Contemporary radiation doses in interventional cardiology: A nationwide study of Patient Doses in Finland

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ABSTRACT

The amount of interventional procedures such as percutaneous coronary intervention, transcatheter aortic valve implantation, pacemaker implantation and ablations has increased within the previous decade. Simultaneously, novel fluoroscopy mainframes enable lower radiation doses for patients and operators. Therefore, there is a need to update the existing DRLs and propose new ones for common or recently introduced procedures. We sought to assess patient radiation doses in interventional cardiology in a large sample from seven hospitals across Finland between 2014 and 2016. Data was used to set updated national diagnostic reference levels for coronary angiographies (KAP 30 $Gycm^2$) and percutaneous coronary interventions (KAP 75 cm^2), and novel levels for pacemaker implantations (KAP 3.5 $Gycm^2$), atrial fibrillation ablation procedures (KAP 25 $Gycm^2$) and transcatheter aortic valve implantations (TAVI, KAP 90 $Gycm^2$). Tentative KAP values were set for implantations of cardiac resynchronization therapy devices (CRT, KAP 22 $Gycm^2$), electrophysiological treatment of atrioventricular nodal reentry tachycardia (6 $Gycm^2$) and atrial flutter procedures (KAP 16 $Gycm^2$). The values for TAVI and cardiac resynchronization therapy device implantation are published for the first time on national level. Dose from image acquisition (cine) constitutes the major part of the total dose in coronary and atrial fibrillation ablation procedures. For TAVI, patient weight is a good predictor of patient dose.

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INTRODUCTION

Fluoroscopic methods do not only play an integral role in contemporary cardiology [1,2,3], but their use has also been steadily growing over the past years. Mainly, this is due to the fact that new technologies have been developed and replaced the need for open surgery [1], the availability of medical aiding devices (such as catheters and stents) has increased, and the robustness of fluoroscopic systems has improved. All of the above have led to the fact that patients' advanced age or present comorbidities, such as previous cardiac surgery or renal disease, do not necessarily constitute contraindications for conducting procedures [1]. As a consequence, the increasingly complex and time-consuming procedures in interventional cardiology (IC) may increase the radiation exposure of patients, even though the technological advances, such as improved image quality or reduced frame rates, have partly compensated for this increase. Moreover, the procedures are often performed by cardiologists, whose knowledge on radiation protection, physics and technology might not be as profound as that of specialized radiologists.

Diagnostic reference levels (DRLs) are an essential tool for procedure optimization and controlling the dose. Their importance has been emphasized recently by the International Commission on Radiological Protection (ICRP) dedicating an entire issue to the use of DRLs [4]. The application of DRLs in IC is challenging, because many factors, the complexity of the procedure being the most important one, affect the dose significantly. At the same time, the parameters that describe the complexity, such as lesion characteristics or disease severity, are often difficult to collect unambiguously [5]. The ICRP proposes to tackle this problem by performing dose audits [4]. In this method, a large amount of data from a given procedure are pooled together and the full distribution of the doses can be analyzed, not just medians or third quartiles as is the case in customary DRL analysis [6].

The ICRP proposes to set DRLs on both regional (international) and national levels. The importance of the latter is emphasized when new techniques with potentially high exposure are implemented into clinical practice. Transcatheter aortic valve implantation (TAVI) can serve as a good example. After the first implantation in year 2008 [7], it is now performed routinely worldwide. Further, the technique has been recommended for patients in high-risk surgical groups [8]. As an increasing number of hospitals are implementing this potentially high-dose procedure, the DRLs on a national level provide an important optimization tool and a reference of what can be achieved when good practice is followed.

Finland has a long history of setting DRLs on a national level. In particular, DRLs for cardiological procedures had already been published in 2005 [9]. However, with technological advances and new techniques implemented into daily routines, they have become outdated. In addition, the ICRP urges updating DRLs on a regular basis [4], in order to account for new methods and encompass new procedure types. In Finland, DRLs for TAVI, pacemaker implantation and electrophysiological procedures have not been published earlier. These procedures however have now become part of the clinical routine and have the potential to result in relatively high patient dose.

The main goal of the study was to update the existing DRLs and propose new ones for common or recently introduced IC procedures. Additional parameters, related to patient anatomy, equipment or performed procedure were used to study variation between hospitals and to investigate the contribution of these parameters to the total dose. Procedures were further categorized – when possible – into subcategories or, in the case of percutaneous coronary intervention (PCI), classified according to the American College of Cardiology/American Heart Association (ACC/AHA) grading to account for differences in procedure complexity.

MATERIALS AND METHODS

Collection of Data

The data was collected from 5 Finnish university hospitals (UH) and 2 central hospitals (CH): Turku (TYKS), Helsinki (HUS), Tampere (TAYS), Oulu (OYS) and Kuopio (KYS) university hospitals and Vaasa (VKS) and Joensuu (PKSSK) central hospitals. At the time of data collection, electrophysiological and TAVI procedures were performed only in the university hospitals. The hospitals were chosen based on the amount of procedures performed. The data collection period was from February 2014 to March 2016 and focused on obtaining 10 procedures per category from each site. Not all hospitals were able to provide data on all requested parameters, such as fluoroscopy or cine kerma-air product (KAP) or fluoroscopy time (FT) or total imaging time.

Procedure categorization, covering 4 procedures divided to subcategories, is presented in **Table I**. Initially, transfemoral, transaortic and transapical access routes were distinguished for TAVI, but due to lack of data for transaortic and transapical routes, TAVI procedures had to be pooled. Angiographic systems and their installation years are presented in **Table II**. Their KAP-meter display accuracies as provided by regular maintenance were accounted for, and all the collected KAP-values were corrected accordingly. In general, these errors were less than 15 %.

Statistical Analysis

DRLs were calculated from the third quartiles of the hospitals' median values in accordance with the ICRP 135 recommendations [4]. Mainly, the amount of data was also in accordance with the recommendations. No data imputation was carried out. For the cases where complete data was available, impact of various parameters on patient dose in the four procedure categories was estimated using Spearman correlation coefficients with 95% confidence intervals (95% CI) calculated using Fisher's z transformation. For binary variables (patient gender, previous bypass surgery and cardiologist fellow or trainee), a Kruskal-Wallis test was performed to test the differences between the groups. AHA classification [10, 11, 12] was treated as an ordinal variable ranging from a low to high difficulty and from a low to high radiation dose.

Two tailed tests of significance (95% CI) were performed to assess the dose level differences between hospitals and how much they deviated from the national median. For these tests, the dose data was transformed with natural logarithm and normality was checked with histograms. After the transformation, several procedures performed in UH2 (Coronary angiographies (CA), PCI, and pacemaker implantation (PI)) were conspicuous as having anomalously high numbers of low doses, but generally the data was deemed sufficiently normal. Dose level differences between different procedures or between hospitals were tested with t-tests for independent samples.

The analysis methods were selected based on the amount of obtained data and the observed variance. Statistical power was not calculated before data collection. Statistical analyses were performed by an experienced statistician using SAS System for Windows, Version 9.4 (SAS Institute Inc., Cary, NC) and only some obvious typos were removed from the data.

RESULTS

Dose data from 21 278 procedures was collected. Most of the data was for coronary procedures (n=18 296). For comparison, according to the Finnish Cardiovascular Diseases Register and Finnish Cardiac Society chief physician survey 2015 [1,13], the total amount of collected dose data corresponded to roughly 44 % of procedures performed annually in Finland.

The main result of the study are the new DRLs, tentative KAP and FT values, calculated as third quartiles of the hospitals' median values and presented in **Tables III** and **IV**. The tables highlight the novelty of many of the new DRLs. Compared to other results, the new Finnish DRLs are mainly lower.

Comparison of doses between the procedure types has been shown in **Figure 1**. Compared to other procedures, PCI and TAVI stand out with relatively high dose level and large variance. **Figure 2** shows boxplots of the total KAP values in different hospitals and the numbers of procedures performed. Because of the low number of procedures combined with the deviating results, the following hospitals were excluded from the DRL calculations: UH4 for PCI and CH1 for PI. For the same reasons, actual DRLs were not set for implantation of cardiac resynchronization device (CRT), electrophysiological treatment of atrioventricular nodal reentry tachycardia (AVNRT) and atrial flutter, and tentative KAP values calculated in the same way as DRLs were used instead. With good statistics in the t-tests, many hospitals deviated significantly from the total data median in CA procedures. Likewise, UH1 deviated significantly from the total data median in

TAVI procedures. **Figure 3** shows how radiation doses in TAVI procedures have decreased in Finland during the period of data collection (Spearman correlation -0.082, P=0.151).

In **Table V**, relevant statistics for the collected parameters for the cases where complete data was available are presented. As can be seen, the percentage contribution of fluoroscopy and acquisition varies between procedure types. The high standard deviation in PI procedures is due to procedures performed in CH1 being carried out with an older C-arm.

Table VI shows the Spearman correlations of the collected parameters for the total KAP and their total amounts for the cases where complete data was available. The correlation of weight to the total KAP is substantial in the TAVI procedure. Furthermore, cine acquisitions correlate strongly with total KAP in all high dose procedures. In addition, low correlation of AHA-score in CA procedures, low correlation of angiosystem age and negative correlation of patient age in PI procedures are noteworthy.

Male patient gender was an influential and significant factor for total dose in all procedure types (χ^2 = 68.56 with p<0.001 for coronary procedures, χ^2 = 13.33 with p<0.001 for pacemaker implantations, χ^2 = 4.72 with p<0.05 for electrophysiological procedures and χ^2 = 7.08 with p<0.01 for TAVI). In addition, patient's previous bypass surgery had a significant but minor effect on dose in coronary procedures (χ^2 = 6.81 with p<0.01). A cardiologist fellow or trainee performing the procedure had no significant effect on total radiation dose. This was the case for all procedure types.

DISCUSSION

In this study, diagnostic reference levels, in terms of a cumulative KAP as well as FT, were set for several cardiological procedures. The suggested DRLs can be applied in current clinical practice. Some of the new DRL values replace the previous Finnish DRLs set in 2005. The DRLs for TAVI and CRT were set for the first time.

Diagnostic reference levels

The DRLs were calculated as third quartile values of the hospitals' medians for the quantity in question, in line with ICRP recommendations [4] and methodology of the Finnish authority (STUK) for the new DRLs [14]. Traditionally, DRLs have been published as either third quartiles of the whole data or as third quartiles of the hospital medians and this methodology is not always accurately reported [15]. Compared to dose levels calculated as third quartiles of the whole data, on average the new Finnish DRLs (medians of hospital third quartiles) are 30 % lower. This difference, due to the methodology, is in line with results published by Georges et al [15].

For TAVI procedures, the DRLs are among the first DRLs in the world. TAVI is a relatively new procedure in many hospitals and the DRL is an essential optimization tool at the onset of the procedure, when extensive local dose data are not yet available. In this study, different TAVI access routes (i.e. transfemoral, transaortic or transapical) were not distinguished, even though they are known to affect the dose [29]. This was due to an insufficient number of cases in each access route subcategory and accordingly the data had to be pooled together. The most common access route in Finland - transfemoral- does not render the highest nor the lowest doses. The DRL for TAVI is the highest amongst the investigated procedures.

In addition, the tentative KAP value for CRT procedures is among the first published values in the world. Often CRT is categorized as a pacemaker implantation and, thus, the DRL for PI are applied to CRT as well. In this study, the two procedures have been separated since CRT procedures result in significantly higher doses than other pacemaker implantations. Further, for the installation of a peacemaker with one or two leads, the observed dose levels were similar and thus only one DRL is given.

Only a few DRLs for electrophysiological procedures have been published so far [24]. However, since these procedures have become an important part of cardiological routine [30], the DRLs are important to help in the optimization of the procedure. In this study, the subcategories of EF procedures were investigated, unlike most other studies where these procedures are pooled together [24]. Significant variation across the subcategories was observed and, accordingly, the DRLs were set for each subcategory.

Variation between hospitals

Variation of total KAP values between the hospitals is shown in **Figure 2**. The variation is largest in CA and PCI procedures, in particular in university hospitals, where there are more patients and cardiologists performing procedures. Both of these contribute to the observed higher variation. Regarding equipment age, with the exception of PM in CH1 where procedures were partly performed with a mobile C-arm from 2001, equipment age had no significant correlation to patient dose.

Except for CA and PCI, the inter-hospital variation in doses is reasonably small making the DRL setting straightforward. This might be due to the fact that cardiologists in Finland obtain extensive radiation protection training in which patient protection and dose optimization are continuously emphasized resulting in a consistent approach across the country. Additionally, medical physicists often work together with clinical practitioners in optimization processes in cardiology clinics.

Protocol optimization plays an integral role in patients' radiation exposure level. Poorly optimized equipment might force users to increase the dose to unnecessarily high level (i.e. excessive use of cine) in order to obtain an acceptable image quality. A previous study that investigated 18 fluoroscopy systems from 13 medical facilities within one city, found that dose rates and image quality vary widely between systems and the difference in image quality was considerable [31]. Moreover, inappropriate use of zoom or position of the x-ray tube and the detector can have a large influence on patient exposure.

Comparison to other studies

DRLs for certain cardiological procedures have been published earlier (**Table III**). Most commonly the DRLs have been set for CA and PCI procedures. The DRL for CA and PCI presented here are at the same level as DRLs from the studies published after 2010 (Australia's DRL [27] being an exception). As compared to previous Finnish national DRLs from 2005 [9] and to RAD-IR DRLs in the US from 2003 it can clearly be seen that in these 15 years the doses have decreased significantly [17,18,19]. Particularly, the difference between the new and old Finnish CA DRLs (50%) emphasizes the need for regular updates of DRLs as suggested by the ICRP [4]. The decrease can possibly be explained by the technological advances, such as improvements in x-ray tubes, detectors and post-processing, and highlights the importance of embracing new technology. This observed decrease in dose, however, does not guarantee that the collective dose to all patients (and thus the dose to the staff) is reduced, because the decrease can readily be counterbalanced by the increasing number of procedures performed on the aging population.

The DRLs for the PI, AVNRT, atrial flutter and AF were significantly lower in the present study than in previous studies (**Table III**). A part of this difference can be explained by the different procedure definitions. For example, in Greek DRLs from 2013 [24] no distinction was made between atrial flutter and AF, and DRLs for radiofrequency cardiac ablation were reported instead.

The DRL for TAVI (90 $Gycm^2$) has been set in this study for the first time in Finland but some comparison can be found for the median value presented in **Table IV**. The median KAP value in this study (76.7 $Gycm^2$) was lower than most previously reported median KAP values, which vary between 75-186 $Gycm^2$ [32,33,34,35]. Interestingly, the value found in the present study was at the same level as Sharma et al. [34] reported for the "modified image acquisition setting", a protocol that reduces the dose. This emphasizes the importance of careful dose optimization. Further, for TAVI, a technique that is relatively complex, a learning curve is present (**Figure 3**). It is apparent that immediately after implementing the technique the doses are higher; however, as the performing staff acquire more experience and with possible protocol adjustments, the dose decreases and stabilizes. This has also been observed previously [29].

Similar to TAVI, a tentative KAP value for CRT has not been published before in Finland. The value for the median dose in CRT implantation, 13.4 $Gycm^2$, was lower than that published earlier, 26 Gycm2 [36]. The dose for CRT is significantly higher than for other investigated PI procedures.

In this study, DRLs for FT were not set because its use as a surrogate for patient doses is not encouraged [4]. However, typical FT values are given in **Table IV**, calculated in the same way as the DRLs. No significant differences in FT are observable when comparing the results from this and previous studies. One noticeable fact is that although TAVI and CA are higher-dose procedures than CRT, they have shorter FT. This is also visible in **Table VI**, where FT (or total imaging time) is an inferior predictor of total KAP than the number of cine series or images. Accordingly, FT cannot be the only factor used to assess the patient's dose. Further, the alert levels for preventing radiation induced skin damage that are based solely on FT may be misleading.

Factors associated with changes in Kerma-area product

Factors associated with increased KAP are presented in **Table VI**. In CA procedures, use of acquisition (i.e. cine) is an important factor explaining the total KAP. In EF procedures, use of cine is even more pronounced considering the 3D imaging performed in some EF procedures. As such, despite all the technological advances, minimizing the use of cine in IC is still an effective way to decrease patient (and staff) doses.

DRLs are conventionally set for patients within a predetermined weight range. The ICRP urges normalizing the data by compensating for differences in patient body habitus and weight [4]. The results from the present study show that, with the exception of TAVI, weight is a poor determinant of the total dose: the correlations were significant but weak. We have also investigated whether the body mass index (BMI) would improve the correlation. However, the BMI transpired to be an even poorer determinant of total KAP. In TAVI procedures, unlike in the others, patient's weight is a relatively strong predictor of the total dose, a finding that is in line with previous studies [32]. However, this may be influenced by the limited number of available cases in the statistical analysis as suggested by the result that the number of acquisition images and FT are not significant predictors of the TAVI dose (**Table VI**). Patient gender had a reasonably big influence on patient dose in all procedure types. This can be mostly attributed to gender correlating strongly with patient size.

The result that the AHA-score has a low correlation to the radiation dose means that alone it is not sufficient to estimate the difficulty of a procedure from the perspective of using radiation. The result that a cardiologist fellow performing a procedure does not correlate with higher or lower doses in any procedures can be due to inter-hospital variation as to who performs what procedures and inter-fellow variation. In addition, angiosystem age correlating very little can be interpreted to highlight the importance of the other factors. Lastly, the result that patient age has a negative correlation in PI procedures can be assumed to be mostly due to the type of pacemaker implanted.

CONCLUSION

In this study, a comprehensive analysis of patient doses in contemporary interventional cardiology in Finland has been presented. The data was used to update the existing national DRLs for CA and PCI with lower ones that better reflect contemporary practice and to set new DRLs for pacemaker implantation, electrophysiological procedures and TAVI procedures. In addition, tentative KAP values were presented for CRT, AVNRT and atrial flutter procedures. Both the TAVI DRL and the CRT tentative KAP value are among the first to be published. The results show that even though technical advances have helped to reduce the radiation burden of patients and staff, the careful optimization of the procedure (e.g. amount of cine used) is still an essential part of dose optimization.

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Table I. Used procedure categorization.

Coronary procedures		
Type 1: Coronary angiography (CA)	**Type 2:** Percutaneous coronary angioplasty (PCI)	
Pacemaker implantations (PI)		
Type 1: Single chamber (1C) or dual chamber (2C)	**Type 2:** Cardiac resynchronization therapy (CRT)	
Electrophysiological procedures (EF)		
Type 1: Atrioventricular Nodal Reentrant Tachycardia (AVNRT)	**Type 2:** Atrial flutter	**Type 3:** Atrial fibrillation (AF)
Transcatheter aortic valve implantations (TAVI) – procedure types combined		

Table II. Angiography systems and their installation years in different hospitals.

	System	Installation year
Coronary procedures		
UH1	Siemens Artis Zee	2013
UH2	Siemens Artis Zee	2005
UH3	GE Innova 2100 IQ	2006
UH4	Siemens Axiom Artis	2006
UH5	Siemens Artis Q Zen	2014
CH1	Philips Velara 100	2005
CH2	Siemens Artis Zee	2011
CH3	Philips Allura Xper	2010
Pacemaker Implantations		
UH1	Siemens Artis Zee	2012
UH2	Siemens Artis Zee	2011
UH3	Philips Allura Xper	2009
UH4	Siemens Artis Zee	2009
UH5	Philips Allura Xper	2010
CH1	GE Innova 4100 IQ pro/Ziehm Exposcop 8000 (Mobile C-arm)	2009/2001
CH2	Siemens Axiom Artis	2007
CH3	GE Innova IGS 520	2013
Electrophysiological procedures		
UH1	Siemens Artis Zee	2013
UH2	Siemens Artis Zee	2012
UH3	Philips Allura Xper	2009
UH4	Siemens Artis Zee	2010
UH5	Philips Allura Xper	2010
TAVI procedures		
UH1	Siemens Artis Zee Ceiling	2012
UH2	Siemens Artis Zeego	2014
UH3	Siemens Innova 2100 IQ	2006
UH4	Siemens Axiom Artis dFA	2006
UH5	Siemens Artis Q zen	2014

Table III. Published DRLs and published results of patient KAP values (Gycm^2) in interventional cardiology. Calculation method may vary between national and international DRLs.

Publication / Procedure and parameter	CA KAP	PCI KAP	PI KAP	CRT KAP	AVNRT KAP	Atrial flutter KAP	AF KAP	TAVI KAP
This study and Finnish national DRLs and tentative 3rd quartile values calculated similarly to DRLs [14] (2016)	30	75	3.5	22*	6*	16*	25	90
Finnish national DRLs [9] (2005)	60	100	NA	NA	NA	NA	NA	NA
Sentinel EU, DRLs [16] (2008)	45	85	NA	NA	NA	NA	35	NA
RAD-IR, USA, DRLs [17,18,19] (2003)	83	193	NA	NA	NA	NA	NA	NA
Switzerland DRLs [20] (2018)	50	100	5	NA	EF 20	RFA 30		100
Ireland KAP DRLs and mean FT's [21] (2008)	46.5	106.5	16.9	NA	NA	NA	NA	NA
Croatia DRLs [22] (2009)	32	NA	NA	NA	NA	NA	NA	NA
Bulgaria KAP DRLs and mean FT's [23] (2012)	40	NA	NA	NA	NA	NA	NA	NA
Greece 75th percentiles [24] (2013)	53	129	36	NA	NA	RFA 146		NA
Pantos et al (averages) [25] (2009)	39.9	78.3	NA	NA	EF 14.5	RFA 54.6		NA
Norwegian DRL [26] (2010)	21	NA	NA	NA	NA	NA	NA	NA
Queensland, Australia DRL [27] (2014)	58.6	129	NA	NA	NA	NA	NA	NA
2nd RAY'ACT study, France [14] (2017)	26	60	NA	NA	NA	NA	NA	NA
UK [28] (2009)	29	NA	NA	NA	NA	NA	NA	NA

CA = coronary angiography. PCI = percutaneous coronary angioplasty. PI = pacemaker installation. EF = electrophysiological study. RFA = radiofrequency ablation.

Table IV. Published fluoroscopy times (FT, min) in interventional cardiology.

Publication / Procedure and parameter	CA FT	PCI FT	PI FT	CRT FT	AVNRT FT	Atrial flutter FT	AF FT	TAVI FT
Present study 3rd quartile values calculated similarly to DRLs	6.0	18.4	6.7	20.5	13.3	23.1	14.0	21.5
Finnish national DRLs [9] (2005)	8	20	NA	NA	NA	NA	NA	NA
Sentinel EU, DRLs [16] (2008)	6.5	15.5	NA	NA	NA	NA	21	NA
RAD-IR, USA, DRLs [17,18,19] (2003)	5.4	18.5	NA	NA	NA	NA	NA	NA
Switzerland DRLs [20] (2018)	8	20	5	NA	EF 10	RFA 9		30
Ireland mean FT's [21] (2008)	4.3	14.5	6.6	NA	NA	NA	NA	NA
Croatia DRLs [22] (2009)	6.6	NA	NA	NA	NA	NA	NA	NA
Bulgaria mean FT's [23] (2012)	5.1	NA	NA	NA	NA	NA	NA	NA
Pantos et al (mean values) [25] (2009)	4.7	15	NA	NA	EF 9	RFA 45.8		NA
2nd RAY'ACT study, France DRLs [14] (2017)	4	11	NA	NA	NA	NA	NA	NA
UK DRLs [28] (2009)	4.5	13	8.2	NA	NA	NA	NA	NA

CA = coronary angiography. PCI = percutaneous coronary angioplasty. PI = pacemaker installation. EF = electrophysiological study. RFA = radiofrequency ablation.

Table V. Analyzed relevant statistics of the collected data. Due to non-normality, KAP and imaging time values are presented as medians, whereas others are presented as means or percentages.

Procedure type and total amount of collected data	CA n=364	PCI n=290	PI n=166	CRT n=31	AVNRT n=54	Atrial flutter n=13	AF n=45	TAVI n=38
Age (y)	67.2	67.4	73.7	65.4	49.9	61.1	57.8	82.0
Male gender	59.1%	72.4%	54.4%	71.6%	41.0%	72.0%	70.8%	52.0%
Weight (kg)	81.9	82.7	81.1	85.0	77.0	88.6	87.6	75.0
Height (cm)	169.8	170.6	169.5	172.0	169.0	174.2	175.8	165.9
Previous bypass surgery	3.3%	4.8%	3.0%	3.2%	0	0	0	0
Cardiologist fellow/trainee	11.8%	6.9%	7.2%	3.2%	0%	0%	0%	0%
AHA/ACC classification [12,13,14]	NA	A: 11.0% B: 32.8% C: 23.4%	NA	NA	NA	NA	NA	NA
Fluoroscopy time (min)	3.2	11.2	4.4	15.5	8.0	17.3	7.9	20.8
Total radiation time (min)	4.2	12.4	2.8	20.1	6.8	NA	12.3	15.3
Fluoroscopy KAP ($Gycm^2$) (% of total KAP)	2.0 (11.0 %)	10.9 (27.2 %)	3.3 (100 %)	8.2 (51.2 %)	3.4 (100 %)	12.8 (62.7 %)	5.8 (21.1 %)	35.8 (50.9 %)
Acquisition KAP ($Gycm^2$) (% of total KAP)	16.2 (89.0 %)	29.2 (72.8 %)	0	7.8 (48.8 %)	0	7.6 (37.3 %)	21.7 (78.3 %)	34.5 (49.1 %)
Number of acquisitions	24.0	27.7	0	5.7	0	1.2	3.8	13.2
KAP per acquisition ($Gycm^2$)	0.68	1.05	NA	1.37	NA	6.33	5.71	2.61
Number of acquisition images	771.8	1270.2	74.8	225.0	4.6	0	181.2	521.8
Total KAP ($Gycm^2$)	20.3	46.1	3.2	22.8	3.1	15.4	24.6	83.0
TOTAL KAP Standard deviation*	37.3	63.6	17.9	41.7	18.5	37.2	23.4	48.4
Air kerma (mGy)	409.0	1187.4	55.4	426.9	85.0	194.7	367.0	1068.4

CA = Coronary Angiography, PCI = Percutaneous Coronary Angioplasty, PI = Pacemaker Implantation, CRT = Cardiac Resynchronization Therapy, AVNRT = Atrioventricular Nodal Reentrant Tachycardia, AF = Atrial Fibrillation, TAVI = Transcatheter aortic valve implantations.

* Standard deviation calculated with outliers.

Table VI. Statistically significant ($p<0.05$) factors affecting total dose in the different procedure categories. Presented values are Spearman correlations. Values in parenthesis are total amounts of data specific to the parameter.

Factor	Coronary procedures	Confidence intervals	Pacemaker implantations	Confidence intervals	Electrophysiological procedures	Confidence intervals	TAVI procedures	Confidence intervals
Fluoroscopy KAP (n)	0.856 (526)	0.831-0.877	0.905 (90)	0.859-0.937	0.720 (72)	0.586-0.816	0.820 (22)	0.608-0.922
Acquisition KAP (n)	0.835 (521)	0.807-0.859	0.431 (90)	0.245-0.586	0.598 (72)	0.425-0.729	0.784 (22)	0.541-0.906
Air kerma (n)	0.830 (646)	0.805-0.853	0.974 (154)	0.964-0.981	0.931 (101)	0.899-0.953	0.765 (37)	0.587-0.873
Amount of acquisition images (n)	0.613 (104)	0.476-0.720	Not significant		0.864 (17)	0.655-0.950	Not significant	
Fluoroscopy time (n)	0.626 (493)	0.569-0.677	0.788 (120)	0.709-0.848	0.358 (73)	0.139-0.543	Not significant	
Amount of acquisition series (n)	0.636 (540)	0.582-0.683	0.470 (100)	0.301-0.610	0.414 (77)	0.209-0.584	Not significant	
Total imaging time (n)	0.560 (234)	0.465-0.642	0.723 (75)	0.594-0.816	0.319 (43)	0.020-0.565	Not significant	
Weight (n)	0.335 (650)	0.265-0.402	0.261 (195)	0.125-0.387	0.527 (112)	0.378-0.649	0.759 (37)	0.577-0.869
AHA-classification (n)	0.261 (654)	0.188-0.331	NA		NA		NA	
Height (n)	0.253 (647)	0.179-0.324	0.162 (193)	0.021-0.296	0.309 (111)	0.130-0.468	0.555(37)	0.281-0.745
BMI* (n)	0.257 (646)	0.184-0.328	0.249 (193)	0.111-0.377	0.430 (111)	0.265-0.571	0.525 (37)	0.243-0.726
Angiosystem age (n)	0.111 (654)	0.034-0.186	0.190 (197)	0.051-0.321	Not significant		Not significant	
Patient Age (n)	Not significant		-0.204 (182)	-0.339 – -0.060	Not significant		Not significant	

* Body Mass Index

Figure 1. Comparison of patient doses in cardiological procedures from all the hospitals. CA = Coronary Angiography, PCI = Percutaneous Coronary Angioplasty, PI = Pacemaker Implantation, CRT = Cardiac Resynchronization Therapy, AVNRT = Atrioventricular Nodal Reentrant Tachycardia, AF = Atrial Fibrillation, TAVI = Transcatheter aortic valve implantations. The boxes show 25th, 50th and 75th percentiles and the tails show the minimum and maximum of the data. Far out and extreme outliers of the data as analyzed by SPSS have been omitted from the figure. These data points ranged from several $Gycm^2$ for most procedure types to above 1 000 $Gycm^2$ for some retrospective data in CA and PCI.

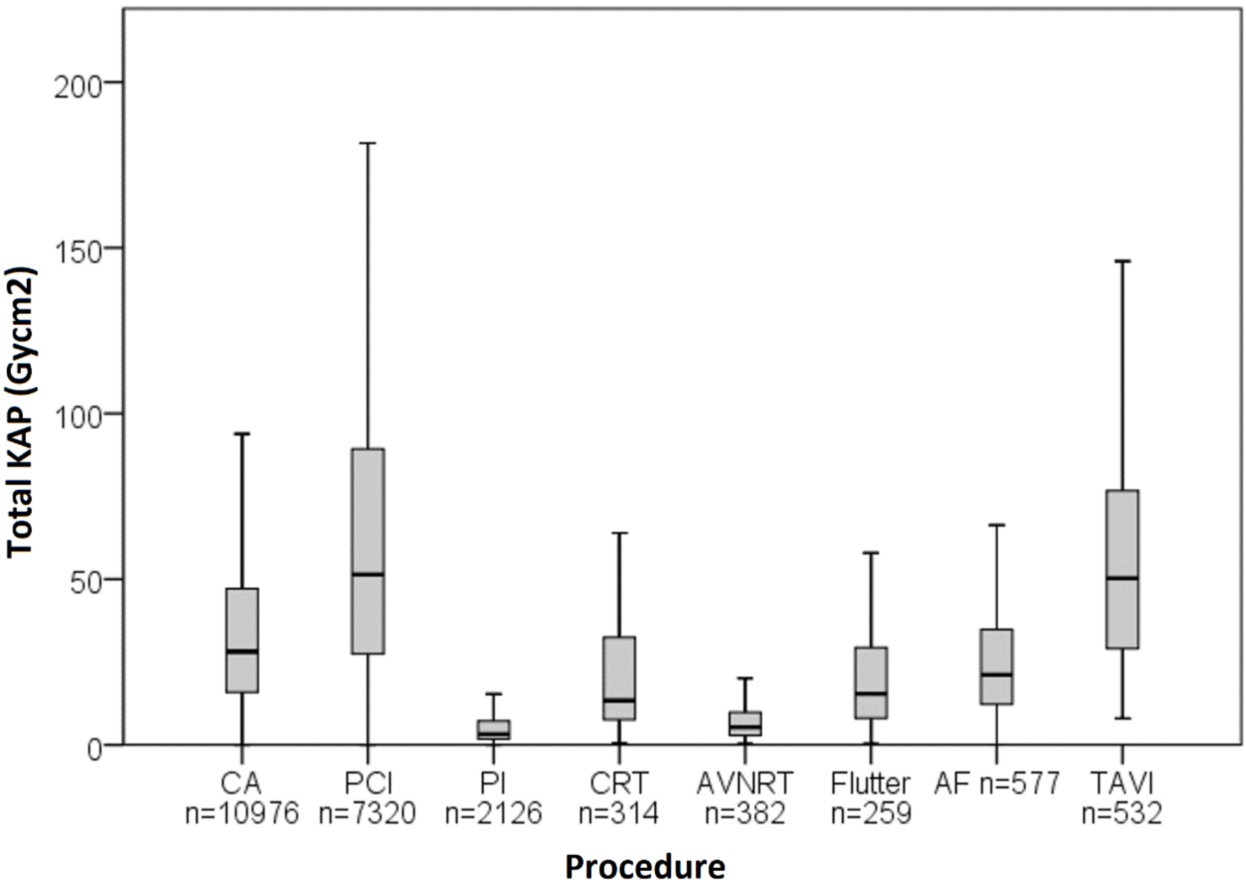

Figure 2. Total KAP values in different hospitals. The boxes show the 25th, 50th and 75th percentiles and the tails show the minimum and maximum data. Far out and extreme outliers of the data as analyzed by SPSS have been omitted from the figure. UH = university hospital, CH = central hospital. Asterisks denote hospitals whose medians deviate significantly (P<0.05) from that of the aggregate data.

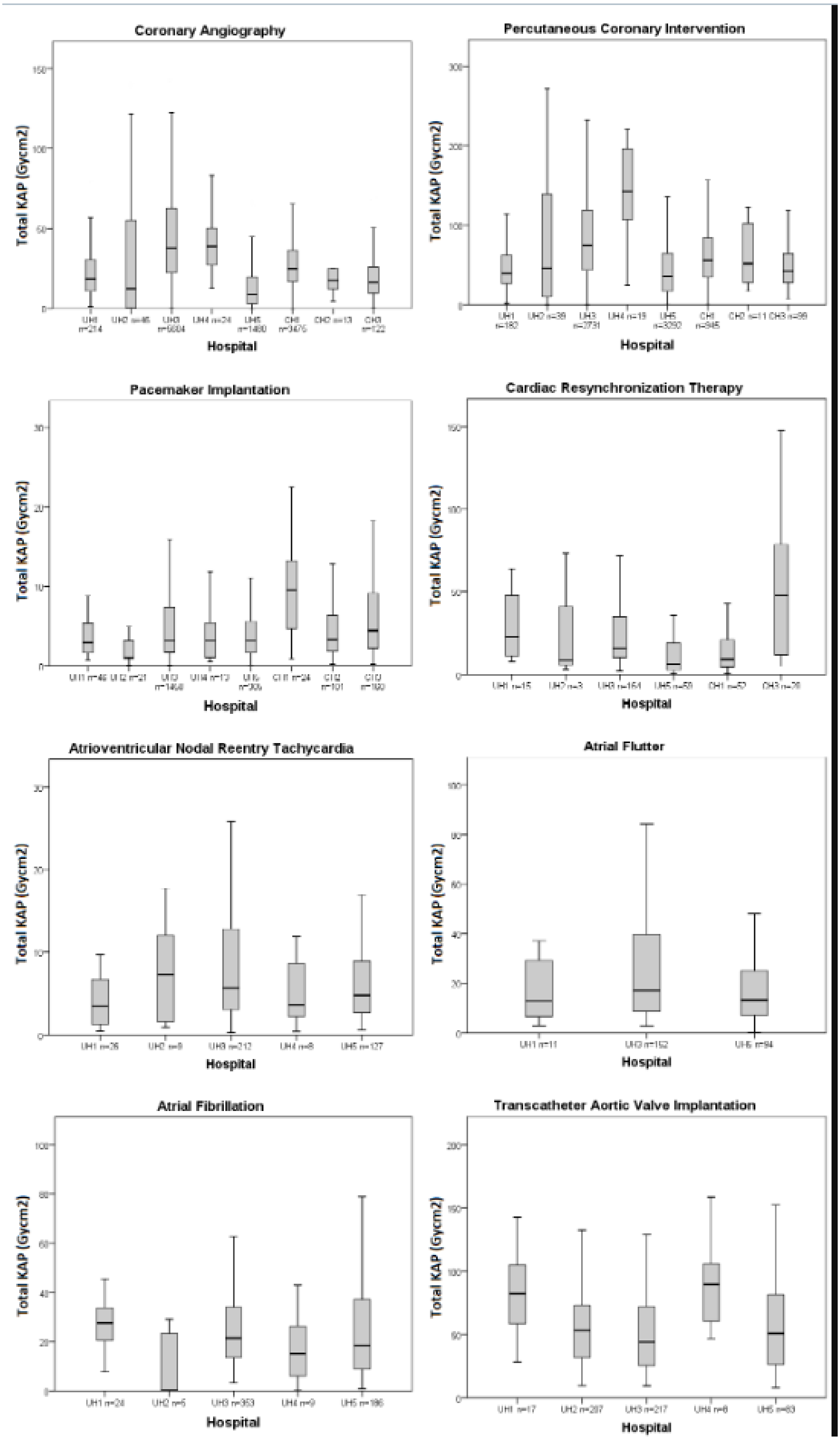
Coronary Angiography
Percutaneous Coronary Intervention
Pacemaker Implantation
Cardiac Resynchronization Therapy
Atrioventricular Nodal Reentry Tachycardia
Atrial Flutter
Atrial Fibrillation
Transcatheter Aortic Valve Implantation
Total KAP (Gycm2)
Hospital

Figure 3. TAVI KAP as function of procedure date.