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Original article

# Long-term strategies support autonomy in radiation safety in invasive cardiology

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ABSTRACT

*Background and purpose:* Despite comprehensive radiation safety programs, radiation exposure in invasive cardiology remains considerable. According to the 2013 German Registry, median in-hospital dose area products (DAP) amount to 19.8 Gy cm$^2$ for invasive coronary angiography (CA). We analyzed long-term radiation-reducing strategies for an experienced interventionalist from 1997 to 2012, for the target intervention of CA.

*Methods:* Among representative cohorts, we evaluated iterative alterations in collimation, time on beam, pulse rates, detector entrance doses, and angulations on the basis of DAP, radiographic DAP$^R$ and fluoroscopic DAP$^F$, the respective times on beam, and the number of frames and runs.

*Results:* Patients' median overall DAP decreased from 33.8 Gy cm$^2$ at baseline to 2.4 and 0.6 Gy cm$^2$ for CA in conventional (C) and electrocardiogram-gated (E) modes – one diastolic radiographic frame per heartbeat at 77% of the RR interval. Further median dose parameters for CA at baseline and finally in C/E mode were as follows: effective dose (6.76–0.48/0.13 mSv), radiography time (43.8–12.9/21.7 s), frames (548–105/25), frames/run (41.3–14.4/3.4), DAP$^R$/frame (42.6–16.6/12.6 mGy cm$^2$), DAP$^R$/s (532–130/13.8 mGy cm$^2$/s), fluoroscopy time (195–120/119 s), DAP$^F$/pulse (2.0–1.1/0.8 mGy cm$^2$), and DAP$^F$/s (48.9–4.4/3.1 mGy cm$^2$/s).

*Conclusions:* Our data highlight the efficacy of various radiation-reducing strategies by autonomous control and iterative training in radiation safety toward submillisievert levels for CA, and define realizable benchmarks for comparison with the performance data of any individual.

## Introduction

Despite comprehensive guidelines and training concepts on radiation safety practice [1–4], patient exposure in invasive cardiology (Fig. 1) [2–24] – i.e. for coronary angiography (CA) and interventions (Fig. 2) [10–24] – remains considerable and varies greatly. It depends on body mass index, age, sex [16–18], procedure complexity [20] and interventional experience [16–18], catheterization mode [10], technology [12,16], as well as equipment handling techniques such as optimization of time on beam [21,22], collimation [21], magnification, copper filtering [16], pulsing and detector entrance dose [10,12,23], and preference for less-irradiating angulations [25]. CA is both a well-accepted target and marker intervention for radiation safety efforts [13,16].

By implementation of radiation-reducing interventional techniques and by application of new technologies, we have since 1997 succeeded in decreasing median dose area products (DAP) for CA from 33.8 to 0.6 Gy cm$^2$ [10,21]. Comprehensive long-term assessment of multiple key dose parameters has provided step-by-step support with this plan-do-check-act approach. The objective here is to develop reliable tools for documentation, disclose essential determinants of patient radiation exposure, and analyze the efficacy of various radiation safety strategies. Our objective was – irrespective of any confounding cathlab technology – to provide the cardiologist with reliable data for comparison with any individual performance and to qualify him or her toward

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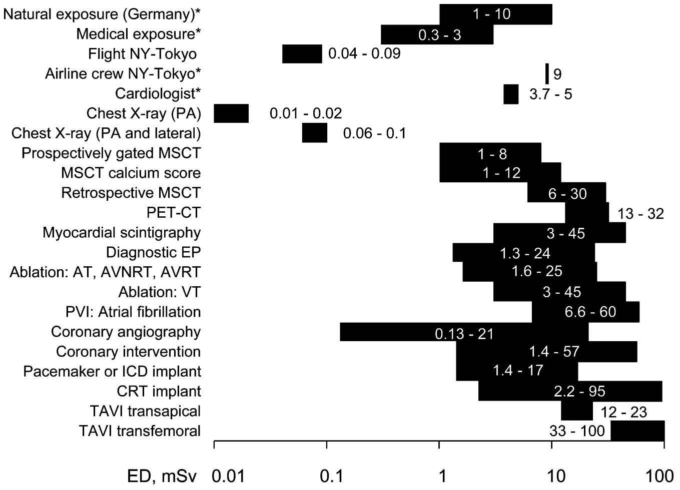

**Fig. 1.** Typical effective doses (ED) for natural, occupational and medical sources of radiation. Summarized range of data (*cumulative yearly average) [2–24]. AT, atrial tachycardia; AV, atrioventricular; AVNRT, AV nodal reentry tachycardia; AVRT, AV reentry tachycardia; CRT, cardiac resynchronization therapy; CT, computed tomography; EP, electrophysiologic procedure; ICD, implantable cardioverter/defibrillator; MS, multislice; NY, New York; PA, posteroanterior; PET, positron emission tomography; PVI, pulmonary vein isolation; TAVI, transcatheter aortic valve implantation; VT, ventricular tachycardia.

autonomous self-surveillance and iterative radiation safety improvements [16–18].

## Methods

### Definitions

Total air kerma is the cumulative dose to the air at the interventional reference point [$K_{A,R}$; unit: Gray (Gy)]. Skin dose includes backscatter in the upper skin layers and characterizes deterministic skin lesions. The DAP (unit: Gy cm$^2$) is the product of $K_{A,R}$ and the irradiated skin area. The ED [unit: Sievert (Sv)] is the sum of all weighted equivalent doses of exposed organs in the body and characterizes future cancer risks. DAP-to-ED conversion factors have been calculated at ~0.2 mSv/Gy cm$^2$ in adults. They are 2-fold for acute radiation exposure; ~10-, 2-, and ~0.5-fold for <10, <20, and >80 years, respectively; and ~1.4-fold for women [4,11].

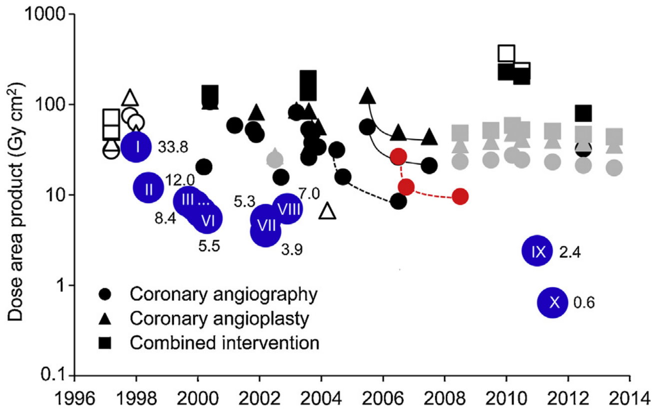

**Fig. 2.** Iterative 15-year, long-term optimization of dose area products (DAP) due to coronary angiography (CA) (highlighted by large blue dots) in the course of 10 study periods (I–X: detailed analysis in Table 2) [10,12,21–23] in comparison with median (filled symbols) and mean (open symbols) DAPs for CA (circles), coronary angioplasties (triangles), and combined interventions (squares), for single (black) and multicenter (red) analyses, course initiatives (joined symbols), the long-term results of the Encourage Less-Irradiating Cardiologic Interventional Techniques (ELICIT) initiative (broken lines), and the countrywide German quality registry (gray) [10–23].

### Equipment

We used digital single-arm undercouch tube catheterization systems. Based on the previous fluoroscopic pulse, an automatic algorithm dependent on tube voltage, current, and acquisition time determined the thickness of copper and/or aluminum filters adequate for the next frame. Since 2011, conventional image intensifier acquisition systems (Philips Integris H3000, Eindhoven, Netherlands; GE Advantx LC+, Fairfield, USA) have been superseded by an advanced flat-panel detector system (Siemens Axiom Artis zee, Erlangen, Germany) that includes, by means of a table-attached interface, multiple preselectable choices for pulsing and detector entrance doses (Table 1).

### Patients

Our study design was reviewed and received approval by the local institutional Ethics Committee. All patients gave informed written consent for prospectively gated CA [10]. Between 1997 and 2012 (periods I–X at representative cohorts of 91–200 patients), one interventionalist – with a lifelong experience of ~3200 (period I) and finally ~12,000 CA (period X) interventions (Fig. 2 and Table 2) – documented a total of 1182 CAs (femoral access) as follows: DAP, radiographic DAP$^R$ and fluoroscopic DAP$^F$, times on beam, radiographic frames and runs, DAP$^R$/frame, and DAP$^F$/pulse as cumulative indicators of collimation and detector entrance dose. DAP$^R$/s and DAP$^F$/s depend on pulse rates and characterize time-adjusted dose intensities. We excluded emergency and bypass graft catheterizations, since they are inhomogeneous. To minimize the residual effects of possibly existing, differing complexity levels among the various patient cohorts, we retrospectively recalculated all previously published mean values as medians [21–23]. Using conventional catheterization systems, the interventionalist iteratively improved and evaluated his working performance (Fig. 2 and Table 2): compared to baseline (period I), he focused on essential radiographic runs and frames, consistent collimation, low-level fluoroscopy, inspiration during radiography, and lower irradiating angulations (period II) [21]. Furthermore (periods III–VI), he reduced radiographic detector entrance doses step by step to evaluate adequate image quality for diagnostic purposes [23] and (period VII) investigated the efficacy of a new interface for predialing the length of radiographic runs [22]. Subsequently (period VIII), we evaluated CA without left ventricular angiography at a conventional catheterization unit (period IX) in comparison to an advanced system with flat-panel technology, fluoroscopy-free collimation, and preselectable pulse rates, as well as detector entrance dose levels [12]. Finally, we validated electrocardiogram (ECG)-gated CA for feasibility and dose reduction in invasive cardiology (period X). Analogously to noninvasive flash-computed tomography CA [24], we triggered one single frame/heartbeat prospectively toward the diastolic moment immediately before atrial contraction (77% of ECG RR interval), as most likely to provide motion-free resolution of the coronary tree [10].

## Results

In a first step of radiation-reducing efforts (Table 2), differentiation between radiographic and fluoroscopic DAP fractions at baseline disclosed the potential of dose reduction feasible for each fraction. The cardiologist at the conventional Philips Integris H3000 system achieved a significant 64% DAP reduction from