

# Radiation Exposure during Elective Endovascular Abdominal Aortic Aneurysm Repair: A Nationwide Study of Patient Doses in Finland

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## WHAT THIS PAPER ADDS

This is the first publication concerning radiation exposure during endovascular aortic repair in Finland. It adds one more country and multiple centres to the international pool of published radiation doses. This paper is one of the few papers to publish detailed exposure parameters of the angiography systems, making it possible for any centre to adjust their systems accordingly. By analysing a nationwide cohort in Finland, large variations in radiation exposure were observed between the centres during endovascular aneurysm repair, even when similar angiography systems were used in most interventions, highlighting the importance of optimising imaging protocols.

**Objective:** Endovascular aneurysm repair (EVAR) predisposes patients to significant radiation exposure, with well known harmful effects. This study aimed to assess the radiation doses and their consistency in Finland and to investigate the factors affecting the doses, to potentially allow future dose reductions.

**Methods:** This retrospective, nationwide, multicentre study included all patients who underwent an elective standard EVAR procedure in Finland between 2017 – 2022. Data were collected from: body mass index (BMI); fluoroscopy time (FT); radiation exposure, including kerma area product (KAP) and cumulative air kerma at the patient reference entrance point ( $K_{a,r}$ ) from fluoroscopy and digital subtraction angiography (DSA); number of DSA series; and exposure parameters of the angiography systems. Descriptive statistics and linear regression analyses were performed to identify the parameters that significantly influenced radiation exposure.

**Results:** From all five centres that perform EVAR in Finland 1185 EVAR procedures were included. Large variation in medians of total procedure KAP between the centres was observed, ranging 22.5 – 135.0 Gy·cm<sup>2</sup>. Median FT ranged 16.1 – 29.1 minutes. Both fluoroscopy and DSA showed large variation in radiation exposure. BMI did not significantly differ between the centres. The factors significantly affecting the dose in the multivariable linear regression model were BMI, FT, number of DSA acquisitions, DSA frame rate, and maximum copper filtration in fluoroscopy.

**Conclusion:** Surprisingly high, up to six fold, between centre variability in total procedure radiation exposure was observed. The variability in the doses was mostly attributable to differences in exposure parameters (e.g., dose at detector level, copper filtration, and pulse rate); the manner in which radiation is used also played a significant role. In other words, both angiography system parameters and the working habits of the operator need to be optimised.

**Keywords:** Abdominal aortic aneurysm, Endovascular aneurysm repair, Kerma area product, Radiation exposure

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## INTRODUCTION

Endovascular aneurysm repair (EVAR) has become the treatment of choice for infrarenal abdominal aortic aneurysm (AAA) in most patients, due to its superior short and midterm outcomes.<sup>1</sup> EVAR procedures are performed under fluoroscopic guidance with additional digital subtraction angiography (DSA) series. Additionally, in certain cases, an intra-operative cone beam computed tomography (CBCT) scan may be performed, for example, to assess the correct placement and morphology of the stent graft. All these imaging methods use Xrays, which predispose patients and staff to ionising radiation.

The well known harmful effects of ionising radiation are classified into two categories: tissue reactions (deterministic effects) and stochastic effects.<sup>2,3</sup> Tissue reactions generally occur only when the absorbed dose for a specific organ is above a certain threshold, and the severity of the reaction increases with increasing dose.<sup>4</sup> According to the linear non-threshold model, stochastic effects, most notably an increased risk of malignancy, do not have a threshold value; however, an increasing dose increases the risk but not the severity of the effect.<sup>4,5</sup>

Modern angiography systems that are used for EVAR procedures automatically record multiple radiation exposure parameters, including fluoroscopy time (FT), kerma area product (KAP), and cumulative air kerma at the patient reference entrance point ( $K_{a,r}$ ). KAP can be used as a surrogate to represent the stochastic risk of radiation.<sup>6–8</sup>  $K_{a,r}$  is considered as a parameter to represent the risk of tissue reactions, such as radiation induced skin burns.<sup>6–8</sup>

Highly variable KAP values have been reported in EVAR procedures, ranging 9 – 337 Gy·cm<sup>2</sup>.<sup>4</sup> To compare the radiation exposure with background radiation, the effective doses can be roughly estimated from the KAP values using pre-determined conversion factors.<sup>9</sup> Efthymiou *et al.* have listed effective doses during EVAR procedures from multiple studies between 2005 – 2020, ranging 3.5 – 129 mSv.<sup>10</sup> The annual average background dose from natural and artificial radiation sources worldwide has been estimated to be 3.0 mSv;<sup>11</sup> thus, the lowest reported dose during EVAR equals slightly more than one year of background radiation, while the highest equals as much as 43 years of background radiation. With such a high variation in radiation exposure, establishing a diagnostic reference level (DRL) and harmonising imaging protocols and practices are clearly needed.

This nationwide study aimed to analyse radiation exposure during EVAR procedures in Finland, assess the consistency of dose levels between centres, and identify the factors affecting the doses and whether they are related to the angiography systems or to the operators. Additionally, typical dose levels were determined to give simple guidelines on how the radiation doses can be optimised.

## MATERIALS AND METHODS

### Study design and patients

This nationwide, retrospective, registry study enrolled every patient who underwent an elective EVAR procedure

in Finland between 2017 and 2022. Patients were treated in the five Finnish university hospitals: Helsinki University Hospital, Kuopio University Hospital, Oulu University Hospital, Tampere University Hospital, and Turku University Hospital; the centres are listed in alphabetical order here, the numerical identifiers in later sections are in random order.

As the focus on this study was on radiation exposure, the aim was to minimise procedure related factors; hence, only standard elective EVAR procedures for non-ruptured infrarenal AAAs performed using iodine based contrast media were included. EVARs with additional procedures (e.g., iliac branch endoprosthesis, side branch embolisation, fenestrated EVAR) were excluded from the analyses, except for centre three, which routinely performs side branch embolisation during almost every procedure and considers procedures with one or two side branch embolisation as standard EVAR. An EVAR was excluded if performed with carbon dioxide contrast or if CBCT was employed. The patient selection process is presented in Figure 1.

EVARs were performed in hybrid operating rooms with the following angiography systems: Siemens ARTIS zeego, Siemens ARTIS pheno, Siemens ARTIS zee Multipurpose, Siemens ARTIS Q ceiling (Siemens Healthineers, Erlangen, Germany), and Philips Allura (Philips Healthcare, Best, the Netherlands). Pheno was equipped with a crystalline silicon detector, while the other systems had amorphous silicon detectors.

The study was authorised by the HUS institutional review board (study number: HUS 100187). Written consent from the patients was waived in accordance with national regulations, due to the retrospective study design.

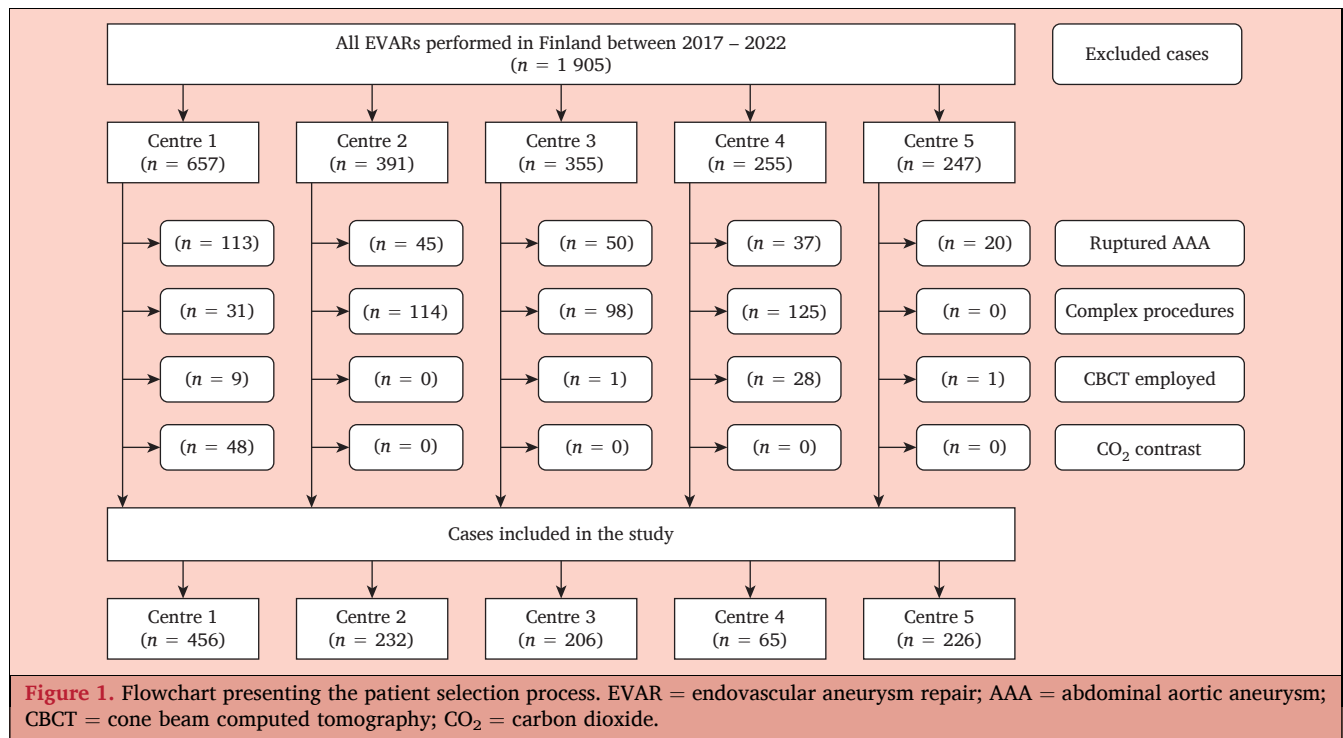
### Clinical and exposure parameters

The clinical patient data were collected from hospital records, and radiation exposure data were acquired from Picture Archiving and Communications Systems. Collected clinical data included body mass index (BMI). Exposure parameters included FT, KAP, and  $K_{a,r}$  from total procedure, fluoroscopy, and DSA, and number of DSA acquisitions. Radiation exposure data were recorded by the integrated, regularly calibrated, KAP meters of the angiography systems. Data related to the angiography systems included the manufacturer and model, pulse rates, minimum and maximum copper filtration and dose at detector levels of both fluoroscopy and DSA.

To further minimise the differences in technical execution of interventions and to emphasise the performance of the angiography systems, parameters “KAP per minute of fluoroscopy” and “KAP per DSA acquisition” were also introduced. These parameters describe how much KAP the patient was exposed to with each minute of fluoroscopy and how much KAP the patient was exposed to with each DSA acquisition, respectively.

### Outcome parameters

The primary outcome parameter was KAP (Gy·cm<sup>2</sup>) from the total procedure, fluoroscopy, and DSA. Secondary



outcomes included  $K_{a,r}$  (mGy), FT (minutes), and number of DSA acquisitions.

### Statistical analysis

Continuous variables are presented as medians and interquartile ranges (IQRs), except the copper filtration and dose at detector levels, which are presented as medians

(ranges). A Kolmogorov–Smirnov test was used to assess variable normality. When variables were not normally distributed, the median values were compared with a Kruskal–Wallis  $H$  test or Mann–Whitney  $U$  test, if only two centres were compared.

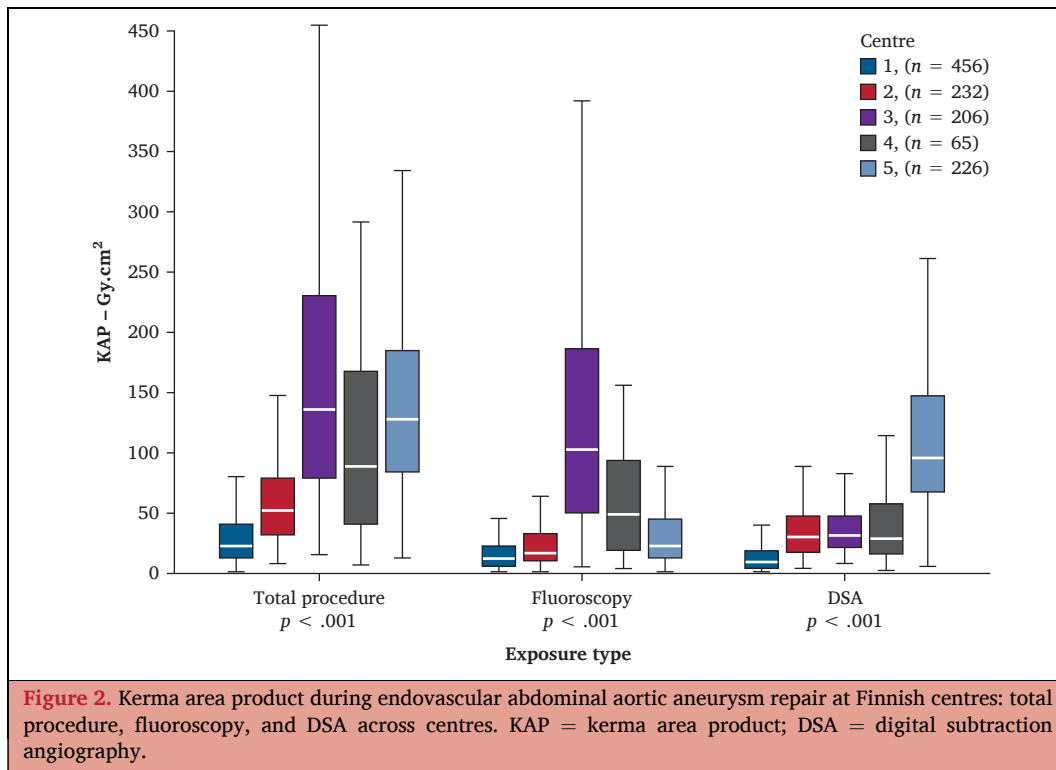
The preliminary national DRL was suggested by calculating the 75th percentile of the total procedure KAP value

**Table 1.** Clinical and radiation exposure parameters during elective endovascular abdominal aortic aneurysm repair in the five Finnish centres (n = 1 185).

	Centre					p value
	1 (n = 456)	2 (n = 232)	3 (n = 206)	4 (n = 65)	5 (n = 226)	
BMI – kg/m <sup>2</sup>	25.7 (22.7, 29.0)	26.2 (23.3, 29.5)	26.4 (23.5, 29.6)	26.3 (23.7, 30.2)	26.6 (23.8, 30.1)	.60
Fluoroscopy time – min	18.3 (13.5, 25.8)	16.1 (12.0, 21.6)	29.4 (19.8, 42.8)	17.8 (14.6, 27.4)	19.1 (13.1, 27.4)	<.001
KAP – Gy·cm <sup>2</sup>						
Total procedure	22.5 (12.3, 40.2)	51.4 (31.1, 79.3)	135.5 (78.1, 233.2)	88.2 (39.6, 170.2)	126.6 (83.5, 184.7)	<.001
Fluoroscopy	11.8 (5.8, 21.7)	16.2 (10.2, 32.4)	102.6 (49.2, 189.3)	48.4 (18.5, 95.5)	21.8 (13.1, 44.1)	<.001
DSA	8.75 (3.8, 18.3)	30.1 (17.1, 46.5)	30.7 (21.0, 46.8)	28.2 (15.5, 58.9)	95.6 (66.4, 146.4)	<.001
$K_{a,r}$ – mGy						
Total procedure	175.6 (93.9, 305.3)	320.9 (183.7, 537.2)	1 112.2 (577.0, 2 012.0)	518.4 (228.6, 1 019.5)	818.5 (516.2, 1 292.0)	<.001
Fluoroscopy	96.4 (50.2, 188.6)	147.6 (80.0, 343.7)	925.9 (437.6, 1 803.0)	342.8 (118.4, 665.0)	177.8 (96.7, 420.5)	<.001
DSA	58.8 (24.9, 111.2)	128.2 (72.5, 207.4)	145.4 (97.7, 211.5)	136.5 (81.9, 250.8)	564.0 (387.3, 828.1)	<.001
Number of DSA acquisitions	4 (3.0, 5.0)	2 (1.0, 3.0)	2 (2.0, 3.0)	6 (5.0, 8.0)	5 (4.0, 7.0)	<.001

Data are shown as median (IQR). IQR = interquartile range; KAP = kerma area product;  $K_{a,r}$  = air kerma at reference point; BMI = body mass index; DSA = digital subtraction angiography.

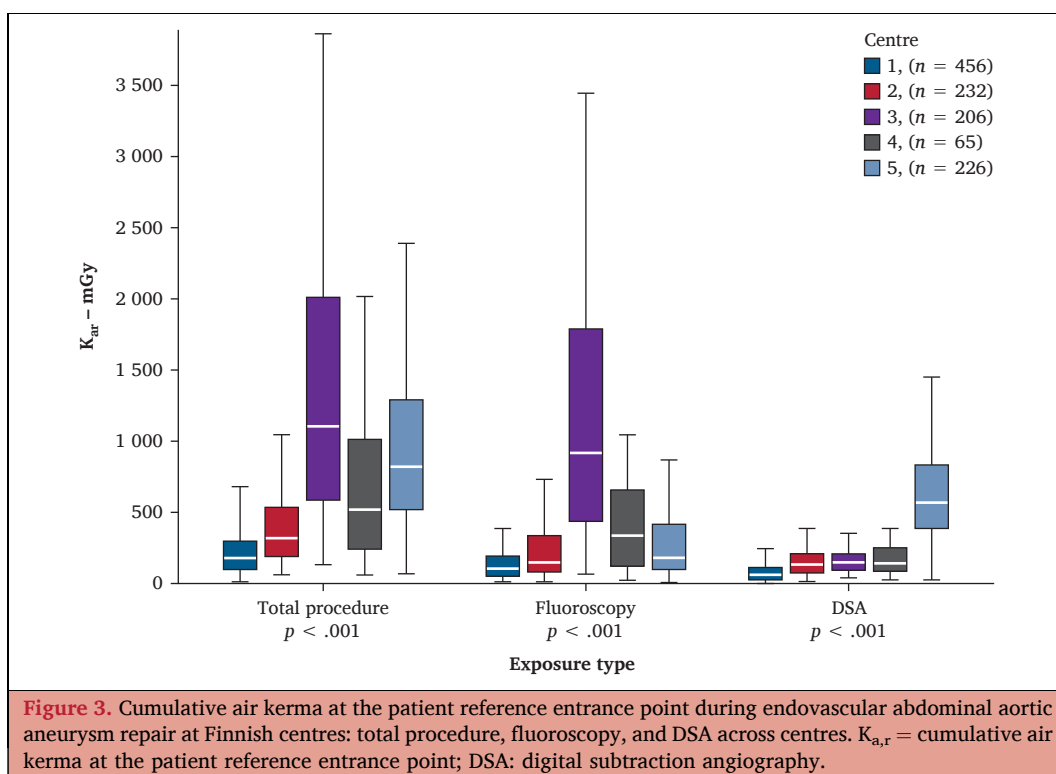
$p < .050$  represents statistically significant difference between the centres.

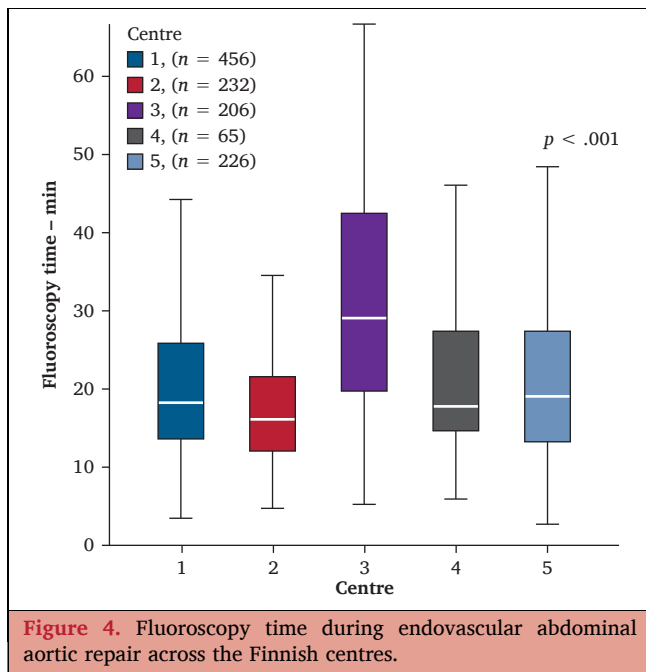


across all centres pooled. Additionally, the parameter “achievable dose” was defined as the median of total procedure KAP from pooled analysis across all centres.

A linear regression analysis was employed to identify factors that significantly contributed to the total radiation

dose (KAP and  $K_{a,r}$ ), first by univariable analysis and then statistically significant variables were analysed by multivariable analysis by using a backward selection method. Radiation doses between hospitals were visualised using boxplots.





**Figure 4.** Fluoroscopy time during endovascular abdominal aortic repair across the Finnish centres.

Statistical analyses were performed using IBM SPSS statistical software version 29.0.0.0 (IBM Inc., Armonk, NY, USA). Two tailed  $p$  values  $< .050$  were considered statistically significant.

## RESULTS

A total of 1905 EVAR procedures were assessed during the study period, of which 1185 standard elective EVAR procedures met the inclusion criteria and were included in the study. Centre specific numbers are presented in Table 1.

Fluoroscopy times and data from KAP and  $K_{a,r}$  of total procedure, fluoroscopy, and DSA are presented in Table 1 and visualised in Figures 2, 3, and 4, respectively. The angiography systems and corresponding exposure parameters used are shown in Table 2.

Other variables apart from maximum copper filtration in DSA were statistically significantly associated with total procedure KAP in univariable linear regression analysis. In the multivariable model, BMI, FT, number of DSA acquisitions, and DSA frame rate were statistically significantly associated with total procedure KAP (Tables 3 and 4). Other variables apart from copper filtration in DSA were statistically significantly associated with  $K_{a,r}$  in univariable linear regression analysis. In the multivariable model, BMI, FT, number of DSA acquisitions, and maximum copper filtration in fluoroscopy showed a significant contribution to total  $K_{a,r}$ .

In centre one, two angiography systems with different detector types were used. In intracentre comparison, the median total procedure KAPs were 27.9 (IQR 18.2, 41.9) and 19.2 (IQR 10.3, 37.6)  $\text{Gy}\cdot\text{cm}^2$  with Siemens ARTIS zeego (amorphous silicon detector) and Siemens ARTIS pheno (crystalline silicon detector) systems. Fluoroscopy KAP per minute values were 0.46 (IQR 0.30, 0.75) and 0.68

(IQR 0.37, 1.31)  $\text{Gy}\cdot\text{cm}^2/\text{min}$  and KAP per DSA acquisition values were 4.38 (IQR 2.82, 6.73) and 1.18 (IQR 0.64, 2.73)  $\text{Gy}\cdot\text{cm}^2$ , respectively. Centre four used a Siemens ARTIS zeego and a Philips Allura system, with fluoroscopy KAP per minute values of 1.82 (IQR 1.00, 3.99) and 2.64 (IQR 2.02, 4.11)  $\text{Gy}\cdot\text{cm}^2/\text{min}$  and KAP per DSA acquisition values of 3.82 (IQR 2.62, 5.98) and 10.97 (IQR 5.64, 16.76)  $\text{Gy}\cdot\text{cm}^2$ , respectively.

The median and the 75th percentile of the total procedure KAPs in the pooled analysis including all centres were 55.4 and 124.0  $\text{Gy}\cdot\text{cm}^2$ , respectively.

## DISCUSSION

The study has shown high inter-centre variation in radiation exposure during basic EVAR procedures. The median KAP from the total procedure was sixfold higher in centre three than in centre one. Using the conversion factors suggested by Miller *et al.*,<sup>9</sup> the doses equalled between 1.3 – 7.7 years of background radiation. An almost equally large variation was seen in fluoroscopy exposure (8.7 fold difference between the medians in centres one and three) and in DSA exposure (10.9 fold difference between the medians in centres one and five).

The factors significantly affecting the total dose in the multivariable linear regression model were BMI, fluoroscopy time, number of DSA acquisitions, DSA frame rate, and maximum copper filtration in fluoroscopy. No statistical difference in BMIs was observed between the centres, and as a characteristic of the patient, it is a parameter that could not be influenced. However, the rest of the parameters were subject to optimisation.

The complexity of an EVAR procedure, including the anatomy of the AAA and the potential need for additional procedures, plays a significant role in radiation exposure. As the dataset did not include detailed data from the procedures beyond the classification into standard or complex, FT was used as a surrogate. FT was almost identical in all centres except centre three, which showed an approximately 60% longer median FT than other centres. However, the longer FT can be attributed to differences in reporting methods, as in centre three, a “standard EVAR” also included procedures with one or two side branch embolisations. Six of their patients were treated without any side branch embolisation and this small subset of data showed FTs comparable to other centres.

Otherwise, most of the variation in radiation doses could not be attributed to the technical complexity of the procedures. Multiple fold differences were also observed in the derived parameters of KAP per minute of fluoroscopy and KAP per DSA acquisition. As KAP is a product of the dose and the area of the Xray field, either the dose or the area must be higher in centres with higher radiation exposure.

KAP on fluoroscopy was markedly higher in centre three than in other centres. Obviously, the 60% longer FT resulted in a higher cumulative fluoroscopy KAP value, but the KAP per minute of fluoroscopy was also higher than in other

**Table 2. Angiography system exposure parameters used in the Finnish centres during endovascular aneurysm repair.**

	Centre					p value
	1	2	3	4	5	
Angiography system	Siemens ARTIS zeego (35.3%), Siemens ARTIS pheno (63.8%)	Siemens ARTIS zeego (100%)	Siemens ARTIS zeego (98.1%), Siemens ARTIS Q ceiling (1.9%)	Siemens ARTIS zeego (76.9%), Philips Allura (16.9%), Siemens ARTIS zee Multipurpose (4.6%)	Siemens ARTIS zeego (100%)	
Detector type	zeego: Amorphous silicon, pheno: Crystalline silicon	Amorphous silicon	Amorphous Silicon	Amorphous silicon	Amorphous silicon	
<b>Fluoroscopy</b>						
Pulse rate – frames/s	4.0 (4.0, 4.0)	7.5 (7.5, 7.5)	7.5 (7.5, 7.5)	–	4.0 (4.0, 4.0)	<.001
Cu min – mm	0.1 (0.1–0.6)	0.6 (0.6–0.6)	0.1 (0.1–0.3)	–	0.2 (0.2–0.2)	<.001
Cu max – mm	0.9 (0.9–0.9)	0.9 (0.9–0.9)	0.6 (0.2–0.9)	–	0.6 (0.6–0.6)	<.001
Dose at detector – $\mu\text{Gy}/\text{frame}$	zeego: 0.029 pheno 0.012*	–	–	–	0.029	.002
KAP per minute – $\text{Gy}\cdot\text{cm}^2/\text{min}$	0.58 (0.34, 1.06)	1.00 (0.64, 1.71)	3.47 (2.03, 6.09)	2.36 (1.41, 3.93)	1.16 (0.73, 2.10)	<.001
<b>DSA</b>						
Pulse rate – frames/s	2.0 (2.0, 2.0)	4.0 (4.0, 4.0)	3.0 (3.0, 3.0)	2.0 (2.0, 3.0)	3.0 (3.0, 3.0)	<.001
Cu min – mm	0.1 (0.0–0.6)	0.1 (0.1–0.1)	0.2 (0.0–0.2)	0.2 (0.0–0.3)	0.0 (0.0–0.0)	<.001
Cu max – mm	0.2 (0.0–0.9)	0.1 (0.1–0.1)	0.2 (0.0–0.3)	0.2 (0.0–0.3)	0.3 (0.3–0.3)	<.001
Dose at detector – $\mu\text{Gy}/\text{frame}$	0.36 (0.36–3.0)	–	–	–	3.0 (3.0–3.0)	<.001
KAP per acquisition – $\text{Gy}\cdot\text{cm}^2$	2.27 (0.92, 4.70)	14.78 (9.70, 23.87)	11.25 (8.09, 18.68)	4.45 (3.05, 8.86)	19.93 (13.56, 26.9)	<.001

Data are presented as medians (IQR), copper filtration and dose at detector as medians (range). IQR = interquartile range; DSA = digital subtraction angiography; Cu min = minimum copper filtration; Cu max = maximum copper filtration; KAP = kerma area product.  $p < .050$  represents a statistically significant difference between the centres.

\* Pheno uses contrast to noise ratio driven exposure control (CEC) mode, presented values apply when the CEC mode is off.

centres. The key factors contributing to the high radiation exposure seem to be the high median fluoroscopy pulse rate (7.5 pulses per second). Additionally, the median maximum copper filtration (0.6 mm) was lower in centre three than in centres one and two. The dataset did not include the dose at detector level from centre three.

Centres two to five showed 1.7 – 5.8 fold higher radiation exposure per minute of fluoroscopy than centre one. Centre five had a similar Siemens ARTIS zeego system with similar pulse rates and dose at detector levels as centre one, but still a 90% higher dose. However, the copper filtration was thicker in centre one (minimum 0.6 mm,

**Table 3. Univariable linear regression analysis performed for all collected variables to show whether they have a statistically significant effect on radiation exposure during endovascular abdominal aortic aneurysm repair.**

Variable	Total procedure KAP – $\text{Gy}\cdot\text{cm}^2$			Total procedure $K_{a,r}$ – mGy		
	B	95% CI	p value	B	95% CI	p value
BMI – $\text{kg}/\text{m}^2$	8.60	7.42–9.77	<.001	64.3	54.2–74.5	<.001
<b>Fluoroscopy</b>						
Time – min	2.78	2.44–3.13	<.001	28.7	25.9–31.5	<.001
Pulse rate – 1/s	12.22	9.43–15.01	<.001	112.2	87.8–136.7	<.001
Cu min – mm	–92.0	–118– –65.3	<.001	–854	–1 090 – –620	<.001
Cu max – mm	–341	–372 – –310	<.001	–2 680	–2 970 – –2 400	<.001
Dose at detector – $\mu\text{Gy}/\text{frame}$	4 110	3 450–4 780	<.001	26 600	21 600–31 600	<.001
<b>DSA</b>						
Number of acquisitions – n	11.8	9.2–14.4	<.001	81.2	58.6–104	<.001
Pulse rate – 1/s	27.5	20.5–34.5	<.001	185	125–245	<.001
Cu min – mm	–155	–220 – –90.3	<.001	–566	–1 130–1.60	.051
Cu max – mm	52.2	–8.4–113	.091	303	–221–828	.26
Dose at detector – $\mu\text{Gy}/\text{frame}$	45.1	40.8–49.3	<.001	290	257–323	<.001

BMI = body mass index; KAP = kerma area product;  $K_{a,r}$  = air kerma at reference point; B = regression coefficient; CI = confidence interval; DSA = digital subtraction angiography; Cu min = minimum copper filtration; Cu max = maximum copper filtration.

$p < .050$  was considered statistically significant.

**Table 4.** Multivariable linear regression analysis performed with variables that were significant in the univariable model to show whether they have a statistically significant influence on radiation exposure during endovascular abdominal aortic aneurysm repair. The backward selection method was used to remove non-significant variables.

Variable	Total procedure KAP – Gy·cm <sup>2</sup>			Total procedure K <sub>a,r</sub> – mGy		
	B	95% CI	p value	B	95% CI	p value
BMI – kg/m <sup>2</sup>	5.83	4.92–6.73	<.001	46.3	39.7–53.0	<.001
Fluoroscopy time – min	1.22	0.88–1.56	<.001	10.7	8.2–13.1	<.001
Number of DSA acquisitions – n	9.66	7.23–12.1	<.001	83.2	65.4–101	<.001
Fluoroscopy Cu max – mm	–	–	–	–1 960	–2 190 - –1 730	<.001
DSA pulse rate	95.6	86.2–105.1	<.001	–	–	–

KAP = kerma area product; K<sub>a,r</sub> = air kerma at reference point; B = regression coefficient; CI = confidence interval; BMI = body mass index; DSA = digital subtraction angiography; Cu max = maximum copper filtration.

$p < .050$  was considered statistically significant.

maximum 0.9 mm vs. 0.2 – 0.6 mm in centre five), which probably contributed most of the observed difference; however, this cannot be certain because the dataset did not include data from collimated field size. Doses at detector level were unavailable from centres two to four.

Centre five presented markedly higher DSA exposure than other centres. Major contributors to a higher dose were: quite a high number of DSA acquisitions (five), the lowest minimum copper filtration (0 mm), and, most importantly, a high dose at the detector level (3.0 µGy/frame), which was 8.3 fold higher than centre one. The exposure from a single DSA acquisition was between 2.0 – 8.8 fold higher in centres two to five than in centre one, respectively. DSA pulse rates ranged 2 – 4; however, the number of total frames captured was not included in the dataset. Median copper filtration was nearly identical between the centres, but the maximum thickness of copper filtration in DSA was higher in centre one than in other centres (0.9 vs. 0.3 mm).

As most of the interventions were performed using similar Siemens ARTIS zeego systems, the exposure parameters obviously play a significant role in the radiation exposure. Centre one used two different angiography systems and while the newer pheno achieved 63% lower exposure per DSA acquisition, the older zeego outperformed the pheno in fluoroscopy by providing 67% less exposure per unit of time, implying that the target signal to noise ratio was set too high. On the other hand, even older systems can achieve low exposure levels when the imaging protocols are carefully adjusted. Eleven procedures were performed with Philips systems, with somewhat higher radiation exposure than with zeego in centre four. When assessing the K<sub>a,r</sub>, similar observations were made, centres with high KAP presented with high K<sub>a,r</sub>.

A large proportion of complex procedures and fairly routine utilisation of CBCT reduced eligible patients in centre four more than in other centres (Fig. 1). Centre one was the largest volume centre and presented with the lowest radiation exposure; however, across the other centres, the number of patients treated showed little correlation with the radiation exposure.

The KAP values in the Finnish centres were comparable with the values reported in the literature. In a single centre analysis, the values from centre one were on the lower side compared with the list reported by Modarai *et al.*<sup>4</sup> supplemented with more recent studies.<sup>12–19</sup> Few centres in the listed 47 studies reported lower KAP values than centre one. Unfortunately, exposure parameters are usually not published.

In a recent Swiss study, markedly low radiation exposure was achieved (median KAP of 5.6 Gy·cm<sup>2</sup>) during standard EVAR.<sup>12</sup> Their methods to achieve this were optimised exposure control software, careful magnification, collimation, detector distance levels, and standardised clinical pathway. Unfortunately, only pulse rates (fluoroscopy 2 pps, DSA 4 fps) but no other exposure parameters were reported. Additionally, fusion imaging methods, using fluoroscopy fade instead of digital roadmap, three dimensional printed simulator aneurysms, operator controlled imaging, real time noise reduction technologies, and non-radiation based guidance (intravascular ultrasound, fiberoptic methods) have been associated with reduced radiation exposure.<sup>14,16,20–24</sup>

DRLs represent the expected average radiation exposure for an average sized patient for a given imaging study.<sup>25</sup> The International Commission on Radiological Protection also recommends the application of DRLs to interventional procedures.<sup>26</sup> In European countries, a DRL for EVAR procedures has not yet been established. A couple of European studies have reported DRLs for EVAR ranging 103 – 278 Gy·cm<sup>2</sup>.<sup>13,27–29</sup> The 75th percentile in this study was 124.0 Gy·cm<sup>2</sup>, which is consistent with the reported values. However, few angiography systems provide enough data points to propose official national DRLs and hence the value is only suggested. Additionally, most of the angiography systems used during the study period have already changed, so the fairly high value does not represent the current state of exposure today. The median value of 55.5 Gy·cm<sup>2</sup> is closer to what can be considered as an “achievable dose” during EVAR.

### Limitations

Limitations of this study included missing doses at detector levels from centres two to four. Additionally, the dataset

did not include data of magnification, collimated field size, and distances from radiation source to isocentre and from isocentre to detector. Due to missing data, it cannot be certain whether some observed differences were attributable to exposure parameters or to the manners in which the radiation was applied. Automatic exposure control adjusts, among others, the copper filtration level during the intervention, and the copper filtration data included only maximum and minimum levels from fluoroscopy and DSA from every complete intervention, not detailed data from every acquisition. Practically all included interventions were performed with Siemens angiography systems, reducing possible contributors to the doses, but do not allow comparison of systems from different manufacturers. Additionally, the dataset did not include any data on the morphology of the AAAs, which could influence radiation exposure.

Radiation exposure to the patient and staff remains an important part of endovascular interventions. Future research aims to harmonise the dose levels between the centres and to further reduce radiation exposure. Additionally, there are no reported data on the association between EVAR radiation exposure and clinical outcome in the current literature.

The dataset suggests that the key technical parameters for the observed differences were the dose at detector level, pulse rate, and copper filtration. Most of the interventions were performed using similar angiography systems, highlighting the importance of optimising imaging protocols, as the culprit for high doses is often not the angiography system but its settings.

The manufacturers of the angiography systems or medical physicists should provide optimised intervention specific imaging protocols in collaboration with the operators, and new angiography systems often require local optimisation; example parameters are presented in Table 2. The aim is not to maximise image quality, but rather to obtain images of sufficient quality to ensure the technical success of the intervention, while accepting a certain level of noise. A low pulse rate of two to four pulses per second should be used in both fluoroscopy and DSA. Additionally, constant education of operators to focus on collimated field size, to minimise magnification and patient to detector distance, and to maximise patient to Xray source distance remains an important part in decreasing unnecessary radiation exposure. Additionally, fluoroscopy time and number of DSA acquisitions should be kept as low as reasonably achievable.

### Conclusion

Large, up to sixfold, variation in radiation exposure was observed between the five Finnish centres. The variability of the doses is mostly attributable to differences in exposure parameters (e.g., dose at detector level, copper filtration, and pulse rate) but also the manner in which radiation is used play a significant role. In other words, both the parameters of the angiography system and the working habits of the operators need to be optimised.

### CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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None.

### DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION PROCESS

During the preparation of this work the author(s) used ChatGPT to correct grammatical errors in individual sentences. The bulk of the text is written by the authors and not by AI. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

### APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ejvs.2025.11.058>.

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