Reducing Radiation Dose in Coronary Angiography and Angioplasty Using Image Noise Reduction Technology

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This study sought to quantitatively evaluate the reduction of radiation dose in coronary angiography and angioplasty with the use of image noise reduction technology in a routine clinical setting. Radiation dose data from consecutive 605 coronary procedures (397 consecutive coronary angiograms and 208 consecutive coronary interventions) performed from October 2014 to April 2015 on a coronary angiography system with noise reduction technology (Allura Clarity IQ) were collected. For comparison, radiation dose data from consecutive 695 coronary procedures (435 coronary angiograms and 260 coronary interventions) performed on a conventional coronary angiography system from October 2013 to April 2014 were evaluated. Patient radiation dosage was evaluated based on the cumulative dose area product. Operators and operator practice did not change between the 2 evaluated periods. Patient characteristics were collected to evaluate similarity of patient groups. Image quality was evaluated on a 5-grade scale in 30 patients of each group. There were no significant differences between the 2 evaluated groups in gender, age, weight, and fluoroscopy time (6.8 ± 6.1 vs 6.9 ± 6.3 minutes, not significant). The dose area product was reduced from 3195 ± 2359 to 983 ± 972 cGycm^2 (65%, p <0.001) in coronary angiograms and from 7123 ± 4551 to 2431 ± 1788 cGycm^2 (69%, p <0.001) in coronary interventions using the new noise reduction technology. Image quality was graded as similar between the evaluated systems (4.0 ± 0.7 vs 4.2 ± 0.6, not significant). In conclusion, a new x-ray technology with image noise reduction algorithm provides a substantial reduction in radiation exposure without the need to prolong the procedure or fluoroscopy time. **(Am J Cardiol 2016;118:353−356)**

This study aims to quantify the radiation dose reduction in coronary angiography and coronary angioplasty in a routine clinical setting by the use of the new imaging system.

Methods

Consecutive patients undergoing coronary angiography and angioplasty in a catheterization laboratory exclusively used for coronary angiography and coronary angioplasty at the Bonifatius Hospital Lingen (Lingen, Germany) were included in this study. Patients were included from 2 periods (period A: January 2014 to June 2014 and period B: November 2014 to April 2015). During period A, patients were studied on a conventional biplane angiography system. After replacement of the system, patients were studied during period B on a biplane angiography system with an image processing chain for noise reduction in fluoroscopy. A total of 1,295 patients were included in the study, 690 patients during period A and 605 patients during period B. Patient characteristics and procedural characteristics are given in Table 1. No patient was excluded for poor renal function or high body mass index (BMI). There were no changes in operators or operator techniques between the 2 study periods. In 84% the access site has been the radial artery for invasive and interventional procedures during period A and in 85% in period B. To evaluate the impact of BMI on the reduction of radiation dosage, 3 different BMI groups were evaluated; group A: BMI below 20 kg/m^2, group B: BMI 20 to 30 kg/m^2, and group C: BMI above 30 kg/m^2. Procedures were divided into diagnostic and interventional. Procedures with ad hoc intervention were counted as interventional only. Procedural data such as fluoroscopy time and contrast medium volume were collected to compare procedure complexity. The cumulative dose area product in cGycm^2 was determined as indicator of radiation dose.

During period A, a conventional biplane angiography system (Siemens BICOR HI-P/Hicor TOP; Siemens, Erlangen, Germany) was used. During period B, a biplane flat panel angiography system with advanced real-time image noise reduction algorithms and optimized acquisition chain for fluoroscopy and exposure techniques (Allura Xper FD 20/10; Philips Healthcare, Best, the Netherlands, with Clarity IQ technology) was used. The real-time image noise reduction algorithm (Clarity IQ) uses several features to allow reduction of radiation dose. Noise reduction consists of both temporal and spatial noise reduction. Temporal noise reduction refers to processing that is carried out over time, thus, over subsequent images, and spatial noise reduction refers to processing

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Table 1
Patient demographics and baseline characteristics

Coronary angiography	Reference Patients	Noise reduction Patients
	(N=431)	(N=397)
Age (years)	66.5±12.1	67.7±12.2
Men	276 (64%)	255 (64%)
Weight (kg)	84.0±18.4	86.2±20.0
Size (cm)	172.1±9.4	171.9±9.8
Body mass index (kg/m^2)	28.3±5.3	28.8±5.0
Coronary angioplasty	**(N=259)**	**(N=208)**
Age (years)	70.4±10.9	69.0±11.6
Men	173 (67%)	139 (67%)
Weight (kg)	84.8±16.3	87.0±18.8
Size (cm)	172.1±8.9	172.5±9.6
Body mass index (kg/m^2)	28.6±5.2	29.4±6.7
All procedures	**(N=690)**	**(N=605)**
Age (years)	68.0±11.8	68.1±11.8
Men	449 (65%)	394 (65%)
Weight (kg)	84.3±17.8	86.1±19.0
Size (cm)	172.1±11.1	172.1±14.5
Body mass index (kg/m^2)	28.4±5.4	29.0±5.6

cm = centimeter; kg = kilogram; kg/m^2 = kg/square meter.

Table 2
Procedural data and radiation dosages

Coronary angiography	Reference Patients	Noise reduction Patients	P
	(N=431)	(N=397)	
Fluoroscopy time (min)	4.6±4.3	4.7±4.4	n.s.
Contrast volume (cc)	72.6±43.8	81.0±47.7	n.s.
Dose area product (cGycm^2)	3193±2358	984±975	<0.001
Coronary angioplasty	**(N=259)**	**(N=208)**	
Fluoroscopy time (min)	10.4±6.9	11.1±7.1	n.s.
Contrast volume (cc)	170.2±69.1	175.2±73.1	n.s.
Dose area product (cGycm^2)	7123±4551	2430±1981	<0.001
All procedures	**(N=690)**	**(N=605)**	
Fluoroscopy time (min)	6.8±6.1	6.9±6.3	n.s.
Contrast volume (cc)	109.1±72.3	113.4±73.5	n.s.
Dose area product (cGycm^2)	4663±3852	1478±1559	<0.001

cc = cubic centimeters; cGycm^2 = centi Gray cm^2; min = minutes; n.s. = not significant.

carried out over an area within one image. Temporal noise is reduced by averaging several frames. The Clarity IQ noise reduction algorithm uses motion compensation by aligning moving structures before averaging. Thus, considering motion compensation, more frames can be used and stronger temporal filtering can be applied. The result is a better noise reduction for moving structures. Spatial noise reduction refers to finding the noise within a single image and filtering it out pixel by pixel. Pixels of the so-called neighborhood are considered for the spatial filtering algorithms. By averaging the pixel intensity of the surrounding, noise can be filtered out. By averaging larger neighborhoods due to more computational power, more noise can be reduced. Subsequently, by improved temporal and spatial noise reduction, more noise is reduced allowing less radiation dosage for similar image quality. Furthermore, the x-ray acquisition chain was optimized to allow patient radiation dose reduction with similar image quality.

For analysis of image quality, 30 randomly selected coronary angiograms were evaluated from each group. In each study, a cine run of the left coronary artery was evaluated. The projection had to be left anterior oblique 45° with a cranial angle of 20°. Image quality was assessed on a scale from 1 to 5 with 1 indicating poor image quality and 5 indicating excellent image quality. Reading of images was performed by 2 doctors blinded to the acquisition fashion. The assessment of the 2 doctors was averaged for each case.

Statistical analysis was performed using SPSS software, version 17.0 (SPSS, Inc., Chicago, Illinois). Categorical data are presented as frequencies and were compared using the Fischer's exact test. Continuous data were presented as mean ± SD and compared using the Student *t* test or analysis of variance as adequate. Dose area product was related to BMI using linear regression analysis. A $p < 0.05$ was considered significant.

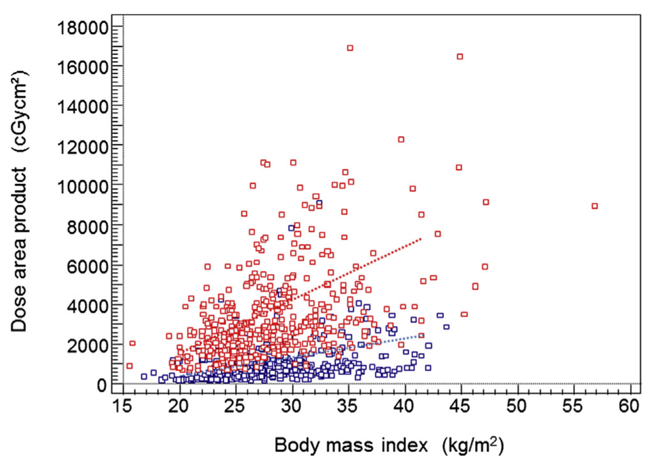

Figure 1. Dose area product for coronary angiography related to BMI using the conventional imaging system (*red dots*, n = 431 patients) and using the radiation noise reduction system (*blue dots*, n = 397 patients). There is a correlation between dose area product and BMI for both imaging systems. The regression line for the conventional imaging system is at a substantially higher dose area product level compared with the radiation noise reduction system.

Results

The fluoroscopy times between the 2 patient groups were similar. This finding relates to coronary angiography and coronary angioplasty procedures (Table 2).

There was a substantial decrease of more than 60% in radiation dosage for both coronary angiography and coronary angioplasty procedures (Table 2). Considering all procedures, the mean dose area product decreased from 4663 ± 3852 to 1477 ± 1556 cGycm^2 ($p < 0.001$). Mean dose area product using the conventional system and considering all procedures was 3275 ± 3063 cGycm^2 for female patients and 5417 ± 4027 cGycm^2 for male patients.

Considering the radiation noise reduction system, the mean dose area product was 1045 ± 1112 $cGycm^2$ for female patients and 1711 ± 1712 $cGycm^2$ for male patients. Mean dose area product with the conventional fluoroscopy system was 1672 ± 981 $cGycm^2$ in patients with a BMI <20 kg/m^2, 4094 ± 3482 $cGycm^2$ in patients with a BMI 20 to 30 kg/m^2 and 6009 ± 4249 $cGycm^2$ in patients with a BMI ≥30 kg/m^2. Considering the radiation noise reduction system, mean dose area product was 556 ± 369 $cGycm^2$ in patients with a BMI <20 kg/m^2, 1261 ± 1175 $cGycm^2$ in patients with a BMI 20 to 30 kg/m^2 and 1899 ± 2015 $cGycm^2$ in patients with a BMI ≥30 kg/m^2. Thus, the mean reduction in dose area product was equal between the 3 BMI groups (67%, 69%, and 68%, respectively). There was a correlation of patient dose area product with the BMI considering conventional and image noise reduction technology. However, considering the image noise reduction technology, the regression line was on a significantly lower dose area product level (Figure 1).

The average image quality using the conventional imaging system was graded as 4.0 ± 0.7. Using the radiation noise reduction system, the average image quality was graded as 4.2 ± 0.6 (p = not significant).

Discussion

The main findings of this study are (1) image quality using noise reduction technology is not inferior to image quality using conventional radiation technology; (2) radiation dosage is substantially reduced with radiation noise reduction technology compared with conventional radiation technology; and (3) the reduction in radiation dosage affects all patient groups and all procedures and does not result in higher contrast media consumption.

Although the benefits of cardiac intervention procedures are indisputable for the patients, the growing number of procedures with the use of ionizing radiation in medical imaging and intervention has contributed substantially to an increase in radiation exposure.[1] Similarly, significant radiation exposure to the operator has been associated with a substantial risk to develop considerable adverse effects and even malignancy.[2–4] Thus, there is an increasing awareness of potential risks of radiation exposure to patient and operator. To reduce patient and operator radiation dose involves optimization of medical imaging equipment and best control of the equipment by the operator. There is considerable variation in reported radiation dosages due to differences in procedure complexity, patient sizes, x-ray equipment technology, acquisition by monoplane or biplane techniques and experience by the operator.[5–8] Significant reductions in radiation dosage can be achieved by intelligent usage of x-ray equipment by the operator.[9,10] In addition, developments in imaging equipment have aimed at lowering per procedure radiation dosage.[11–13]

The introduction of new x-ray imaging technology using an image noise reduction technology has been reported and radiation dose reduction has been described using this technology.[14,15] This technology enables a significant reduction in patient entrance dose due to a combination of advanced real-time image noise reduction algorithms with modern hardware and an optimized full acquisition chain (grid switch, beam filtering, pulse width, spot size, detector, and image processing engine). Christopoulos et al[16] performed a bench testing with an anthropomorphic phantom using different projections to compare radiation dose between 4 fluoroscopy systems. They reported considerable differences in radiation dose between the 4 systems with the dose area product being only 26% with the novel noise reduction technology compared with the system with highest radiation exposure. The impact of the new technology in clinical practice has first been evaluated in neuroangiography. Söderman et al[15] reported on the use of the image noise reduction technology in a population study based on 614 patients. They demonstrated an approximately 60% radiation dose reduction in neuroangiography and interventional neuroradiology with the use of the image noise reduction technology. The number of studies which have evaluated the new technology in the clinical setting of cardiology is limited. Haas et al[16] reported on the use of the technology in pediatric and adult congenital heart disease patients in comparison with a reference system. Considering different patient weight groups, there was a reduction of radiation dose between 56% and 71% using the new technology compared with the reference technique.[16] The new system has been used in the electrophysiology setting in a study which included 136 patients.[17] All patients were studied on the same fluoroscopy system. However, in half of the patients, conventional imaging settings were applied with the new imaging chain being switched off, whereas in the other half, the novel imaging technology was used. There was a 43% reduction in dose area product using the new acquisition technique. Interestingly, this study also found a 50% reduction in operator radiation dose with the new imaging technology.

Nakamura et al[18] reported on the radiation dosage using the new noise reduction technology in comparison with reference technique for cardiac angiography and intervention. They reported a 66% patient dose reduction in interventional cardiology. Bracken et al[19] reported data of 135 patients in whom the dose reduction technology was used for cardiac procedures and compared the data to 268 reference patient. They reported a reduction in dose area product of 46% in diagnostic procedures and of 34% in interventional procedures. There has been one study including 50 patients which evaluated the impact of image noise reduction technology by studying the same patients twice.[20] All patients underwent one image acquisition with standard image processing and exposure setting and one with advanced image processing and optimized exposure system settings. Cine images acquired with the novel x-ray image noise reduction technology were considered to have equal or better image quality compared with the reference cine. Median dose area product per patient was reduced by 53%. However, the study evaluated only the left anterior oblique cranial angulation.

Thus, the results of our study confirm in a large patient number reflecting the routine clinical setting that the image noise reduction technology allows a significant reduction in radiation dose. The German National Registry on coronary angiography and percutaneous coronary intervention provides annual insights into the mean dose area product reported from all catheterization laboratories in Germany.[21]

The mean dose area product reported from the 2013 German National Registry has been 2710 $cGycm^2$ for coronary angiography. In this study, a mean dose area product of only 983 $cGycm^2$ was observed in those patients in whom the image noise reduction technology was applied. Thus, as imaging and interventional techniques at this center reflect German standards, the substantially lower radiation dosage achieved in a routine clinical setting with the image noise reduction technique, provide further evidence of the substantial impact of the new technology. They indicate potential reduction in radiation dosage in invasive and interventional cardiology with more diffusion of newer radiation technology in clinical practice.

This study has several limitations. Patients have not been randomized to the 2 applied imaging technologies. Changes in procedural workflow would have been better accounted for by a randomization process. However, there was no change in operator participation between the evaluated time periods, procedural techniques remained stable as reflected by the similarity in fluoroscopy times and applied contrast volume between study groups, and patients were also very similar between the evaluated cohorts regarding age, gender, size, and body mass. This study reports only the results of one center. Data acquired at multiple centers would have better reflected variations in procedural techniques and operators.

Disclosures

The authors have no conflicts of interest to disclose.

1. Fazel R, Krumholz HM, Wang Y, Ross JS, Chen J, Ting HH, Shah ND, Nasir K, Einstein AJ, Nallamothu BK. Exposure to low-dose ionizing radiation from medical imaging procedures. *N Engl J Med* 2009;361:849−857.
2. Knuuti J, Järvinen J. CardioPulse. Radiation exposure and the risk of cancer for interventional cardiologists and electrophysiologists. *Eur Heart J* 2014;35:603−604.
3. Roguin A, Goldstein J, Bar O, Goldstein JA. Brain and neck tumors among physicians performing interventional procedures. *Am J Cardiol* 2013;111:1368−1372.
4. Buchanan GL, Chieffo A, Mehilli J, Mikhail GW, Mauri F, Presbitero P, Grinfeld L, Petronio AS, Skelding KA, Hoye A, Mehran R, Morice MC; Women In Innovation Group. The occupational effects of interventional cardiology: results from the WIN for Safety survey. *EuroIntervention* 2012;8:658−663.
5. Bar O, Maccia C, Pages P, Blanchard D. A multicentre survey of patient exposure to ionizing radiation during interventional cardiology procedures in France. *EuroIntervention* 2008;3:593−599.
6. Miller DL, Hilohi CH, Spelic DC. Patient radiation doses in interventional cardiology in the U.S.: advisory data sets and possible initial values for U.S. reference levels. *Med Phys* 2012;39:6276−6286.
7. Pantos I, Patatoukas G, Katritsis DG, Efstathopoulos E. Patient radiation doses in interventional cardiology. *Curr Cardiol Rev* 2009;5:1−11.
8. Fetterly KA, Lennon RJ, Bell MR, Holmes DR Jr, Rihal CS. Clinical determinants of radiation dose in percutaneous coronary interventional procedures. Influence of patient size, procedure complexity, and performing physician. *JACC Cardiovasc Interv* 2011;4:336−343.
9. Wassef AW, Hiebert B, Ravandi A, Ducas J, Minhas K, Vo M, Kass M, Parmar G, Hussain F. Radiation dose reduction in the cardiac catheterization laboratory using a novel protocol. *JACC Cardiovasc Interv* 2014;7:550−557.
10. Agarwal S, Parashar A, Bajaj NS, Khan I, Ahmad I, Heupler FA Jr, Bunte M, Modi DK, Tuzcu EM, Kapadia SR. Relationship of beam angulation and radiation exposure in the cardiac catheterization laboratory. *JACC Cardiovasc Interv* 2014;7:558−566.
11. Plastaras C, Appasamy M, Sayeed Y, McLaughlin C, Charles J, Joshi A, Macron D, Pukenas B. Fluoroscopy procedure and equipment changes to reduce staff radiation exposure in the interventional spine suite. *Pain Physician* 2013;16:E731−E738.
12. Agarwal S, Parashar A, Ellis SG, Heupler FA Jr, Lau E, Tuzcu EM, Kapadia SR. Measures to reduce radiation in a modern cardiac catheterization laboratory. *Circ Cardiovasc Interv* 2014;7:447−455.
13. Christopoulos G, Papayannis AC, Alomar M, Kotsia A, Michael TT, Rangan BV, Roesle M, Shorrock D, Makke L, Layne R, Grabarkewitz R, Haagen D, Maragkoudakis S, Mohammad A, Sarode K, Cipher DJ, Chambers CE, Banerjee S, Brilakis ES. Effect of a real-time radiation monitoring device on operator radiation exposure during cardiac catheterization: the radiation reduction during cardiac catheterization using real-time monitoring study. *Circ Cardiovasc Interv* 2014;7:744−750.
14. Söderman M, Holmin S, Andersson T, Palmgren C, Babic D, Hoornaert B. Image noise reduction algorithm for digital subtraction angiography: clinical results. *Radiology* 2013;269:553−560.
15. Söderman M, Mauti M, Boon S, Omar A, Marteinsdottir M, Andersson T, Holmin S, Hoornaert B. Radiation dose in neuroangiography using image noise reduction technology: a population study based on 614 patients. *Neuroradiology* 2013;55:1365−1372.
16. Haas NA, Happel CM, Mauti M, Sahyoun C, Tebart LZ, Kececioglu D, Laser KT. Substantial radiation reduction in pediatric and adult congenital heart disease interventions with a novel X-ray imaging technology. *Int J Cardiol* 2015;6:101−109.
17. Dekker LR, van der Voort PH, Simmers TA, Verbeek XA, Bullens RW, Veer MV, Brands PJ, Meijer A. New image processing and noise reduction technology allows reduction of radiation exposure in complex electrophysiologic interventions while maintaining optimal image quality: a randomized clinical trial. *Heart Rhythm* 2013;10:1678−1682.
18. Nakamura S, Kobayashi T, Funatsu A, Okada T, Mauti M, Waizumi Y, Yamada S. Patient radiation dose reduction using an X-ray imaging noise reduction technology for cardiac angiography and intervention. *Heart Vessels* 2016;31:655−663.
19. Bracken JA, Mauti M, Kim MS, Messenger JC, Carroll JD. A radiation dose reduction technology to improve patient safety during cardiac catheterization interventions. *J Interv Cardiol* 2015;28:493−497.
20. ten Cate T, van Wely M, Gehlmann H, Mauti M, Camaro C, Reifert N, Suryapranata H, de Boer MJ. Novel X-ray image noise reduction technology reduces patient radiation dose while maintaining image quality in coronary angiography. *Neth Heart J* 2015;23:525−530.
21. AQUA-Federal evaluation. Coronary Angiography and Percutaneous Coronary Intervention (PCI). Indicators of Quality. Göttingen: AQUA-Institute for applied quality support and research in health service Ltd; 2013:62. [updated 2014 May 7], Available at: http:/www.sqg.de/sqg/upload/CONTENT/Qualitätsberichte/2013/AQUA-Qualitätsreport-2013.pdf. Accessed on May 1, 2016.