No. 2

Protection of patients in x-ray diagnostics

Shielding of gonads

No. 2

Protection of patients in x-ray diagnostics

Shielding of gonads

The radiation protection and nuclear safety authorities in
Denmark, Finland, Iceland, Norway and Sweden

Summary :   This publication describes the Code of Practice for gonad shielding in X-ray diagnostics.
                   The intention is to achieve protection of the patient and common routines in Nordic
                   health institutions.

TABLE OF CONTENTS

I. INTRODUCTION.

It is generally assumed that exposure of the human germ cells to ionising radiation can cause hereditary detrimental effects in the progeny of the exposed population. A significant portion of the gonad doses results from medical x-ray diagnostic examinations. In order to minimise the adverse effects of radiation and to reduce the gonad doses to a level as low as reasonable achievable (optimi-zation, ref. 1) the radiation protection institutes in the five Nordic countries have agreed to recommend the code of practice given in this publication.

In addition to radiation protection purposes, the intention behind this recommendation is to achieve a common set of routines in x-ray diagnostic work in the Nordic countries. It is an objective that any confusion and uncertainty experienced by patients and staff members caused by variable practice shall be avoided.

This code of practice covers medical x-ray diagnostics. Gonad shielding is generally not warranted in dental x-ray diagnostics due to the distance between the headand the gonads and the projections used.

II. BASIC PROTECTION PRINCIPLES

A reduction of the patient doses results in a reduction of the gonad doses. Every x-ray examination shall be adopted and performed with due consideration of general radiation protection principles which include:

1. Every x-ray examination shall be based on a clinical judgement and the indications for examinations shall be clearly stated. Information from earlier examinations should be available and be evaluated before an x-ray examination is performed. Other diagnostic procedures without using ionising radiation shall be considered.

2. Every x-ray examination shall be performed in such a manner that relevant diagnostic information is achieved with lowest possible radiation dose to the patient. This involve:

   - proper choice of equipment
   - x-ray apparatus equipped and functioning according to radiation protection regulations and quality assurance requirements
   - use of image formation systems with high sensitivity
   - proper choice of technical parameters
   - optimal collimation of the beam
   - careful positioning of the patient
   - minimizing the fluoroscopy time
   - minimizing the number of exposures

It should be emphasized that careful positioning of the patient and optimal collimation of the x-ray beam are among the most important factors in dose reduction. Compression should also be considered as a mean of reducing the dose.

General principles for protection of the patients are given in ICRP 34 (ref. 10).

III. CODE OF PRACTICE FOR GONAD SHIELDING OF PATIENTS IN
      X-RAY DIAGNOSTICS

III.1   SUMMARY

This code of practice is based on information and
experimental data reviewed in the annexes.

In this code of practice, use of the scrotum capsule device is
recommended for male patients. Usually, a dose reduction in
the range 85 - 95 % can be achieved when the testes are
located within the primary x-ray beam. Outside the x-ray beam,
but close to the beam edge, a dose reduction up to 50 % can be
achieved (Annex 3).

The problem of hygiene can be solved by inserting a disposable
plastic bag into the capsule prior to each application. Adole-
scents and adults should be able to mount the capsule
according to instructions given by the staff or from written
instructions (Annex 4).

For female patients shielding of the ovaries may obscure
structures of clinical importance and must therefore be
abadoned. For shielding of the ovaries, use of shaped contact
shields are recommended. Due to uncertainty in the location of
the ovaries (Annex 3), the real shielding effectiveness cannot
always be predicted. When the ovaries lie in the primary beam
and behind the shield, a dose reduction up to 50 % can be
achieved.

The shadow shields are not recommended in this code of
practice neither as an alternative to the scrotum capsules nor
as an alternative to the shaped contact shields for ovary
shielding.

III.2   GENERAL PROCEDURES

A.   Gonad shielding shall be considered for patients with
     a reproductive potential.

B.   Gonad shielding shall not be applied when the clinical
     objectives of the examination can be compromised.

C. Gonad shielding shall not be used as a substitute for careful positioning of the patient and optimal collimation of the x-ray beam.

III.3 PROTECTION OF MALE PATIENTS

D. Shielding of the testes shall be considered according to the recommendations A-E above. Shielding of the testes should be used when the testes are located within the primary x-ray beam or lie closer than 5 cm from the beam edge. In most examinations the testes can be shielded without interfering with the clinical objective.

E. Shielding of the testes should preferably be performed by use of the scrotum capsule device. It is essential that the shield closes without gaps around the scrotum. Care shall therefore be taken to use a capsule of suitable size in each case.

F. The physical properties of the scrotum capsules shall be in accordance with the recommendations given in section III.5.1 and II.5.4.

III.4 PROTECTION OF FEMALE PATIENTS

G. Shielding of the ovaries shall be considered according to the recommendations A-E above. Shielding should be considered when the ovaries are located within the primary x-ray beam in an anterior-posterior projection. In some situations shielding of the ovaries may obscure adjacent structures of clinical importance and must therefore be abandoned.

H. Shielding of the ovaries is not warranted when the ovaries are outside the primary x-ray beam. In these situations the major part of the ovarial doses are caused by internal scattering.

I. Shielding of the ovaries should be performed by shaped contact shields of proper size giving maximum protection without interfering with the clinical purpose of the examination. In case of patient movements and for standing patients means for securing the position of the shield shall be provided.

J. The physical properties of the ovary shields shall be in accordance with the recommendations given in section III.5.2 and III.5.4.

III.5   PHYSICAL REQUIREMENTS AND MARKING OF SHIELDING MATERIALS

The physical requirements and requirements for marking shall be in accordance with the IEC recommendations (ref. 9).

III.5.1   THE SCROTUM CAPSULE

1. Scrotum capsules are intended to protect the male gonads against unnecessary irradiation when they are close to or located within the primary radiation beam.

2. Scrotum capsules shall enclose the scrotum entirely. The opening admitting the scrotum or the scrotum and the penis shall be as small as practical. It is essential that the scrotum capsule closes around the scrotum without gaps. For this purpose, different sizes of scrotum capsules shall be available. The scrotum capsules shall contain a minimum volume of at least 80 cm^3. An upper limit of the inside volume of approximately 300 cm^3 seems acceptable.

3. The protective material of the capsule shall consist of a waterresistant material or shall be covered on all outer and inner surfaces with a waterresistant material allowing for easy cleaning and sterilization. -

4. The protective material of scrotum capsules specified for use by adults shall have an attenuation equivalent of at least 0.5 mm Pb over its entire area. For scrotum capsules specified to be used by children the attenuation equivalent shall be of at least 0.35 mm Pb.

III.5.2   THE OVARY SHIELD

1. Ovary shields are intended to protect the female gonads against unnecessary irradiation when the ovaries are located within the primary radiation beam.

2. The ovary shields shall be sufficiently large to enable covering the entire region of the ovaries. To obtain maximum protection without interfering with the clinical purpose of the examination, ovary shields shall be available as a set of suitable sizes and shapes or as single ovary shields with possibility for adjusting them to various sizes and shapes.

3. The protective material of the shields shall consist of a waterresistant material or shall be covered on all surfaces with a waterresistant material allowing for easy cleaning and sterilization.

4. The protective material of ovary shields shall have an attenuation equivalent of at least 1 mm Pb over its entire surface.

III.5.3   MARKING

Shields shall be marked clearly and indelibly with the following information:

1. Name or trademark of manufacturer or supplier.

2. Indication for use.

3. Indication of compliance with international standard.

4. Indication of size if applicable.

5. Attenuation equivalence in the numerical value of the thickness of lead (in millimetres) at a corresponding tube voltage (in kV).

REFERENCES

1. ICRP Publication 26. Recommendations of the International
    Commission on Radiological Protection.
    Annals of the ICRP. Volume 1, No. 3, 1977.

2. Sources, Effects and Risks of Ionizing Radiation.
    United Nations Scientific Committee on the Effects of
    Atomic Radiation.
    1988 Report to the General Assembly, with annexes.
    United Nations, New York 1988.

3. Genetic and Somatic Effects of Ionizing Radiation.
    United Nations Scientific Committee on the Effects of
    Atomic Radiation.
    1986 Report to the General Assembly, with annexes.
    United Nations, New York 1986.

4. The Institute of Physical Sciences in Medicine.
    Are X-rays Safe Enough ?
    Patient Doses an Risks in Diagnostic Radiology.
    Ed: K. Faulkner and B. F. Wall.
    Report No. 55,
    The Institute of Physical Sciences in Medicine, 1988.
    2 Low Ousegate, York YO1 1QU.
    ISBN 0 904181 52 9.

5. NCRP Report No 64.
    Influence of Dose and its Distribution in Time on Dose-
    Response Relationships for low-LET radiation.
    Recommendations of the National Council on Radiation
    Protection and Measurements.
    April 1, 1980.
    National Council on radiation Protection and Measurements
    7910 Woodmont Avenue, Washington ,D.C. 20014

6. T. G. Baker and P. Neal,
    Action of ionizing radiation on the mammalian ovary.
    The Ovary, Vol. I, Ed. by S. Zuckerman and B. J. Weir.
    pp. 1-47, Academic Press, New York.

7. BEIR 1980, The Effects on Populations of Exposure to Low
    Levels of Ionizing Radiations.
    National Academy of Sciences, Washington DC.

8. B. E. Keane and K. B. Tikhonov,
    Manual on Radiation Protection in Hospitals an General
    Practice.
    Volume 3, X-ray Diagnosis,
    World Health Organisation, Geneva, 1975.

9. IEC 62B-70
    X-ray equipment operating up to 400 kV and accessories.
    Protective devices.
    Draft document, april 1987.

10. Protection of the patient in Diagnostic radiology.
    Annals of the ICRP, ICRP Publication 34.
    Pergamon press, 1982.

11. Specific Area Gonad Shielding.
    Recommendations for Use on Patients During Medical X-ray
    Procedures, August 1976.
    U.S. Department of Health, Education, and Welfare,
    HEW Publication (FDA) 76-8054.
    Public Health Service,
    Food and Drug Administration,
    Bureau of Radiological Health,
    Rockville, Maryland 20852.

12. Warren W. Church and Bruce M. Burnett,
    Lead Equivalence of Male Gonad Shields.
    Health. Phys. Vol. 30 (1976) pp. 229-231

13. Erik Lindholmer and Ole Berg,
    Handy Device for Protection of the Testicles in X-ray
    Examinations.
    Proceedings of the Third International Congress of the
    I.R.P.A., sept. 9-14, 1973, Washington DC, pp. 1121-1126.

14. Gunnar Saxebøl, Hilde M. Olerud og Lars Erik Lundgren,
    Strålehygiensk analyse av medisinsk virksomhet i Norge.
    Status 1/1-1988: Stråledoser til pasienter i røntgen-
    diagnostikk.
    SIS-Rapport 1988:6,
    Statens Institutt for Strålehygiene, Norge, 1988,
    (in norwegian).

15. Gunnar Saxebøl and Lars Erik Lundgren,
    National Institute of Radiation Hygiene
    (Private communications).

16. E. Dale Trout,
    Isodose Curves in a Phantom due to Diagnostic Quality
    Radiation.
    Health Phys. Vol. 33 (1977) pp. 359-367.

17. V. K. Fochem and R. Page,
    Problematik des ovarialschutzes bei röntgenaufnahmen des
    beckens.
    Fortschr. Geb. Roentgenstr. Nuclarmed. 97 (1963)
    pp. 785-793.

18. G. J. D'Angio and M. Tefft,
    Radiation Therapy with Gynecologic cancers.
    Ann. N. Y. Acad. Sci. 142 (1967) pp. 675-694.

19. Åke Cederblad, Marianne Alexandersson, Sten Carlsson,
    Lisbeth Karlsson, Lars Gunnar Månsson og Viveka Nolblad.
    Blyförkläde på Pasienten vid Röntgenundersökningar-
    till Skada eller Nytta ?
    Report RADFYs 84:3 (mars 1984),
    Göteborgs Universitet,
    Radiofysiska institutionen,
    Sahlgrenska sjukehuset,
    413 45 Göteborg, Sweden.

GENETIC EFFECTS FROM IRRADIATION OF THE GONADS

Introduction

It is generally assumed that irradiation of the human germ
cells can cause hereditary detrimental effects in the progeny
even if there are little information on what humans
sustain though irradiation. One reason for this is that the
full tally of hereditary conditions takes many generations to
show and that these conditions would be undistinguishable from
those occurring from other causes.

The genetic effect falls into two main categories:

- gene mutations,
- chromosome aberrations.

The gene mutations are further split into two sub. categories:

- dominant mutations manifests in the children of people
  who first sustained the mutations,

- recessive mutations which only show up in children when
  both the parents have the same mutated gene.

While dominant mutations will be expressed as detriments in
the first generation, the recessive mutations can lie dormant
for many generations before the disease occur.

The chromosome aberrations are further subdivided into
numerical anomalies and structural anomalies.

When the genetic risk from irradiation is considered, the
consept "genetic significant doses" are used. Only the doses
to the gonads of humans having a reproductive potential are
considered to be of genetic significance.

Risk models and risk coefficients.

There are two models used to express the genetic risk from
irradiation, the doubling dose model (or the relative
mutation risk model) and the direct models.

The aim of the doubling dose model is to provide an estimate

of risks in terms of the additional number of cases of genetic diseases due to radiation exposure using as a frame of reference the natural prevalence of such diseases in the population. The doubling dose model is generally used to estimate risks to a population under continuous radiation. The general concept is that, under normal conditions in absence of radiation, there is an equilibrium between those mutations that arise spontaneously and those that are eliminated by selection in every generation. Under condition of continuous irradiation, the population will eventually reach a new equilibrium between those mutations that enter the genetic pool and those that are eliminated. The doubling dose model can be used to estimate risks from the induction of mutational events, irrespective of whether they are operationally classified as dominant or recessive, as well as chromosomal aberrations.

UNSCEAR (ref. 2) using the doubling dose model assume that a dose equivalent of 1 Sv for low-LET radiation given as a genetic significant dose per generation (= 30 years) will result in a doubling of the mutation rate in the population. Table 1.1 summarize the risk estimates for serious genetic diseases from irradiation of a parent generation by 1 Sv (effects in the "first generation" and in the "second generation" after the irradiation) and to all generations ("equilibrium") per million live birth. It should be noted that the risk estimates are given for low dose equivalents delivered at low dose equivalent rates (see below). It can be seen from the table that the risk coefficient for serious genetic diseases in the first generation is 0.0017 Sv^{-1} and that the equilibrium risk coefficient when all generations are irradiated is 0.012 Sv^{-1}.

A systematic comparison of three studies of the estimated live birth of congenital anomalies shows possibly insignificant variations from 8.5 % in United States to 6 % in Hungary and to 4.3 % in British Columbia. UNSCEAR (ref. 3) has used 6 % as an estimate for spontaneous arising congenital anomalies.

Hungarian data suggests that the prevalence of other multi-factorial disorders which are disorders primary of adulthood, may be at least 60 % includeing those appearing up to age 70. Earlier estimate of 4.7 % from British Columbia applies only to disorders appearing before the age of 21.

In the absence of further information on congenital anomalies and multifactorial disorders, particularly on the mechanisms of maintenance in the population and the effects of radiation on their prevalence, no risk estimates for these disorders are provided.

Radiation can induce heritable tumours, however these tumours may show very expressivity and they have not been included in the risk estimates.

The aim of the direct models is to provide an estimate of risks in term of an absolute number of cases of genetic diseases from irradiation of the germ cells. UNSCEAR (ref. 3), using the direct models, report risk estimates for children in the first generation after irradiation of the parents (table 1.2). It can be seen from this table that the maximum risk coefficient for serious genetic diseases in children is 0.0035 Gy^{-1} for irradiation of males and 0.0014 Gy^{-1} for irradiation of females in the parent generation. The risk estimates are given for low-LET radiation delivered as low doses at low dose rates (see below).

ICRP (ref. 1) estimates a risk coefficient of 10^{-2} Sv^{-1} (called risk factor by ICRP) of serious genetic diseases within the first two generations following irradiation of a parent generation of both sexes and all ages (0-75 years). The additional damage to later generations is taken to be of the same magnitude. This risk coefficient is given for low-LET radiation delivered as low doses at low dose rates. It should further be noted that this coefficient are given for a continuous dose rate throughout the life span of the irradiated generation (0-75 years). If it is assumed that the genetic significant dose is received up to an age of 30 years, this represent about 40 % of the total dose received through-out life. The risk coefficient given by ICRP for the first two generations from genetic significant doses to the parents is therefore 0.004 Sv^{-1}.

The total risk coefficients of 0.0017 Sv^{-1} based on the doubling dose model (ref. 2) and the maximum mean value for both sexes of 0.0025 Sv^{-1} from the direct models (ref. 3) are in good agreement considering the uncertainty involved in the risk estimations and that the last figure is a maximum value. ICRP's risk factor of 0.004 Sv^{-1} is given for the first two generations after irradiation. Table 1.1 shows that the total risk for the second generation is comparable to the risk for

the first generation. ICRP's risk factor for the first generation could therefore be given as 0.002 Sv^{-1} which is comparable to the estimates given by UNSCEAR.

We conclude that irradiation of both sexes in a parent generation to a genetic significant dose of low-LET radiation given as low doses at low dose rates results in serious genetic diseases in the first generation of children with a risk coefficient of about 0.002 Sv^{-1}. The risk coefficient from irradiation of males is taken to be 0.003 Sv^{-1} while the risk coefficient from irradiation of females is taken to be 0.001 Sv^{-1}. As can be seen from these figures irradiation of the testes gives three times higher risk values than irradiation of the ovaries from identical doses.

Modifying factors

UNSCEAR (refs. 2,3) and ICRP (ref. 1) have made assumptions regarding the dose effect relationship when risk estimates are given for low doses at low dose rates extrapolated from ex- perimental data at high doses and/or high dose rates. UNSCEAR (ref. 3) use the following terminology:

        low doses   : < 0.2 Gy
        intermediate doses: 0.2 - 2 Gy
        high doses   : > 2 Gy

        low dose rate : < 0.05 mGy/min
        high dose rate: > 0.05 mGy/min

The existence of dose rate effectiveness factors has long been recognized from clinical experience and from studies of both genetic and somatic effects in experimental animals. It is concluded that low-LET radiation delivered at high dose rates is more mutagenic per unit absorbed dose as it is at low dose rates. Based on studies before 1980 a multiplication factor of 3 has been suggested (ref. 5).

In x-ray radiography the doses are delivered as low doses at high dose rates. The risk coefficient from irradiation of males is therefore given by approximately 0.01 Sv^{-1} and for irradiation of females 0.003 Sv^{-1}. In fluoroscopy the doses are usually delivered at dose rates in the range 10 - 30 mGy/min and therefore falls within the high dose rate range.

In the human ovum the first reduction division (meiosis) begins, but is arrested in the diplotene phase after DNA replication has occurred. The oocyte stays in this arrested state until some weeks before ovulation when the first meiotic division is completed. The second reduction division then starts and is completed after fertilisation. The oocytes in multilayered and Graafian follicles are more sensitive to genetic injury, particularly between metaphase I and metaphase II, i.e. the ending of meiosis I and into meiosis II, compared to the sensitivity of the oocytes during the long resting diplotene phase (refs. 6,7). The beginning of this sensitive period starts about 6 or 7 weeks before ovulation and coincides with the formation of zona pellucida and a change in the nuclear morphology of the oocyte. For irradiation in a period starting 6-7 weeks prior to conception and ending at conception which usually occurs within one day after ovulation the risk coefficient for irradiation of females must be multiplied by a factor of about 20 (ref. 7) giving a risk coefficient for this period of 0.02 Sv^{-1}. According to BEIR (ref. 7) this includes the effects of high dose rates. It should be emphasized that this risk coefficient comes to effect only if conception occurs at the end of the 6-7 weeks period. In cases of irradiation before this period the risk coefficients for females given above should be used.

The opportunity for expression of genetic effects of radiation falls with increasing age in line with the reduced expectation of parenthood. Child expectancy data as a function of age and sex can be used to generate curves representing the probability of expression of genetic effects in a population as a function of age at exposure and sex. Probability of expression of genetic effects in the english population as a function of age at exposure and sex is given in figure 1.1 (ref. 4). Similar curves for the population in the Nordic countries can be expected to have close resemblance to those in figure 1.1 at least at the end points of the curves.

As can be seen from figure 1.1 the probability of expression of genetic effects from irradiation are of importance only for males below 50 years of age and females below 45 years of age.

Table 1.1

Estimates of risk of severe genetic diseases per million live birth in a population exposed to a genetically significant dose equivalent of 1 Sv per generation of low-LET radiation at low dose rate and low dose irradiation, according to the doubling dose method. The doubling dose equivalent assumed is 1 Sv (ref. 2).

Disease-classification	Current incidence per million live birth	Effect of 1 Sv per generation		
		First generation	Second generation	Equilibrium
Autosomal dominant	10 000	1 500	1 300	10 000
Autosomal recessive	2 500	5	5	1 500
Chromosomal:				
- structural anomalies	400	240	96	400
- numerical anomalies	3 400	Probably very small		
Congenital anomalies	60 000	not estimated		
Other multifactorial diseases	600 000	not estimated		
Totals of estimated risk		1 700	1 400	12 000

Table 1.2

Risk of induction of genetic damage in man per 0.01 Gy at low dose rates of low-LET radiation, according to the direct method (ref. 3).

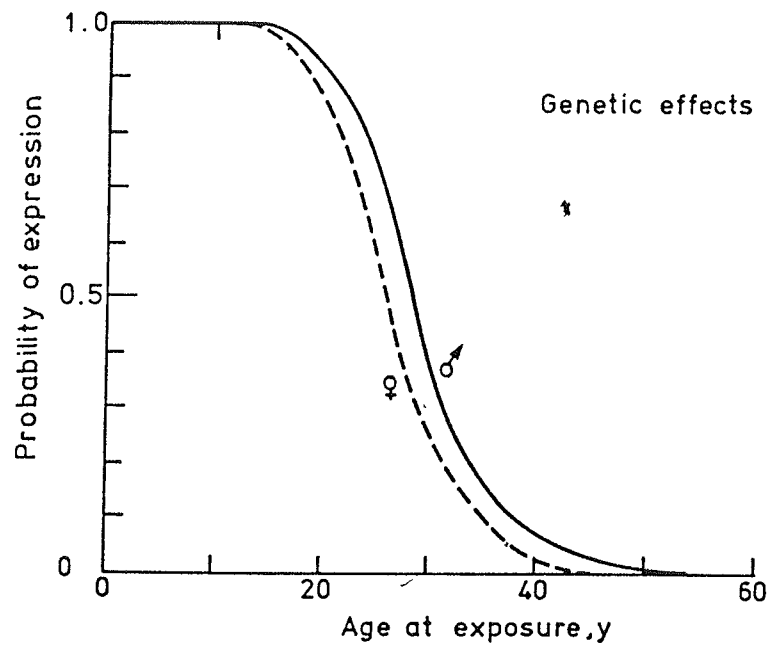| Genetic damage	Expected frequency (per 10^6 live birth) of genetically abnormal children in the first generation after irradiation	
	Males	Females
Dominant mutations	10 - 20	0 - 9
Recessive mutations	0	0
Reciprocal translocations	1 - 15	0 - 5

Figure 1.1: Expression factor curves for genetic effects.

POSITIONING OF THE PATIENTS AND CHARACTERIZATION OF RADIO-
DIAGNOSTIC PROCEDURES ACCORDING TO GENETIC HAZARD.

Among the most important technical methods for limiting the
irradiation of the patients is the use of the smallest
practicable radiation field and its accurate positioning.
Reduction of the field is always of benefit to the patient.
This reduces both the total radiation energy delivered to the
patient, and, almost invariably, the gonad and bone marrow
doses. It also reduces the amount of scatter reaching the
film, thereby improving image quality.

Figure 2.1 and 2.2 shows two examples of "poor technique" and
"good technique". In figure 2.1 a radiograph of the abdomen by
the "poor technique" will result in a gonad dose which is
approximately 250 times higher than from the "good technique".
Use of the "poor technique" during chest radiography (figure
2.2) results in a gonad dose which is approximately 150 times
higher than from the "good technique".

The effect of reducing the beam size combined with a proper
positioning of the patient is illustrated in figure 2.3.
Reduction of the field to cover only the film size in
situation B will reduce the gonad dose by approximately 99 %
compared to situation A. Positioning of the patient as shown
in situation C will give a further reduction of the gonad dose
by approximately 94 % . The total reduction of the gonad dose
in situation C compared to situation A is therefore above 99.9
% .

Radiodiagnostic procedures can be classified according to
genetic hazard expressed as level of gonad dose. Table 2.1
gives a review of procedures involving high gonad dose,
moderate gonad dose and low gonad dose (from ref. 8).

The high gonad dose group comprises examinations where
shielding of the gonads should be considered according to code
of practice. For examinations in the moderate gonad dose
group, shielding should be considered in special cases
dependent of the position of the gonads in relation to the
x-ray field. For examinations in the low gonad dose group,
shielding is not generally warranted if examinations are
performed with due consideration of general radiation
protection principles.

Table 2.1 (from ref. 8)

Examinations involving a <u>HIGH GONAD DOSE:</u>

- Lumbar spine, lumbosacral vertebrae,
- Pelvis,
- Hip and femur (upper third),
- Urography,
- Retrograde pyelography,
- Urethrocystography,
- Lower gastrointestinal tract,
- Abdomen,
- Obstetric abdomen,
- Pelvimetry,
- Hysterosalpingography.

Examinations involving a <u>MODERATE GONAD DOSE</u>

- Stomach and upper gastrointestinal tract,
- Cholecystorgaphy, choleangiography,
- Femur, lower two-thirds.

Examinations involving <u>LOW GONAD DOSE</u>

- Head,
- Cervical spine,
- Dental,
- Arm (including forearm and hand),
- Bony thorax (ribs, sternum, clavicle, shoulder),
- Dorsal spine,
- Lower leg, foot,
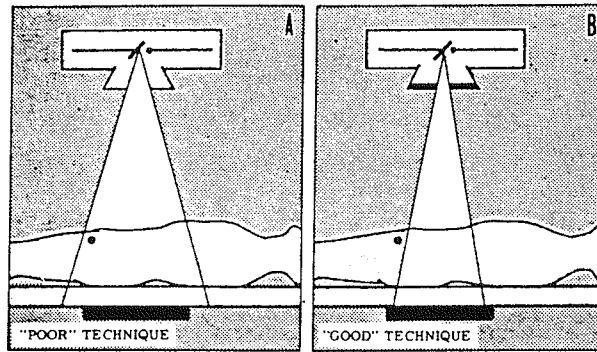- Chest (heart, lung) including mass miniature radio-
  graphy.

Figure 2.1: Radiography of the abdomen, "poor" technique and "good" technique. The gonad dose in situation A is 250 times that in situation B.
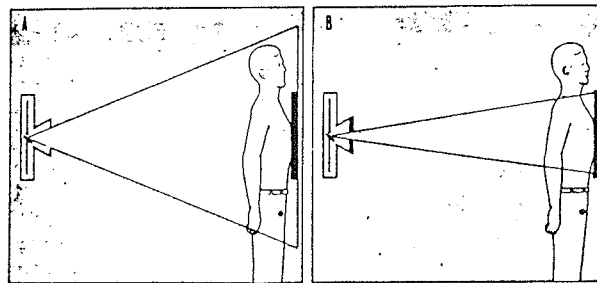

Figure 2.2: Radiography of the lung, "poor" technique and "good" technique. The gonad dose in situation A is 150 times that in situation B.-
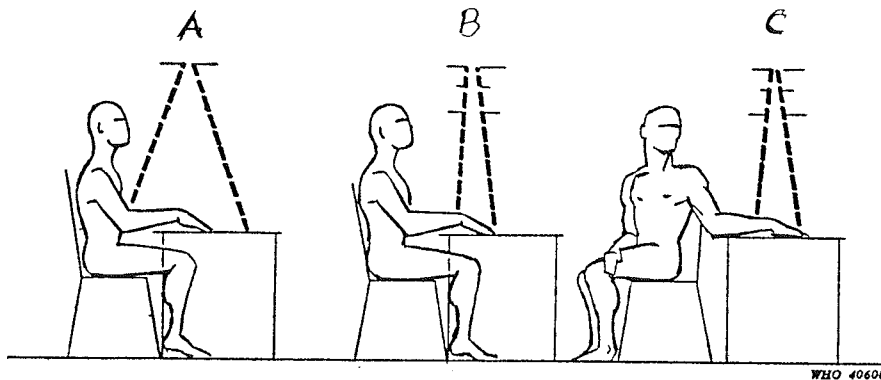

Figure 2.3: Protection of the patient by positioning (from ref. 8).

TYPE OF GONAD SHIELDS AND THEIR EFFECT IN X-RAY DIAGNOSTICS

I. INTRODUCTION

The main rule for using gonad shields is that they shall not compromise the clinical objective of the examinations. Neglecting this rule will most likely lead to repetition of the examination whereby the benefit of the gonad shield is lost when compared to a doubling of doses to organs in the body.

There are two types of gonad shields recommended for use in x-ray diagnostics. These are:

a)   Scrotum capsule.
b)   Shaped ovary shield.

In addition, lead rubber shirts and squares are sometimes used as contact shields for certain examinations. Due to the lack of recommendations, there is a variable practice in use.

Comments on the effect of these shielding devices are given below.

II. THE SCROTUM CAPSULE

Modern scrotum capsules are moulded from lead rubber or lead plastic and are equipped with a spring opening to secure the position of the capsule and automatically adjusting the opening to a smallest possible size in all situations.

Reports on the dose reduction of the scrotum capsule range from 85 % (0.25 mm Pb, ref. 11) to 95 % (refs. 10, 12) and 98-99 % (ref. 13) when the testes is located within the primary x-ray beam.

When the testes are located outside the primary x-ray beam but in close proximity of it, the doses are caused by scattering within the body from the irradiated volume. In such situations the scrotum capsules are reported to give a dose reduction of 50 % (ref. 11) and 28-40 % (ref. 12, kV range: 100 kV - 60 kV) Male gonad exposure as a function of the distance from the

edge of the x-ray beam, with and without contact shielding, is shown in figure 3.1 (from ref. 11). It can be seen that the use of such shield has negligible effect when the gonads are located more than 5 cm from the beam edge. This is due to scattering within the body. Use of a scrotum capsule when the testes is located closer than 5 cm from the beam edge will, on the other hand, give some additional protection against scattered radiation. As a general rule the testes should be shielded for those examinations where the pubic symphysis can be visualized on the film.

Since the scattered radiation to the testes will decrease continuously when the x-ray beam edge is moved away from the testes, the recommended 5 cm as a limit for using the scrotum capsule is given in order to have a specific rule in practical x-ray work. In addition, this recommendation will give the patient a protection in examinations where a primary beam exposure of the testes cannot be disregarded, due to an uncertain position of the beam edge or when the field size and projection is frequently changed during examinations in the abdominal region.

The benefit of scatter reduction by using the scrotum capsule when the testes is in close proximity of the beam can be estimated from patient dose measurements. Measurements from x-ray diagnostics in Norway are used for this illustration (refs. 14, 15).

A collective entrance soft tissue dose of 8800 manGy to the norwegian population per year from examinations where the testes are located closer than 5 cm from the testes, can be calculated from patient statistics, measurements of the mean value of exposure*area for these examinations and from the assumption that the mean field size in all these examinations are 600 cm^2. The average value of the scattered fraction to the testes are taken to be 5 % of the entrance soft tissue dose in these examinations (ref. 16). The genetic significant portion of the doses to the testes are assumed to be received by male patients below 30 years of age (ref. 1). From patient statistics, this is approximately 11 % of the patients (ref. 16). These calculations results in a collective genetic dose to the male norwegian population of approximately 50 manGy per year from x-ray examinations in the abdominal region when the testes is located within 5 cm from the x-ray beam edge. By using the scrotum capsule in these examinations a dose reduction of approximately 25 manGy (50 %) can be achieved.

The genetic risk coefficient for the first generation of progeny from irradiation of males is 0.01 Sv^{-1} for low-LET radiation (annex 1). The frequency of serious genetic damage per year of progeny in the first generation in the norwegian population is therefore 0.5 without use of the scrotum capsule and 0.25 when the scrotum capsule is used in these examinations. In Norway, the number of live births per year is approximately 55 000. The reduction in the frequency of serious genetic diseases by using the scrotum capsule in scatter reduction is 1/220 000 from 1/110 000 to 1/220 000. This practice will be of benefit to one child every four years. In comparison, the annual risk of public exposure to a dose limit of 1 mSv is 1/33 000.

For examinations in the abdominal region when the testes are located more than 5 cm from the x-ray beam edge, an average scatter fraction to the testes of 1 % of the entrance soft tissue dose is assumed (ref. 16). The genetic significant portion to the male norwegian population per year from x-ray examinations in the abdominal region, when the testes are in such positions, is estimated to be approximately 5 manGy. Using the scrotum capsule in these examinations will give a reduction of 2-3 manGy. From calculations above, it can be seen that this reduction is far too low to support a recommendation for using the scrotum capsule in these situations.

As can be seen from the above figures, the benefit of using a scrotum shield when the testes is outside the x-ray beam is questionable.

III. THE OVARY SHIELD

Ovary shields are contact shields of various sizes and shapes. The main problems in connection with the use of the ovary shields are:

a)   The ovaries have no unique position in the body. Figure 3.2 and 3.3 shows the location of the ovaries in 200 women and girls, and in 13 children aged 1 day to 12 years respectively (from refs. 17, 18).

b)   In females, shielding is not always possible since the gonadal region is often diagnostically important in that it contains the ureters, colon and other important

structures.

The ovary shields must be used with due considerations to these problems.

When the ovaries are located in the primary x-ray beam and the true position are below the shield, a dose reduction of 50 % (ref. 10) and 30-45 % (ref. 11) have been reported. In examinations outside the abdominal region, scattered radiation within the body will reach the ovaries and no recommendations for shielding are warranted.

IV. LEAD RUBBER SHIRTS AND SQUARES USED AS CONTACT SHIELDS.

There is a variable practice in using lead rubber shirts and squares as contact shields in the gonadal region when the x-ray field is located outside this region. Such shielding is sometimes used in chest examinations and in examinations of arms and limbs. The effect has been studied by Åke Cederblad et. al. (ref. 19). They have measured gonad doses with and without lead rubber shielding in chest examinations and in examinations of hands and knees. The results of these measurements are reproduced in table 3.1. The gonad dose reduction in μGy could be compared with an average effective dose equivalent of approximately 3 μSv per day from natural sources (excluding radon).

As can be seen from table 3.1, the dose reduction by using lead rubber shielding when the x-ray beam is located far from the gonadal region is comparable to the effective dose equivalent received during approximate one day from natural sources. From this fact, recommendations for use of lead rubber shielding in such examinations are not warranted.

Table 3.1

The effect lead rubber shirts and squares on gonad doses (from ref. 19).

Examination	Gonad dose without shielding (μGy)	Gonad dose with shielding (μGy)	Dose reduction (μGy)
Women			
Chest (adults)	2.9	1.2	1.7
Chest (babies)	4.5	3.6	0.9
Knee	1.4	0.5	0.9
Hand	0.3	< 0.3	< 0.3
Men			
Chest (adults)	2.0	0.7	1.3
Chest (babies)	1.8	0.7	0.4
Knee	2.3	0.5	1.8
Hand	< 0.3	< 0.3	< 0.3
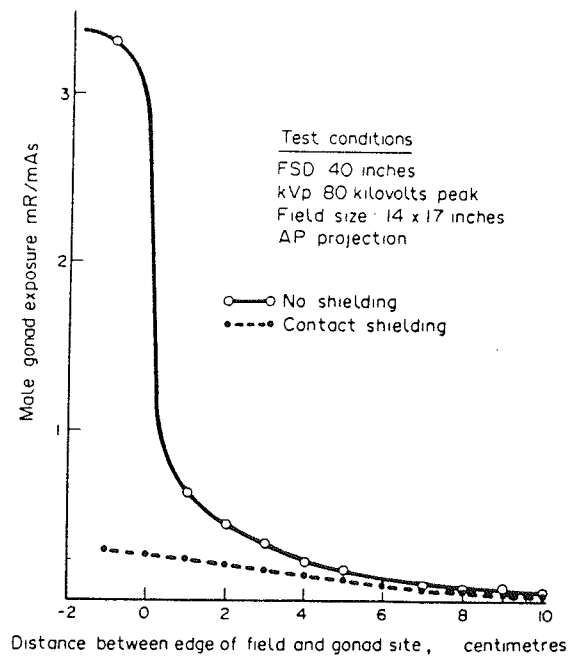
Figure 3.1: Male gonad exposure as a function of distance
between the edge of the x-ray field and the
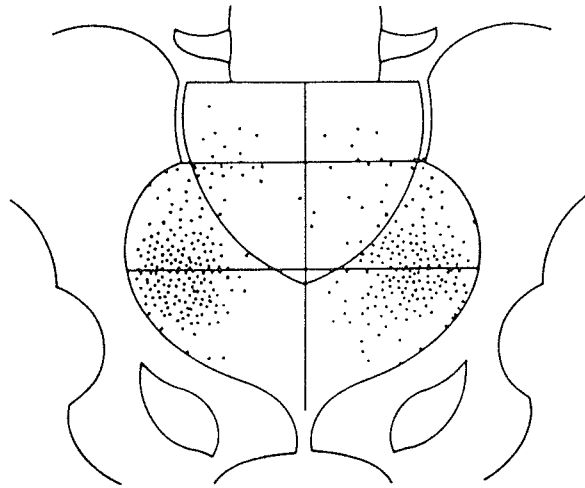location of the gonads (from ref. 11).

Figure 3.2: Location of the ovaries in 200 women and
girls. The location of the ovaries over the
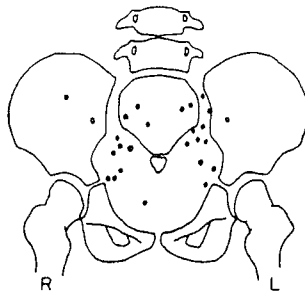sacrum was mainly in girls (from ref. 17).

Figure 3.3: Diagrammatic representation of position of
ovaries in 13 children aged 1 day to 12 years
(from ref. 18).

INSTRUCTION FOR USE OF THE SCROTUM CAPSULE

This guide for mounting and use of the scrotum capsule is
translated from a danish guide accompanying the "NETO" scrotum
capsule manufactured by the danish firm Nilsen & Olsen. The
figures copied are taken from the same source.

The scrotum capsule shall be handed to the patient with a
disposable plastic bag inserted together with these written
instructions. The patient should be informed to mount the
capsule according to instructions and secure its position by
pulling up his underwear tight. Talcum powder should be
available if necessary.

THE SCROTUM CAPSULE SHIELD[x]

GUIDE FOR MOUNTING

You are to undergo an x-ray examination and you are asked to
mount this capsule around your testes in order to shield the
germ cells against x-rays. The shielding is provided to
prevent detrimental effects in the germ cells and therefore to
reduce the risk for hereditary diseases. Use of the scrotum
capsule is recommended by the health authorities.

If the mounting of the capsule should be difficult, the doctor
or the nurse will be at your assistance.

Please follow the instruction for mounting stepwise though the
following figures 4.1-4.4.
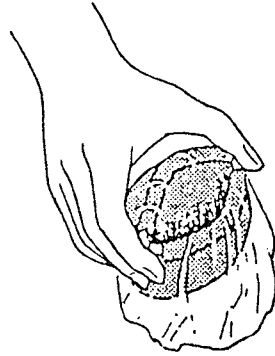
Figure 4.1:   Pull down your underwear and hold the capsule
               in your right hand. Push the hinges of the
               capsule in order to open the capsule. Hold the
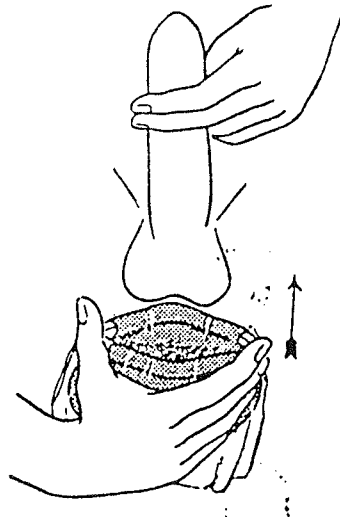   opening under your testes.

Figure 4.2:   Let the teste slide though the opening and down
               into the capsule. If this is difficult, talcum
               powder on the skin can make it easier.

Figure 4.3:   Observe that the testes are completely inside
               the capsule and release the spring opening in
               order to close the opening at the root of the
               testes.
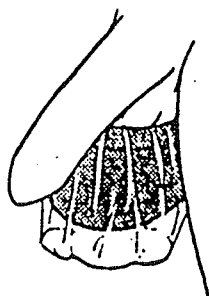

Figure 4.4:   This picture shows the correct positioning of
               the capsule. Keep your pants on unless you have
               received other instructions.