Patient and staff dose reduction with state-of-the-art x-ray technology in cardiac catheterisation

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Aims and objectives

During the last decades there has been an important increase in the use of cardiac catheterization procedures for diagnosis and treatment of several cardiovascular disorders [1,2]. For the latter procedures, extensive use of X-rays is indispensable.

In 2012, the heart centre of the university hospital in Ghent installed, as one of the first, a novel X-ray modality equipped with new and advanced image processing algorithms and an acquisition chain optimized specifically for cardiac catheterization applications (ClarityIQ, Philips Healthcare, The Netherlands). In a previous study we confirmed that this technology drastically reduces patient radiation dose, while maintaining diagnostic image quality [3].

However, in this previous study we did not focus on the radiation exposure of the staff. As staff members of the catheterization lab often need to be in close proximity to the patient during the interventions, the corresponding staff doses are reported to be among the highest for medical staff in general [4-7].

The purpose of current study was to set up a randomized controlled trial to quantify the radiation dose reduction for both patient and staff, using the latter new acquisition technology and real-time staff dose monitoring systems.
Methods and materials

Imaging Modalities

Patient and operator radiation exposure were measured on a reference X-ray modality (room A: Allura Xper FD10, Philips Healthcare, The Netherlands) and on a state-of-the-art modality (room B: Allura Clarity FD20/10, Philips Healthcare, The Netherlands) equipped with ClarityIQ technology (ClarityIQ, Philips Healthcare, The Netherlands). Room A is a monoplane modality, while room B has a biplane configuration.

Study Design

In total 112 adult patients were randomly assigned to one of two cath labs, either the reference X-ray modality or the new X-ray system. Exposure parameters and staff dosemeter readings were recorded for each cinegraphy and fluoroscopy exposure. Patients with CABG were excluded from the study. A standard diagnostic coronary angiography protocol was applied, including one ventriculogram of the left ventricle. Only procedures with right femoral access were included.

Patient Dose - Clinical study

At the end of each procedure a cumulative dose report, containing total DAP, fluoroscopy DAP, cinegraphy DAP, total Air Kerma, etc., was printed in room A. Dose information per acquisition was not available for this modality. Room B is equipped with DICOM Radiation Dose Structured Reporting (RDSR). These digital DICOM reports are also generated at the end of each procedure and sent to a central server inside the department (Figure 1). These RDSRs contain the same cumulative information as the dose reports in room A, with extensive additional information per cine and fluoroscopy run such as tube voltage, tube current, DAP, Air Kerma, rotation and angulation of the C-arm, filtration, number of exposure images, beam size, etc.

Occupational Dose - Clinical study

Staff dose was measured and archived using the DoseAware system (DoseAware, Philips Healthcare, The Netherlands). The latter system consists of a set of calibrated solid-state personal dosemeters (PDM), logging the cumulative personal dose equivalent Hp(10) every second. All PDMs are connected wirelessly to a base station which displays and archives the measurements of all connected dosemeters in real-time. This system was available in room A.

Room B was equipped with an upgraded version, i.e. DoseAware Xtend, digitally linked to the X-ray modality. At the end of the procedure this system automatically sends a
DICOM Structured Report containing the cumulative occupational doses of each PDM measured during the whole procedure, and additionally the occupational dose measured per irradiation event (Figure 1). This structured report is referred to as the Operator Dose Structured Report (ODSR). In each room six PDMs were available, one reference PDM mounted on the C-arm, three for the cardiologist (leg, chest and collar) and two for the technologist (chest and collar).

**Scatter Dose - Phantom study**

To be able to understand the differences in occupational dose (OD) between both cath labs, the occupational dose in both rooms should be compared in a situation where the position of the PDMs and the tube output, i.e. the DAP, are equal in both rooms. Controlled scatter measurements were performed with a 20 cm PMMA phantom, of which the middle was positioned at the isocenter of the C-arm. Three PDMs were attached next to each other to a horizontal rod. Scatter was measured at different heights of the horizontal rod above and below the table. In both rooms the measurements were performed at the same height relative to the table top and at the same distance from the PMMA phantom.
Fig. 1: In room B both the X-ray modality and the DoseAware Xtend system have DICOM Structured Reporting capabilities. The X-ray modality automatically sends a Radiation Dose Structured Report (RDSR) upon completion of the procedure. This report contains patient dose indicators (DAP, Air Kerma) and other exposure parameters (tube current, tube voltage, beam collimation, etc.) for each irradiation event. The DoseAware Xtend system also sends a structured report (Operator Dose Structured Report, ODSR) at the end of the procedure, containing the Hp(10) and Hp(10) rate per irradiation event. Both RDSR and ODSR are sent to a DICOM receiver deployed on a central server inside the department. All parameters and their corresponding values present inside these reports are saved in a database.

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Results

With the novel equipment, DAP values decreased from 54 Gycm² to 20.4 Gycm², which is a 62% reduction compared to the reference room (p<0.001). The C-arm and leg dosemeter readings were reduced with 61% (p<0.001) and 57% (p<0.001) respectively, while chest and collar dosemeter readings increased by 2% and decreased by 6% respectively. The difference between chest and collar dosemeter readings in both rooms were not statistically significant. The occupational dose of the technologists showed no statistically significant differences.

Phantom measurements were performed to define the radiation scatter behavior to which the staff is exposed. These measurements explain why there was a significant difference for the leg dosemeter and not for the chest and collar dosemeters. Figure 2 shows the results of the phantom measurements, with the table top taken as the reference height. Here the operator dose (OD) is normalized by the DAP (OD_{DAP}). This figure clearly shows that for the standard cinegraphy protocol in both rooms, the OD_{DAP} is much higher in room B than in room A. This can be attributed to the higher filtration used for the standard cinegraphy protocol in room B, i.e. 0.4mm Cu + 1mm Al. For the fluoroscopy protocols this difference is no longer present, since in both rooms the same additional beam filtration is used for fluoroscopy. The OD_{DAP} in room B was increased by about the same factor as the DAP was decreased in room B, compared to room A. This explains that the chest and collar measurements did not differ between both rooms.

The lower dose registered by the leg dosemeter in room B is due to a difference in isocenter position between the rooms. In room B the isocenter is located 7 cm higher from the floor than in room A, meaning that the chest and collar dosemeters in room B are closer to the scatter source (i.e. the patient) than in room A, and likewise that the leg dosemeter is further away from the scatter source (Figure 3). When we take the floor level as the reference, instead of the table top as in Figure 2, we take into account this isocenter difference. This is shown in Figure 4, where it is clear that at the height of the leg dosemeter, the OD_{DAP} curves of both rooms are in close proximity for both cinegraphy and fluoroscopy. Figure 5 again shows that the OD_{DAP} differences vary above and below the patient table.
Fig. 2: Variation of the mean occupational personal dose equivalent Hp(10) normalized per DAP (OD_DAP), in function of PDM height. Height is expressed in centimeters, relative to the table top of the patient table. OD_DAP is expressed in µSv/(Gy.cm²). To be able to clearly distinguish both curves, only one side of the symmetric error bars is shown. (a) Cinegraphy acquisition, (b) Fluoroscopy exposure.

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Fig. 3: The distance between the floor of the cath lab and the isocenter of the C-arm is 7 cm higher in room B compared to room A. The chest and collar dosemeters in room B
are therefore closer to the scatter source (i.e. the patient) than in room A, and likewise, the leg dosemeter is further away from the scatter source.

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![Fig. 4](image)

**Fig. 4:** Variation of the mean occupational personal dose equivalent Hp(10) normalized per DAP (OD_DAP), in function of PDM height. Height is expressed in centimeters, relative to the floor of the cath lab. OD_DAP is expressed in µSv/(Gy.cm²). To be able to clearly distinguish both curves, only one side of the symmetric error bars is shown. (a) Cinegraphy acquisition, (b) Fluoroscopy exposure.

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Fig. 5: The ratio of the Hp(10) normalized to DAP in cath lab B relative to cath lab A (OD_DAP Ratio), expressed in percentage. Height is expressed in centimeters. The ground level is taken as the reference equal to 0 cm. The OD_DAP Ratio was calculated for PDMs at the same distance from the floor in cath lab A and B.
Conclusion

The introduction of a novel x-ray and image processing technology, significantly reduces patient dose in coronary angiographies and PCIs with 62%. Applying supplemental DICOM SR capabilities for occupational dose, additional to the use of DICOM SR for reporting patient exposure and geometry settings, makes it easy to directly analyze both patient and operator exposure in more detail. Staff dose was significantly reduced by 63% below table, in the cath lab with novel technology compared to the reference lab. Yet, above table lesser occupational dose reductions were registered at torso and collar level.

Literature often assumes that when patient exposure drops, occupational exposure will also decrease proportionally. Scatter should be monitored at multiple locations, and during different types of procedures, to make general conclusions. This study clearly indicates that the scatter cloud behavior changes with differing positions of measurement and that the scatter behavior is highly dependent on C-arm rotation, operator movement and height, x-ray beam filtration, clinical procedure type and system geometry.
References