Patient and Staff Doses from Digital Bi-plane Coronary Angiography

J. Janeczek, D. James, A. Beal
Tawam Hospital, Al Ain, United Arab Emirates

INTRODUCTION

Coronary Angiography is the standard technique for imaging the left ventricle and coronary arteries. Within the spectrum of diagnostic imaging coronary Angiography is a high dose procedure. The number of examination has significantly increased in recent years, partly due to the introduction of diagnostic X-ray equipment with improved imaging capabilities. This has resulted not only in an improvement in patient care but also in an increase in radiation dose to the staff and patients.

In cardiac catheterization procedures C-arm equipment is often used with minimal local shields. The cardiologist and other staff members are usually working close to the area under examination and receive the dose primarily from scattered radiation from the patient (Fig. 1).

Figure 1. Cardiac catheterization procedure with members of staff locations

When the new Philips Bi-plane BV 5000 angiography unit was installed in Tawam Hospital the assessment of staff and patient doses from coronary angiography procedure was undertaken as a part of ongoing program of quality assurance and radiation protection. Measurement methods include dose-area product and thermoluminescent dosimetry. Both approaches are discussed.

The new angiography unit has dose management features which include the SpectraBeam spectral filter system. It enables better adjustment of the X-ray spectrum to the iodine K-edge which results in reduction of patient dose. The total accumulated Dose Area Product received by the patient is continuously displayed and printed at the end of the examination.

Comparison with results of patient dose reported for the same procedure performed elsewhere show that our results are below or close to the mean value for effective dose quoted by K.C. Leung and C.J. Martin (1996) of 3.1 mSv. This can be attributed in part to the modern technology and built-in dose saving features.

The procedure was slightly modified after half a year of operation by adding cardiac pacing wire insertion prior to diagnostic coronary angiography. Additionally, following the visit of application specialist a number of changes were made in the fluoroscopic and radiographic settings with the aim of improving image quality and reducing patient dose. The measurements were then repeated.

MATERIALS AND METHODS

The equipment used was a Philips BV 5000 bi-plane unit with an Optimus-CP 100 kW multipulse generator. Rotalix tubes with double focus of 0.3 and 1.0 mm were used. The anode angle was 11°. The total beam filtration was 3.5 mm Al equivalent.

The BV 5000 included an automatically programmed radiography (APR) facility, which allows a semiautomatic selection of radiological techniques. For cardiac angiography an acquisition frame rate of 12.5 fps was used. The equipment has an automatic exposure control system, which controls the mA.. Metallic image intensifiers with titanium screens were used. Position of dose reduction feature was 1 (high dose).

Two sets of measurements were conducted: scattered radiation distribution around the unit and patient equivalent dose with additional entrance dose from LAT and AP fields. Prior to the measurements analysis of 10 cardiac procedures involving patients of average size (60-80 kg) was performed. Throughout each examination, the chronological sequence of patient positions and projections was recorded for all periods of fluoroscopy and radiography. Tube potentials, fluoroscopy time and number of digital images were also recorded. Results were entered into a database for subsequent analysis. Dose area product (DAP) was measured during these procedures using a Diamentor ionization chamber (supplied and calibrated by PTW-Frieburg). The mean DAP calculated from the results of 10 patients was used as a reference value in measurements.

The cardiac catheterization procedure was recreated using a Rando Alderson phantom to simulate a patient of average size and following a chronological description of the standard examination derived from analysis of 10 cardiac procedures (Table 1).

Two types of thermoluminescent detectors (TLD) were used: TLD-100 made by Harshaw and TLD-MCP made by Niewiadomski & Co. Krakow. The former were used for patient entrance dose measurements and the latter (due to their higher sensitivity) for scatter radiation measurements.

A. Scatter radiation distribution measurement.

A rack made of thin plastic pipes was used to support TLD chips in a 3-D structure positioned close to the patient (Fig. 2). Its purpose was to measure the scattered dose distribution at the places where the cardiologist, assistant cardiologist and scrub nurse were positioned during the procedure. Other TLDs were placed on plastic poles in the areas where other staff are present during the examination (Fig. 3). Calibration of TLD-MCPs in terms of absorbed dose to air was performed using a 600 cc ion chamber as a reference.

B. Patient effective dose and entrance dose measurements.

TLD-100 were calibrated for patient surface dose measurements. They were placed around the perimeter and within the center of the most irradiated patient regions during the coronary angiogram procedure. The procedure was recreated using Rando Alderson phantom to simulate patient of average size, and following the chronological description of the standard procedure.

Conversion factor of 0.22 mSv Gy^{-1} cm^{-2} from K.C. Leung and C.J. Martin study [1] was used to calculate patient effective dose from DAP values.

Following analysis of the results, consultations with the manufacturer and application specialist changes were made to the dose saving features of the system with possibility of achieving a reduction of patient and staff dose without compromising image quality. In addition, since the initial study, the cardiologists have modified their procedure. Therefore it was decided to repeat the study following these changes.

The changes which have been made after half a year of the unit usage were as follows:

A Fluoroscopy

- In all cardiac catheterization procedures dose setting 3 (low dose) is always used.
- Pulse rate of 6 f/s is used instead of previous 12.5 f/s.
- Additional filtration modifying the X-ray spectrum to adjust it to K-edge of iodine and also to reduce the amount of low energy photons was applied.

These changes did not affected fluoroscopic image quality due to the use of progressive display monitors (PDM). Despite the lower pulse rate the resulting image was without flicker.

B Radiography

In the previous dose setting the pulse rate was 12.5 f/s and pulse duration was 7 ms. In the new dose setting pulse rate remained the same but pulse duration was increased to 10 ms resulting in better quality images.

A follow up study was conducted to assess the changes in patient effective dose .

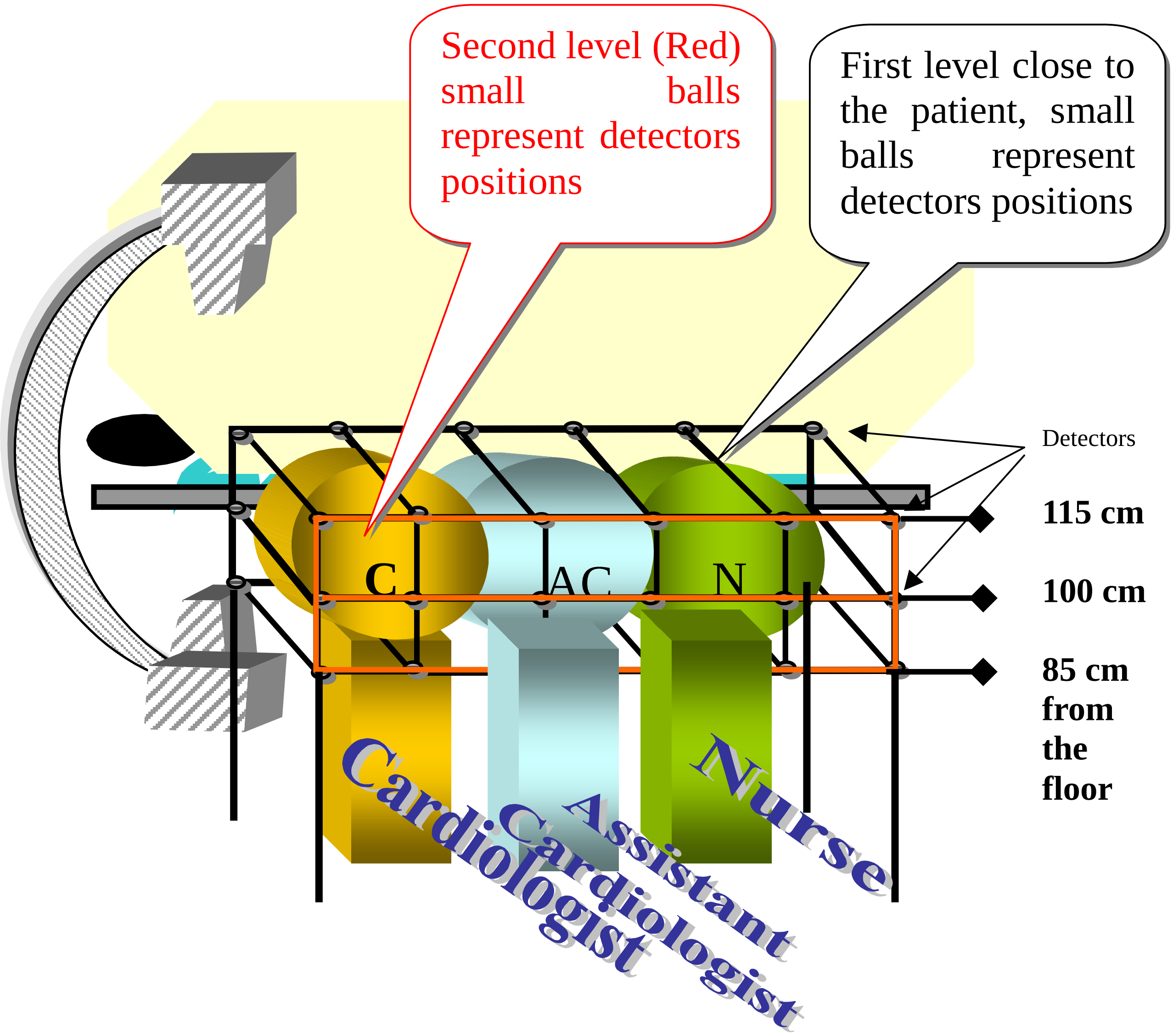


Figure 2. 3-D distribution of TLDs in the area close to the patient, where cardiologist, assistant cardiologist and scrub nurse are positioned during the procedure.

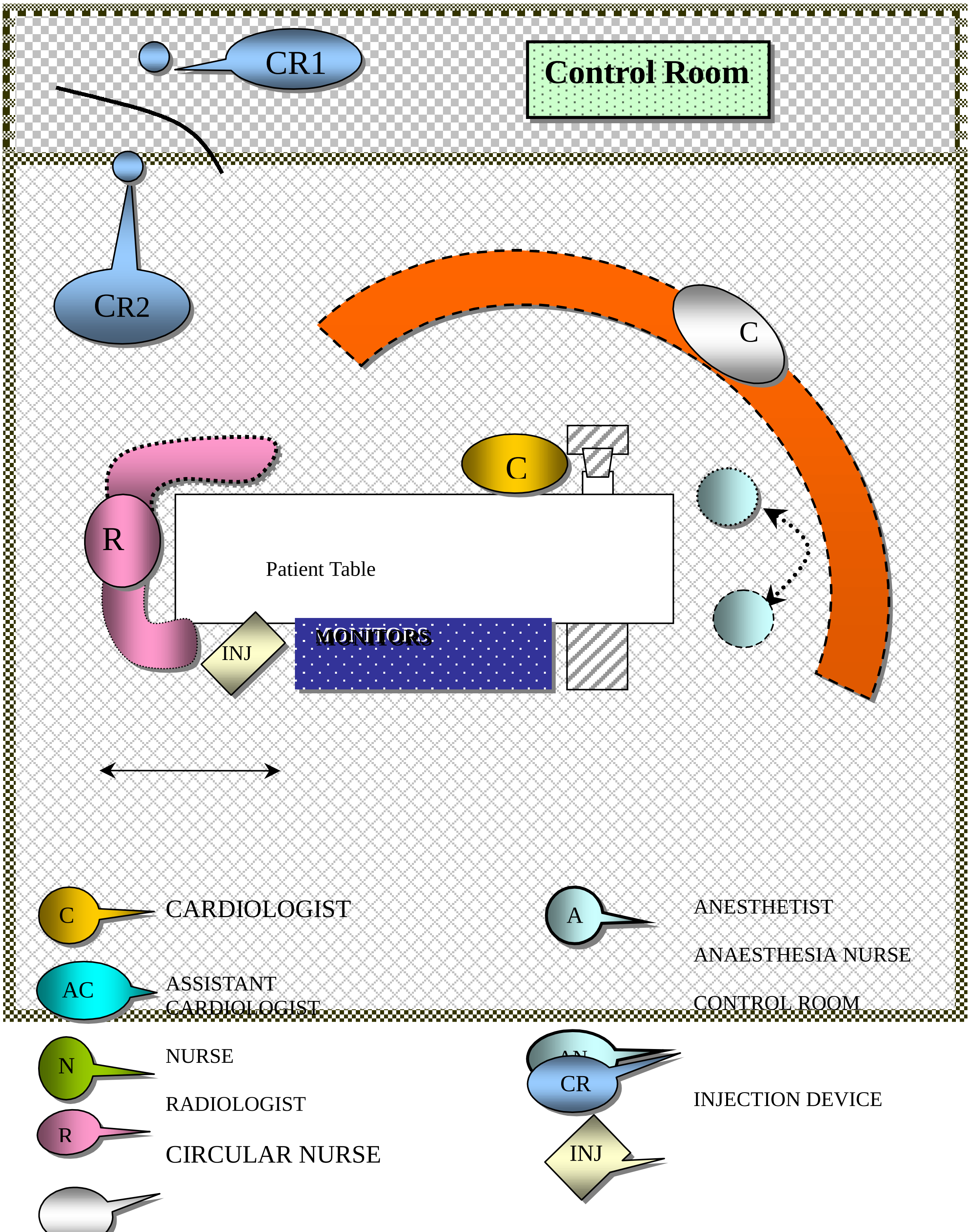


Figure 3. Positions of all the staff with two additional measuring points in the control room.

RESULTS

Simulated examination was performed following a detailed breakdown of the type of projections performed in a routine coronary angiography in Tawam Hospital (Table 1) with dose setting features at position 1 (high dose).

Mode	Region Imaged	**Projection**		**DAP (Gy cm^2)**	**Screen Time (min)**	**Digital Images**
		PA Plane	**Lateral Plane**			
F	LCA (catheterization)	PA		1.64	2.5	
R	LCA	RAO (shallow <30) cranial	LAO (Steep >30)	0.67		191
F	LCA	RAO	LAO	0.98	1.7	
R	LCA	RAO (shallow <30) caudal	LAO (steep >30) caudal	0.7		196
F	LCA	RAO	LAO	0.4	0.6	
R	LCA	RAO (shallow <30) caudal	LAO (steep >30) caudal	0.45		147
F	RCA (catheterization)	RAO	LAO	2.51	4.5	
R	RCA	RAO (shallow <30)	LAO (steep >30)	0.56		197
F	Left Ventricle (catheterization)	RAO	LAO	3.13	5.5	
R	Left Ventricle	RAO (shallow <30)	LAO (steep >30)	0.78		202
		Total DAP		11.82		
		Total Fluoroscopy Time			14.8	
		Total Digital Images				933

F – fluoroscopy R – radiography LCA – left coronary artery RCA – right coronary artery

Table 1. Chronological description of a standard cardiac catheterization examination at Tawam Hospital with mean dose area product (DAP) contributions for 10 patients of average weight.

The terminology used to describe them is taken from Paulin [2]. The majority of the projections are of the left coronary artery. The average number of views taken being six for the left coronary artery, two for the right coronary artery and two for the left ventricle. The sequence of projections used by cardiologist at Tawam Hospital was similar to that described in the UK survey [3]. The mean weight of the ten patients was 77.9 kg.

A. Scatter radiation distribution measurement.

The results of scattered radiation distribution measurements are shown in Fig. 4. Dose levels measured close to the area under examination showed relatively high doses and rapid variation in intensity (Fig. 5). Results for the locations close to the patient where staff would be present are shown in Table 2.

Staff member	**Maximum dose (mGy)**	**Minimum dose (mGy)**
Cardiologist	3.2	0.55
Assistant cardiologist	0.40	0.10
Scrub nurse	0.17	0.025

Table 2. Maximum and minimum dose levels in the places where staff is present close to the patient.

The highest dose levels occurs at the location of the cardiologist’s left arm. This location is closest to the area under examination and to the lateral X-ray tube. Other areas more distant from the beam have doses ranging from 0.095 mGy to 0.008 mGy. The lowest dose levels occur in locations partly shielded during the procedure by the C-arm or the image intensifier.

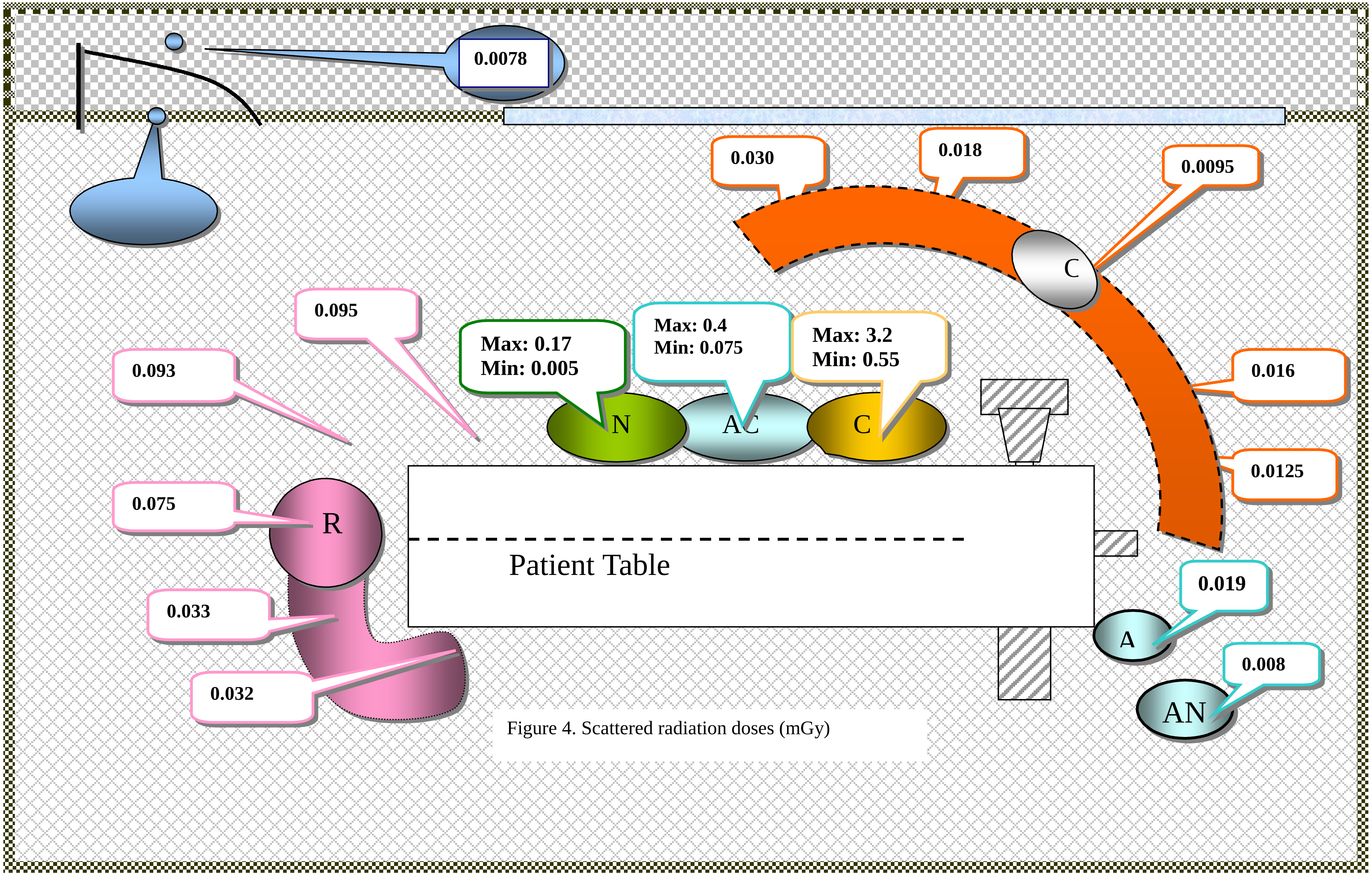
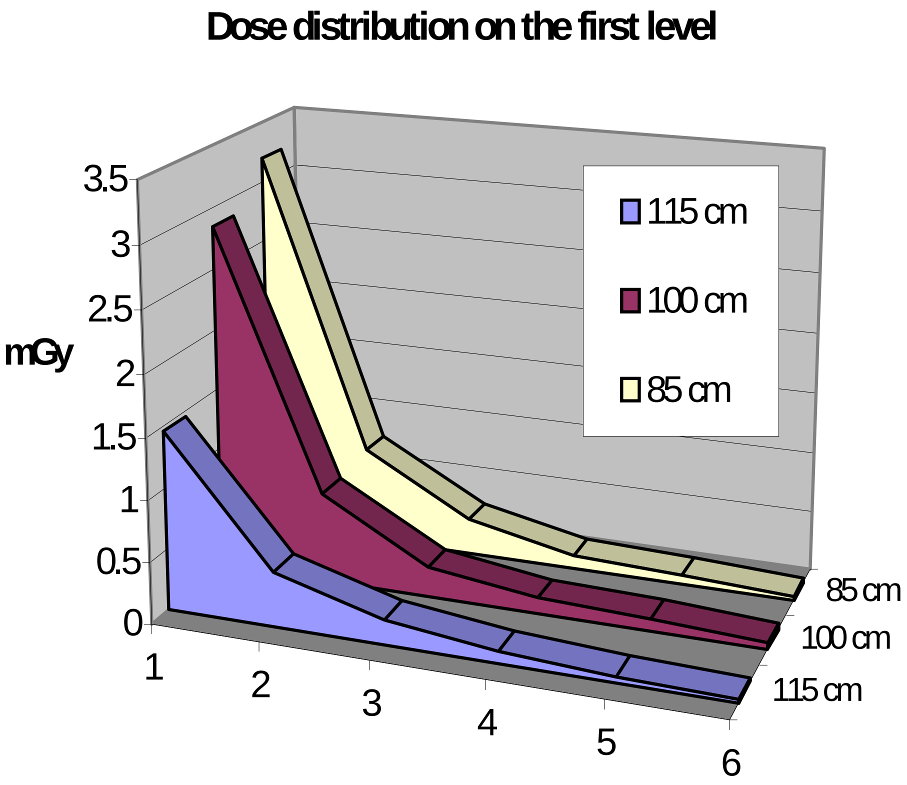


Figure 4. Scattered radiation doses (mGy)



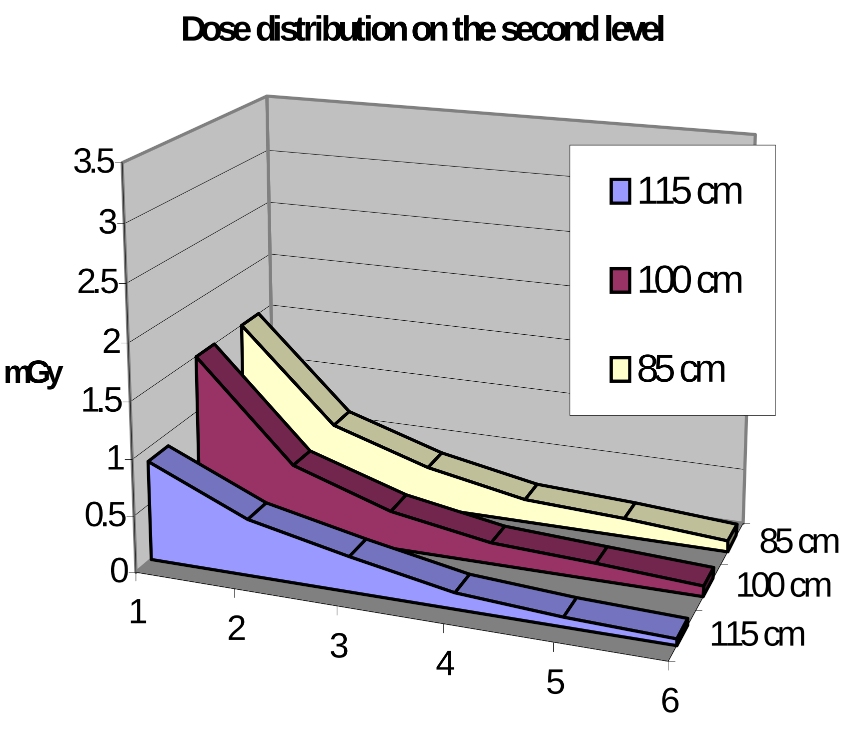


Figure 5. Dose distribution in an area where cardiologist, assistant cardiologist and scrub nurse are positioned.

B. Patient effective and entrance dose measurements.

The mean total DAP calculated from the measurements recorded during the 10 patient examinations was **11.82** Gy cm^2 (dose setting – high). This compares favorably with results reported in other studies [1,3]. Using a conversion coefficient from DAP to effective dose of 0.22 ± 0.01 mSv Gy $^{-1}$cm $^{-2}$ for the whole examination [1] a mean effective dose of **2.6** mSv was derived.

Patient entrance doses of **430** mGy for the lateral field and **180** mGy for the AP field were also measured following the replication of the standard examination procedure using the Alderson Rando phantom.

Following changes in procedure and equipment dose settings the measurements were repeated. Additional AP fluoro time of 2.5 min and DAP of 0.7 Gy cm^2 resulting from the procedure change were added. Maximum patient entrance doses were also measured. Summary of results of both measurements are given in Table 3.

Procedure		**First measurement**	**Second measurement**
Fluoroscopy	Total fluoroscopy time (min)	14.8	17.2
	DAP resulting from fluoroscopy (Gy cm^2)	8.66	4.45
Radiography	Total number of digital images	933	948
	DAP resulting from radiography (Gy cm^2)	3.16	4.0
DAP from the whole procedure (Gy cm^2)		11.82	8.45
Mean effective dose (mSv)		**2.60**	**1.86**
Patient effective dose reduction (%)		**28**	

Table 3. Summary of results from both measurements.

Patient entrance doses of **406** mGy for the lateral field and **150** mGy for the AP field were measured. They are not proportional to the new DAP value because not all the dose reductions took place in these fields.

Scatter radiation dose distribution is not expected to be changed because of modifications. The respective dose levels will be reduced proportionally to the DAPs ratio.

CONCLUSIONS

A. Scatter radiation dose distribution.

The distribution of radiation scattered from the patient undergoing the cardiac catheterization procedure has been investigated. Absorbed dose to air was measured in all positions where staff would be present during the procedure.

The results show relatively high doses and rapid dose changes in the area where cardiologist would be present. Lower dose levels and variations were observed in places of assistant cardiologist and scrub nurse.

As the result of the study the following measures concerning the staff safety, especially the cardiologist have been recommended:

1. Additional radiation protection measures like protective glasses with side shield, thyroid shields and some kind of left arm shielding.
2. Monitoring of the dose to thyroid, eyes and left arm of the cardiologist.
3. Encouragement of the staff rotation.
4. Educational activities aimed at increasing the staff awareness.

B. Patient effective dose.

The patterns of exposure during the cardiac catheterization procedures, which are illustrated by the DAP sequences in Table 1 follow a similar pattern to those reported in the UK study [3]. Therefore

the mean DAP of 11.82 Gy cm^2 for high dose setting was expected and comparable to those values quoted in the literature.

Patient effective dose reduction of 28 % resulting from the modifications of the system is considered substantial. Despite the fluoroscopy time increase by 2.5 min, dose equivalent resulting from this part of the procedure was reduced by more than 50 %. This is a significant reduction for patient and staff dose as well. These reductions were possible because of new technology incorporated in the angiography system. An important factor was the knowledgeable staff to use them properly.

The entrance dose values derived for the lateral plane are much higher than these for the AP plane and can be attributed to the correspondingly greater fluoroscopy times recorded for the lateral plane. It was used more often than the AP plane when catheterizing the right coronary artery and left ventricle.

Regular measurement of patient dose is an essential first step to optimize exposure. It makes operators aware of their own performance.

This study has shown that the procedure followed at Tawam Hospital is similar to that practiced elsewhere, and that this practice together with the new equipment and technology has resulted in considerable patient dose reductions.

REFERENCES

1. K.C. Leung, C. J. Martin, *Effective Doses for Coronary Angiography.* Br. J. Radiol. 69, 426-431, (1996).
2. S. Paulin, *Terminology for radiographic Projections in Cardiac Angiography.* Cathet. Cardiovasc. Diag. 7, 341-344, (1981).
3. R.A. Coulden, L.P. Readman, *Coronary Angiography: an Analysis of Radiographic Practice in the UK*, Br. J. Radiol. 66, 327-331, (1993).

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Richard Davis, Consultant Radiologist; Mr. Hassan Al Khatib, Supervising Radiographer and Miss Fatima Osman, Medical Physicist for their help in the preparation of this presentation.