The ocular radiation hazard for health care practitioners involving radiation exposure and the solutions for reducing this hazard

September 2006
Preamble

The initiation of the current study is based on a conference abstract in 2004 which reported an increased prevalence of radiation crystalline lens damage among interventional radiologists (Haskal, 2004). The suggested reason could be due to an unusually close proximity to the fluoroscope during their routine procedures. Malignant neoplasms and heart diseases are the two leading causes of death in Hong Kong (Hospital Authority, 2003). Apart from surgical treatment, radiotherapy is a common treatment modality available for malignant neoplasms (Lee, 1997). Cardiologists also conduct procedures involving radiation, for example, coronary angiography, coronary angioplasty and coronary stenting (Yu et al., 2000; Rotter et al., 2003). Diagnostic and therapeutic procedures for cerebrovascular lesions all may involve radiation hazard (Delichas et al., 2003; Ting et al., 2003). It has been documented that the effect of radiation on the human crystalline lens is dose-dependent (Britten et al., 1966; Valentin, 2000). Apart from crystalline lens damage, dry eye syndrome could be another radiation related ocular problem (Liao, et al., 2002). A recent animal study reported transient damage on corneal epithelium and endothelium after the influence of ionizing radiation (Kiuchi et al., 2004). There are recommendations for patients to have fewer radiation exposure undergoing some invasive procedures (Kuon et al., 2003). On the contrary, practitioners may not aware of the radiation hazard (Lee et al., 2004). There has been no study on the prevalence of cataracts and other ocular damage potentially from this radiation hazard. There has been no study on the radiation hazard in their workplace.

Objectives

1. To understand and characterize the effects of ocular radiation hazards on this group of health care practitioners. The results could help to establish if there is association between ocular abnormalities and radiation hazards.
2. To measure the radiation absorbed dose to the lens of the health care practitioners and evaluate the factors affecting this by performing radiation measurements using phantom simulation in a typical high risk medical exposure working environment. The results will provide recommendations/guidelines for eye dose reduction on the current high risk radiological practice of health care practitioners in Hong Kong.
Methodology

Objective 1

Radiographers from the Registry of The Radiographers Board, Hong Kong (under the Supplementary Medical Professions Council), radiologists from The Hong Kong College of Radiologists, and cardiologists from The Hong Kong College of Cardiology were invited to fill in a questionnaire (Appendix I). This served to gather information including the number of years of service, types and frequency of radiation related procedures, types and frequency of protective measures used.

These health care practitioners were invited to have comprehensive eye examination conducted by a registered optometrist in the PolyU Optometry Clinic. The eye examination involved all the routine procedures with dilated fundus examination. Particular attention was drawn to the diagnosis of cataract and the assessment of dry eye syndrome. We adopted the classification of cataract, if any, from the World Health Organization (WHO) grading system (Thylefors et al., 2002). The crystalline lens transmission was measured using the Anterior Eye Segment analysis system, EAS-1000 (Nidek Co., Ltd., Aichi, Japan). The retro-illumination mode was used and analysis was performed using the proprietary software provided with the EAS-1000 system (Haskal, 2004; Gudmundsdottir et al., 2005). Conventional tests for dry eye syndrome were carried out, including subjective symptoms, Schirmer test, cotton thread test, and tears break-up time (Smith et al., 2004; Albietz et al., 2005).

Objective 2

Dose record

Candidates participating in this study were asked to provide information about their radiation exposure history, such as the length of time of exposure and personnel whole radiation doses (both surface dose [Hp(0.07)] and deep dose [Hp(10)]) record which included monthly doses in the past 2 years and the cumulative doses since their first registered as designated occupational radiation workers at the Radiation Health Unit (RHU) of the Department of Health (Government of the HKSAR). They got this information either from the Radiation Protection Supervisor of their workplace or from visiting the web sites of the RHU (https://www.dh-rhu.gov) for personal dose history inquiry.
**Lens dose measurement**

Dose records from the above does not equate to the lens dose for workers who regularly work close to the patients under irradiation by X-rays, for example the cardiologists and intervention radiologists (IR). Personal dose record gives information about the dose received by the workers with the radiation monitoring device worn at waist or chest level under a radiation protective lead apron. In order to achieve a good estimation of lens doses from the shielded body dose record, a simulation experiments were carried out with typical modern C-arm fluoroscopic X-ray Units, at the Radiology Department of the Caritas Medical Centre and the Prince of Wales Hospital. One common interventional procedure, the trans-arterial chemo-embolisation (TACE) of the liver tumour was simulated using two anthropomorphic phantoms, one as the patient under irradiation in the horizontal position on the X-ray couch and the other one in the erect position next to the patient, acting as the interventional radiologist performing the task.

Radiation protective devices, including a lead apron and a pair of lead glass were put on the erect phantom (staff simulation). Radiation measuring devices: TLDs (thermoluminescent dosimeters [LiF:Mg,Cu,P pellets]) (Bicron-Harshaw, US) were used to measure the doses received at various sites on the erect phantom: underneath and in front of the lead apron; in front and behind the lead glass for both eyes. The X-ray equipment orientation and staff-patient distance were arranged similar to a typical TACE procedure set. TLDs were removed after a substantial irradiation time with typical exposure parameters. The TLDs were read by a TLD Reader (Rialto, NE Technology, UK) for the doses retrospectively at the radiation physics laboratory of PolyU. The lens dose of the radiologist from a typical IR procedure was measured and the results of these dose data enable the calculation of a conversion factor to convert body shielded dose to lens dose. The lens dose and body dose reduction the radiation protective devices (lead glass and lead apron) was evaluated.

Evaluation of the eye dose reduction methods (other than lead goggles) was also performed by changing the X-ray unit setting parameters, which included the X-ray beam collimation size, magnification factors, image intensifier (I.I.) to patient distance. The change of eye dose in relation to different common X-ray tube angulations was also evaluated.
Results

A total of 1569 letters and questionnaires were sent out to the above-mentioned health care practitioners. There were 363 completed forms received and 199 practitioners went through the eye examination (Table 1).

<table>
<thead>
<tr>
<th></th>
<th>Radiographer</th>
<th>Radiologist</th>
<th>Cardiologist</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of letters sent</td>
<td>1051</td>
<td>383</td>
<td>135</td>
<td>1569</td>
</tr>
<tr>
<td>No. of completed questionnaires received</td>
<td>268</td>
<td>61</td>
<td>34</td>
<td>363</td>
</tr>
<tr>
<td>No. of completed eye examination conducted</td>
<td>173</td>
<td>15</td>
<td>11</td>
<td>199</td>
</tr>
</tbody>
</table>

Table 1. The number of letters sent, questionnaires received, and eye examination conducted for radiographers, radiologists, and cardiologists.

The two most commonly performed procedures for radiographers were intravenous urography and fluoroscopic examinations, and ultrasound and fluoroscopic examinations for radiologists. Table 2 summarizes part of the results obtained from the questionnaires. Over 70% of the respondents had post-qualified working experience within 20 years. Cardiologists had a higher proportion of their duties related to radiation exposure, compared with other practitioners. Although 96% of the responding radiographers used lead apron, they rarely wore lead goggles. While forty-six percent of the radiologists wore lead goggles during fluoroscopic and interventional radiology procedures and 59% of the cardiologists wore lead goggles for the same procedures. No practitioners had radiation dose over the International Commission on Radiological Protection (ICRP) recommendation of 150mGy on total yearly eye dose. One practitioner had radiation life dose over 20mGy.

<table>
<thead>
<tr>
<th></th>
<th>Radiographer</th>
<th>Radiologist</th>
<th>Cardiologist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10 years of post-qualified experience</td>
<td>39.6%</td>
<td>47.5%</td>
<td>14.7%</td>
</tr>
<tr>
<td>Within 10 to 20 years of post-qualified experience</td>
<td>39.6%</td>
<td>31.1%</td>
<td>55.9%</td>
</tr>
<tr>
<td>Within 30% of time involved in radiation related work</td>
<td>72.0%</td>
<td>65.6%</td>
<td>88.2%</td>
</tr>
<tr>
<td>Use of lead apron</td>
<td>95.9%</td>
<td>93.4%</td>
<td>100%</td>
</tr>
<tr>
<td>Wearing of lead goggles</td>
<td>2.6%</td>
<td>45.9%</td>
<td>58.8%</td>
</tr>
</tbody>
</table>

Table 2. Summary of the results from the questionnaires.
From the eye examination, five subjects (ranged from 47 to 54 years) had grade 1 cataract (either nuclear or cortical type) identified using the WHO grading system. Four of them were radiographers and one cardiologist. All of them had this mild cataract on one eye only. No practitioners had lens transmission below 90% on either eye, with an average lens transmission of 98%, evaluated using the EAS-1000 system. Fifty-one subjects had at least two positive findings from the dry eye tests (Schirmer test: < 5mm/5min; cotton thread test: < 10mm/15sec; and tears break-up time: < 7 sec) bilaterally. They included 4 cardiologists, 6 radiologists and 41 radiographers. When excluding 12 subjects with either contact lens wearing or refractive surgery history, only 39 subjects had bilateral dry eye problem. None of these practitioners had clinically detectable cataract. If subjective symptoms were also considered for the diagnosis of dry eye syndrome, the number reduced to 4 radiographers only (i.e. dry eye questionnaire with score > 14, and 2 positive dry eye test results bilaterally).

The mean eye dose measured for a typical abdominal fluoroscopic procedure which lasting 15 minutes was 340μGy. As for the eye protection, the use of lead goggles can reduce dose to the left and right eye by 55% and 59% respectively in the simulated radiation environment. The varying of the three allowable magnification modes shows no significant difference in the operator eye dose. However, the uses of a tight X-ray collimation beam size and the minimum I.I. to patient distance have prominent effect on eye dose reduction. Results show that eye dose reduction could be achieved by a careful selection of the X-ray tube angulation. For example, the mean eye dose with the tube near the operator for a 90° angulation is 1.9 times higher than that when the I.I. is near the operator in the reverse 90° angulation and yet the image generated in both scenario projections provide similar anatomical features.

Discussion

According to the increasing use of interventional radiology in recent years, there is a great concern to healthcare practitioners regarding the radiation hazards. Interventionists appeared to have higher risk in cataract development (Haskal, 2004). On ocular hazard, an acute radiation dose of 2Gy may cause cataract to the patients (Valentin, 2000). Practitioners may develop cataract under a dose of 4Gy within 3 months. All health care practitioners under regular radiation exposure should therefore maintain a record of radiation exposures (Eason, 1974). Our respondents mainly represent practitioners within 20 years of post-qualified experience. It is not surprising that cardiologists are highly engaged in radiation related duties. They are fully aware of the radiation hazard and all of them used lead apron for radiation protection. However,
less than 60% of them wore lead goggles. Radiographers seem do not have the knowledge on ocular radiation protection.

Around 200 health care practitioners completed the eye examination. There were only 5 subjects, age ranged from 47 to 54 years, had grade 1 cataract (either nuclear or cortical type). This mild form of lens changes is therefore age-related. All practitioners had lens transmission over 90%, with an average lens transmission of 98%. Although fifty-one subjects (26% of the examined group) demonstrated ocular signs of dry eye syndrome bilaterally, the number reduced to 4 when subjective symptoms are taken into consideration. The evaluation of dry eye syndrome should include both subjective symptoms as well as clinical signs (Nichols et al., 2004; Albietz et al., 2005). There is no significant ocular problem in our subject group. It could be related to their radiation dose well below the ICRP level. Therefore, ocular problems related to radiation exposure are not anticipated.

For a relatively high workload radiologist, assume working with 4 patients per day for 5 days/week for 40 weeks, the total eye dose in one year could be added up to 400mGy (500μGy × 4 × 5 × 40 = 400mGy). For unprotected eye, the appropriate selection and use of lead goggles could reduce eye dose by at least 60%. Therefore, health care practitioners should be encouraged to wear lead goggles during the procedures. It is well illustrated that increase in magnification factor will decrease eye dose. Tight collimation and minimum I.I. to object distance have significant effects on eye dose reduction. Careful selection of X-ray tube angulation geometry could significantly reduce operator’s eye dose. For example, 90° horizontal tube angulation fluoroscopy, eye dose is 1.9 times higher with the tube positioned near the operator. It is recommended “never stand near the tube in a horizontal lateral beam during any fluoroscopic studies”.

Conclusions
Health care practitioners involving radiation exposure in Hong Kong have effective radiation protective measures in their workplaces. Although they do not have significant radiation-related ocular problems, the use of lead goggles should be encouraged. The use of lead goggles, tight X-ray beam collimation, and minimum I.I. to patient distance were shown to have significant effect in reducing radiation eye dose to operators. It is also advisable to arrange the I.I. (rather than the X-ray tube) near the operator for any tube angulation of the C-arm since similar anatomical feature are provided with significant eye dose reduction.
References

7. Hospital Authority: Statistics and research unit, Professional services and medical development division. Hospital Authority March 2003, pp.31–33.
16. Ting ACW, Cheng SWK, Cheng PW. Carotid stenting for irradiation associated...

Conference presentations

Appendix I

Part I

Questionnaire (please give a √ to your selected answer)

1. Your profession is: □ Diagnostic Radiographer □ Diagnostic Radiologist □ Cardiologist

   For - Diagnostic Radiographer, answer Q2-5
   - Diagnostic Radiologist, answer Q6-10
   - Cardiologist, answer Q11-14

2. Your post-qualified experience is: □ < 2 yrs □ 2 – <5 yrs □ 5 – <10 yrs
   □ 10 – <15 yrs □ 15 – <20 yrs □ 20 – <25 yrs
   □ 25 – <30 yrs □ 30 –<35 yrs □ 35 yrs and above

3. Your post-qualified radiography work include: (can select more than one)
   □ General Radiography □ Fluoroscopic examinations, e.g. Ba studies
   □ IVU □ Interventional Radiology (non-vascular)
   □ CT □ Interventional Radiology (vascular)
   □ MRI □ U/S
   □ Nuclear Medicine

4. Your estimation % of time involved in fluoroscopic, interventional and nuclear medicine
   examinations in your career is:
   □ < 10 % □ 10-20 % □ 21-30 % □ 31-40 % □ 41-50 %
   □ 51-60 % □ 61-70 % □ 71-80 % □ 81-90 % □ 91-100 %

5. Which of the following protective measure/s do you use while you are performing fluoroscopic
   and interventional work? (can select more than one)
   □ lead apron □ lead goggles □ mobile lead screen
   □ thyroid shield □ lead gloves

   For - Diagnostic Radiologist, answer Q6–10
6. Your post-qualified experience in radiology is:

- □ < 2 yrs  □ 2 – <5 yrs  □ 5 – <10 yrs  □ 10 – <15 yrs  □ 15 – <20 yrs
- □ 20 – <25 yrs  □ 25 – <30 yrs  □ 30 –<35 yrs  □ 35 yrs and above

7. Your post-qualified radiology work include: (can select more than one)

- □ General Radiography  □ Fluoroscopic examinations, e.g. Ba studies
- □ IVU  □ Interventional Radiology (non-vascular)
- □ CT  □ Interventional Radiology (vascular)
- □ MRI  □ U/S
- □ Nuclear Medicine

8. Your estimation % of time involved in fluoroscopic, interventional and nuclear medicine examinations in your career is:

- □ < 10 %  □ 10-20 %  □ 21-30 %  □ 31-40 %  □ 41-50 %
- □ 51-60 %  □ 61-70 %  □ 71-80 %  □ 81-90 %  □ 91-100 %

9. Which of the following protective measure/s do you use while you are performing fluoroscopic and interventional work? (can select more than one)

- □ lead apron  □ lead goggles (go to Q.10)  □ mobile lead screen
- □ thyroid shield  □ lead gloves

10. How often do you use the lead goggles in fluoroscopic and interventional work?

- □ rarely  □ occasionally
- □ sometimes  □ always

_for Cardiologist, answer Q11–14_
11. Your post-qualified experience in cardiology is:

□ < 2 yrs □ 2 – <5 yrs □ 5 – <10 yrs □ 10 – <15 yrs □ 15 – <20 yrs
□ 20 – <25 yrs □ 25 – <30 yrs □ 30 – <35 yrs □ 35 yrs and above

12. Your estimation % of time involved in fluoroscopy and interventional work in your career is:

□ < 10 % □ 10-20 % □ 21-30 % □ 31-40 % □ 41-50 %
□ 51-60 % □ 61-70 % □ 71-80 % □ 81-90 % □ 91-100 %

13. Which of the following protective measure/s do you use while you are performing fluoroscopic and interventional work? (can select more than one)

□ lead apron □ lead goggles (go to Q.14) □ mobile lead screen
□ thyroid shield □ lead gloves

14. How often do you use the lead goggles in fluoroscopic and interventional work?

□ rarely □ occasionally
□ sometimes □ always

- END of questionnaire –

Please use the enclosed envelope for returning this questionnaire.

Part II.

Please indicate if you would like to have an eye examination at the PolyU Optometry Clinic.

□ Yes (Contact number: ________________; Name: ____________________________)

Eye examination will be arranged in late 2005 and early 2006.

□ No