head and neck region. It is frequently exposed to scattered radiation and occasionally to primary beam during dental radiography. Because people under age 30 are at greater risk of radiation induced thyroid cancer than older individuals, some have argued that thyroid collars should be used when intraoral radiographic examinations are made on this population. However, it is probable that rectangular collimation for intraoral radiography offers similar level of thyroid protection to lead shielding, in addition to its other dose reducing effects. Thyroid shielding is inappropriate for panoramic radiography as it may interfere with the primary beam. In cephalometric radiography lead thyroid protection is necessary if the beam collimation does not exclude the thyroid gland. Thyroid shielding was found to reduce radiation doses of 45% during CT of the head and is strongly recommended, especially in younger age groups."
>
> Recommendation 4 L
>
> "Lead shielding of the thyroid gland should be used in those cases where the thyroid is in line of, or very close to, the primary beam. [Level C Non-analytic studies (e.g. case reports, case series or cross-sectional surveys) or laboratory studies with risk of bias/experimental error, or expert opinion/non-systematic review article.] "

The National Radiological Protection Board's 2001 Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment from the United Kingdom reached a conclusion that differs from those above (38):

3.46: Protective Clothing

"There is no justification for the routine use of lead aprons for patients in dental radiography. Thyroid collars should be used in those few cases where the thyroid may be in the primary beam, based on advice from an MPE [Medical Physics Expert]. Lead aprons do not protect against radiation scattered internally within the body, and only provide a practicable degree of protection in the case of the infrequently used vertex occlusal projection. Even in this case, the use of the lead apron could only be regarded as prudent for a female patient who is, or may be, pregnant..."

References

1. National Cancer Institute. “Thyroid Cancer.” Cancer.gov. Accessed 6/6/12. http://www.cancer.gov/cancertopics/types/thyroid

2. National Council on Radiation Protection and Measurement 2003 Radiation Protection in Dentistry. NCRP Report No. 145, National Council on Radiation Protection and Measurement, Bethesda, MD.

3. Cardis E, Hatch M. 2011. The Chernobyl Accident - An Epidemiological Perspective. Clin Oncol (R Coll Radiol) 23:251-260.

4. Risk of Thyroid Cancer among Chernobyl Liquidators. Kesminiene A, Evrard AS, Ivanov VK, Malakhova IV, Kurtinaitise J, Stengrevics A, Tekkel M, Chekin S, Drozdovitch V, Gavrilin Y, Golovanov I, Kryuchkov VP, Maceika E, Mirkhaidarov AK, Polyakov S, Tenet V, Tukov AR, Byrnes G, Cardis E. Radiat Res. 2012 Nov;178(5):425-36.

5. Richardson DB. 2009. Exposure to Ionizing Radiation in Adulthood and Thyroid Cancer Incidence. Epidemiology 20:181-187.

6. National Research Council 2006 Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2, National Academy Press, Washington, D.C.

7. Sinnott B, Ron E, Schneider AB. 2010. Exposing the Thyroid to Radiation: A Review of its Current Extent, Risks, and Implications. Endocr Rev 31:756-773.

8. Schonfeld SJ, Lee C, Berrington DG. 2011. Medical Exposure to Radiation and Thyroid Cancer. Clin Oncol (R Coll Radiol) 23:244-250.

9. American College of Radiology and Society of Breast Imaging. “The ACR and Society of Breast Imaging Statement on Radiation Received to the Thyroid from Mammography.” (2011). Accessed 6/6/12. http://www.acr.org/~/media/ACR/Documents/PDF/QualitySafety/Resources/Breast%20Imaging/ThyroidStatement.pdf

10. Mettler FA Jr, Bhargavan M, Faulkner K, et al. 2009. Radiologic and Nuclear Medicine Studies in the United States and Worldwide: Frequency, Radiation Dose, and Comparison with Other Radiation Sources—1950-2007. Radiolog; 253(2):520–531.

11. Kocher KE, Meurer WJ, Fazel R, Scott PA, Krumholz HM, Nallamothu BK. 2011. National Trends in Use of Computed Tomography in the Emergency Department. Ann Emerg Med 58(5):452-62.e3.

12. Berrington de González A, Mahesh M, Kim KP, et al. 2009. Projected Cancer Risks from Computed Tomographic Scans Performed in the United States in 2007. Arch Intern Med 169: 2071–2077.

13. The Alliance for Radiation Safety and Pediatric Imaging. "How to Develop CT Protocols for Children. Pedrad.org, Accessed 6/6/12. http://www.pedrad.org/associations/5364/files/Protocols.pdf

14. Goske MJ, Applegate KE, Boylan J, Butler PF, Callahan MJ, Coley BD, Farley S, Frush DP, Hernanz-Schulman M, Jaramillo D, Johnson ND, Kaste SC, Morrison G, Strauss KJ, Tuggle N. 2008. The Image Gently Campaign: Working Together to Change Practice. AJR Am J Roentgenol 190:273-274.

15. National Council on Radiation Protection and Measurement 2009 Ionizing Radiation Exposure of the Population of the United States. Report No. 160, National Council on Radiation Protection and Measurement, Bethesda, MD.

16. Bollen AM, Cunha-Cruz J, Hujoel PP. 2007 Secular Trends in Preadult Orthodontic Care in the United States: 1942-2002. Am J Orthod Dentofacial Orthop 132:579-585.

17. Hujoel P, Hollender L, Bollen AM, Young JD, Cunha-Cruz J, McGee M, Grosso. A 2006 Thyroid Shields and Neck Exposures in Cephalometric Radiography. BMC Med Imaging 6:6.

18. Ron E, Lubin JH, Shore RE, Mabuchi K, Modan B, Pottern LM, Schneider AB, Tucker MA, Boice JD, Jr. 1995. Thyroid Cancer After Exposure to External Radiation: A Pooled Analysis of Seven Studies. Radiat Res 141:259-277.

19. Sadetzki S, Chetrit A, Lubina A, Stovall M, Novikov I 2006 Risk of thyroid cancer after childhood exposure to ionizing radiation for tinea capitis. J Clin Endocrinol Metab 91:4798-4804.

20. Sechopoulos I, Hendrick RE 2012 Mammography and the risk of thyroid cancer. AJR Am J Roentgenol 198:705-707.

21. Baker SR, Hsieh YH, Maldjian PD, Scanlan MT. 2009. Inadvertent Thyroid Irradiation in Protocol-Driven Trauma CT: A Survey of Hospital ERs. Emerg Radiol 16:203-207.

22. Mueller DL, Hatab M, Al Senan R, Cohn SM, Corneille MG, Dent DL, Michalek JE, Myers JG, Wolf SE, Stewart RM. 2011. Pediatric Radiation Exposure During the Initial Evaluation for Blunt Trauma. J Trauma 70:724-731.

23. Preston-Martin S, Henderson BE, Bernstein L. 1985. Medical and Dental X-Rays as Risk Factors for Recently Diagnosed Tumors of the Head. Natl Cancer Inst Monogr 69:175-179.

24. Preston-Martin S, Thomas DC, White SC, Cohen D. 1988. Prior Exposure to Medical and Dental X-Rays Related to Tumors of the Parotid Gland. J Natl Cancer Inst 80:943-949.

25. Memon A, Godward S, Williams D, Siddique I, Al Saleh K. 2010. Dental X-Rays and the Risk of Thyroid Cancer: A Case-Control Study. Acta Oncol 49:447-453.

26. Berrington DG, Ekbom A, Glass AG, Galanti MR, Grimelius L, Allison MJ, Inskip PD. 2003. Comparison of Documented and Recalled Histories of Exposure to Diagnostic X-Rays in Case-Control Studies of Thyroid Cancer. Am J Epidemiol 157:652-663.

27. Hallquist A, Jansson P. 2005. Self-Reported Diagnostic X-Ray Investigation and Data from Medical Records in Case-Control Studies on Thyroid Cancer: Evidence of Recall Bias? Eur J Cancer Prev 14:271-276.

28. Hujoel P, Hollender L, Bollen AM, Young JD, McGee M, Grosso A. 2008. Head-and-Neck Organ Doses from an Episode of Orthodontic Care. Am J Orthod Dentofacial Orthop 133:210-217.

29. Hayakawa Y, Kobayashi N, Kuroyanagi K, Nishizawa K. 2001. Paediatric Absorbed Doses from Rotational Panoramic Radiography. Dentomaxillofac Radiol 30:285-292.

30. Gijbels F, Jacobs R, Bogaerts R, Debaveye D, Verlinden S, Sanderink G 2005 Dosimetry of digital panoramic imaging. Part I: Patient exposure. Dentomaxillofac Radiol 34:145-149.

31. Ludlow JB, Davies-Ludlow LE, Brooks SL, Howerton WB. 2006. Dosimetry of 3 CBCT Devices for Oral and Maxillofacial Radiology: CB Mercuray, NewTom 3G and I-CAT. Dentomaxillofac Radiol 35:219-226.

32. Theodorakou C, Walker A, Horner K, Pauwels R, Bogaerts R, Jacobs DR. 2012. Estimation of Paediatric Organ and Effective Doses from Dental Cone Beam CT Using Anthropomorphic Phantoms. Br J Radiol 85:153-160.

33. Ohman A, Kull L, Andersson J, Flygare L. 2008. Radiation Doses in Examination of Lower Third Molars with Computed Tomography and Conventional Radiography. Dentomaxillofac Radiol 37:445-452.

34. Geist JR, Katz JO. 2002. Radiation Dose-Reduction Techniques in North American Dental Schools. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 93:496-505.

35. America Dental Association Council on Scientific Affairs. 2006. The Use of Dental Radiographs - Update and Recommendations. Journal of the American Dental Association 137:1304-1312.

36. ADA Council on Scientific Affairs. 2001. An Update on radiographic Practices: Information and recommendations. ADA Council on Scientific Affairs. J Am Dent Assoc 132:234-238.

37. European Commission. 2004. European Guidelines on Radiation Protection: The Safe Use of Radiographs in Dental Practice, Office for Official Publications of the European Communities, Luxembourg, Netherlands.

38. National Radiological Protection Board. 2001 Guidance Notes for Dental Practitioners on the Safe Use of X-Ray Equipment. Department of Health, England.