Lowest reported dose area product of 2.4 Gy*cm^2 for ultra-low-dose endovascular aortic aneurysm repair of a standard infrarenal aortic aneurysm

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ABSTRACT

This is a report of successful treatment of an abdominal aortic aneurysm via standard endovascular aortic repair with an ultra-low dose (ULD) of 2.4 Gy*cm^2 using the latest imaging software in a hybrid operating room. To the best of our knowledge, no case has yet been reported achieving a successful outcome with such ULD values to date. The key factors to achieving an ULD regarding the dose area product comprise the right technology, procedural standardization, and team education and training. This case highlights the potential for reducing the radiation dose routinely for patients and staff alike, especially for operating room staff with daily radiation exposure. (J Vasc Surg Cases Innov Tech 2024;10:101496.)

Keywords: Abdominal aortic aneurysm; Diagnostic reference levels; Endovascular aneurysm repair; Radiation dosage

Endovascular aortic repair (EVAR) has become the most frequently used treatment of abdominal aortic aneurysms (AAAs) due to its minimally invasive nature.[1,2] However, concerns remain regarding the potential long-term effects of ionizing radiation exposure to the staff involved.[3]

The literature and official diagnostic reference levels report a wide spectrum of dose area product (DAP) values, starting from 12 Gy*cm^2 to >200 Gy*cm^2.[4,5] It is, therefore, difficult to determine which benchmark dose should be used in alignment with ALARA (as low as reasonably achievable) principles. Most vascular surgeons are aware of immediate protection such as lead shields or walls, as described in recent European Society for Vascular Surgery guidelines.[6] However, there is more to learn about dose reduction. With patient consent, the purpose of this report is to describe a benchmark and the potential for routine dose saving during standard EVAR.

MILESTONE APPROACH FOR DOSE BENCHMARKING: THE "Lucerne EVAR MILESTONE APPROACH"

Preliminary tests on a water phantom were performed before beginning the study.[7] Next, the settings of the imaging system were adjusted. To standardize EVAR and dose reporting in the hybrid operating room, a "milestone approach" was developed (Table). The Lucerne EVAR milestone approach is divided into eight steps, five of which are intraoperative. Later, technical setups for each milestone and for the new surgical workflow were defined. Thus, dose level reporting was structured, generating stepwise benchmarking (dose checkpoints at the end of each milestone). The method referred to during this case was previously reported by our ULD working group.[7,8]

CASE REPORT

A 76-year-old woman, with a body mass index of 23 kg/m^2 and a history of neuroendocrine pulmonary carcinoma, chronic obstructive pulmonary disease, arterial hypertension, and atrial fibrillation presented with an asymptomatic infrarenal AAA measuring 5.7 cm in diameter. EVAR was planned according to the guidelines due to the favorable anatomy and relevant comorbidities (Fig 1).[9,10] The operation was performed in the hybrid operating room (ARTIS pheno System; Siemens Healthineers). ULD software was used as a standard at our institution (OPTIQ Software; Siemens Healthineers).[11] The settings for collimation, digital zoom, and angulations are described in the Table.

Milestones 1 and 2. A trimodular off-the-shelf stent graft system was selected (main body: TREO 33-100; leg extension: TREO 13-120 [right], TREO 13-100 [left]; Terumo Aortic; Bolton Medical Inc; a standard device in our institution). During planning, the necessary positions of the radiation source and corresponding angulations were considered. A navigation mask was created from the preoperative three-dimensional data from the computed tomography angiogram (EVAR Guidance; Siemens Healthineers). Surgery was performed under general anesthesia.

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Table. Lucerne endovascular aortic repair (EVAR) milestone approach

Procedural phase	Milestone step	Description	Settings during reported case	Cumulative DAP (Gy*cm^2)
Preoperative	1. Decision making	Strategic conceptualization based on patient demographics, comorbidities, and anatomy	—	—
	2. Planning and device sizing	Planning procedure based on CT (device type, length, diameter, positioning, landing zones, ostia rings, C-arm angulations)	—	—
Intraoperative	3. 2D/3D registration	Two 90° fluoroscopy images merged with 3D preoperative CT image	Fluoroscopy in two planes, AP and lateral; no collimation, digital zoom 42 cm, 4 frames/s	0.44
	4. Repeat registration	After insertion of wire and stent, readjustment of overlay to actual anatomy to reach real time roadmap	Fluoroscopy for wire positioning and stent positioning: digital zoom 32; maximum collimation fluoroscopy for checking carrier system, 4 frames/s; zoom 32 cm and collimation; DSA: 0° CC, 5° LAO, digital zoom 32, 4 frames/s, collimation aligned with aorta and proximal renal arteries, with a length revealing end of contralateral leg	1.26
	5. End of cannulation contralateral leg	End of contralateral leg cannulation with full deployment (cumulated dose of fluoroscopy images and DSA sequences measured)	DSA: parallax compensation, 14° CC, 4 frames/s	1.39
	6. Full deployment and completion DSA	End of deployment of main body and ipsilateral leg (cumulated dose of fluoroscopy image and DSA sequences measured)	First DSA: 10° CC, 4 frames/s; second DSA: changing from 10° CC to 0° CC, 4 frames/s	2.39
	7. Cone-beam CT (optional)	Mostly used for fenestrated and branched EVAR procedures—not for standard EVAR procedures	Not performed	—
Postoperative	8. Postoperative follow-up	Reference for further follow-up, control CTA (with or without contrast-enhanced ultrasound)	According to guidelines after 6 weeks	—

2D, Two-dimensional; *3D*, three-dimensional; *AP*, anteroposterior; *CC*, craniocaudal; *CT*, computed tomography; *CTA*, computed tomography angiography; *DAP*, dose area product; *DSA*, digital subtraction angiography; *LAO*, left anterior oblique.

Milestone 3. Two-dimensional and three-dimensional registration was performed by matching the computed tomography-derived navigation mask with bony landmarks on fluoroscopy in two perpendicular planes.[12]

Milestone 4. Percutaneous access and wire positioning in the proximal descending aorta (Terumo Aortic; Bolton Medical Inc) and positioning of the angiography catheter at the level of the renal arteries were conducted. Maximum collimation, the influence of which on DAP is significant, enabled only one-sided visibility of the iliac arteries.

Ex situ control of the device markers in the sheath was performed under fluoroscopic guidance with advancement of the main body. During advancement of wires or catheters, fluoroscopy was not used continuously (Fig 2).

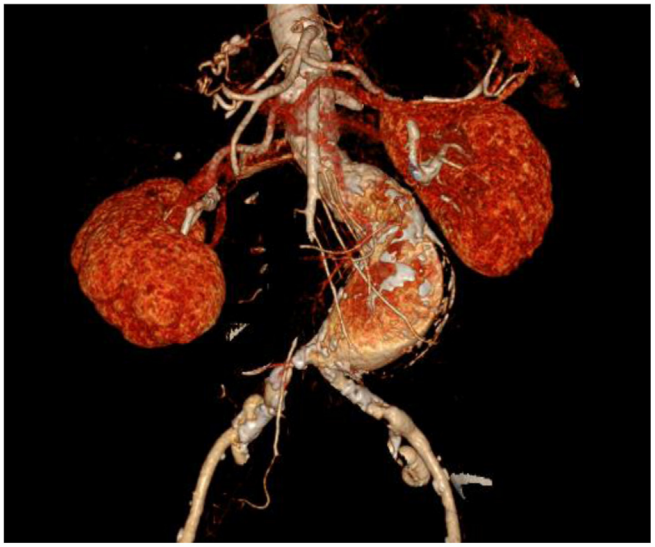

Fig 1. Infrarenal aortic aneurysm in anteroposterior view with slight beta angulation, suitable landing zones for endovascular aortic repair (EVAR), and visibility of hypogastric arteries.

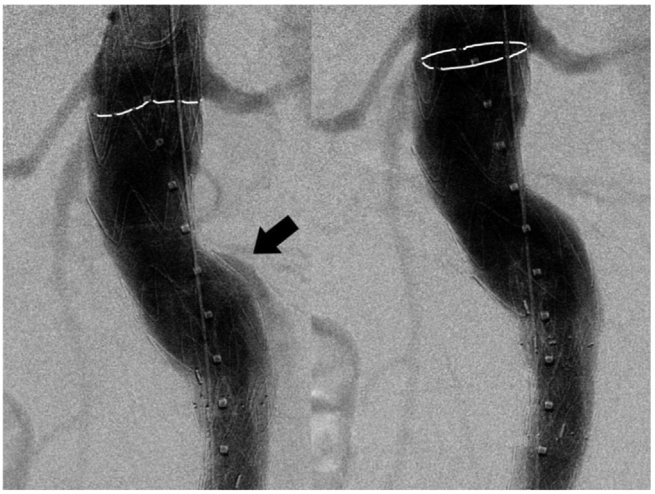

Fig 3. Completion digital subtraction angiography (DSA). **Left,** First DSA with 10° craniocaudal and cranial markers standing in line. *Arrow* indicates persistent type Ia endoleak. **Right,** Second final DSA with 0° craniocaudal and cranial markers not in line showing no persistence of the endoleak.

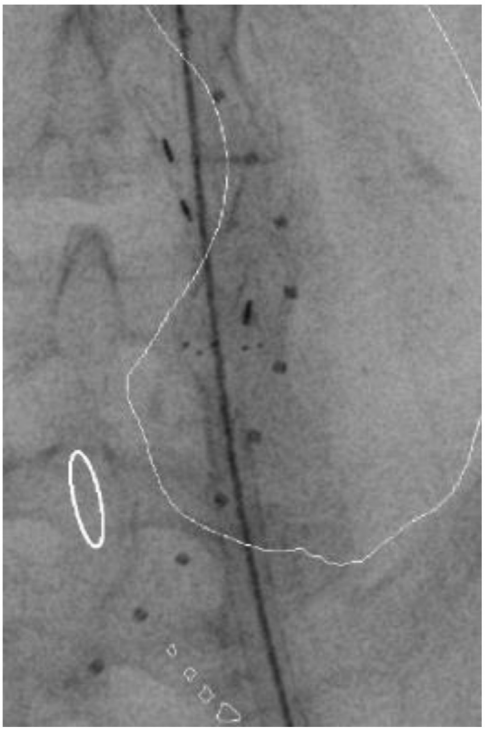

Fig 2. Image quality with four frames per second showing the markers clearly.

Next, digital subtraction angiography (DSA) was performed under parallax correction (collimation: showing proximal renal arteries up to the end of the contralateral leg). Digital zoom can be increased up to this frame. According to these data, the navigation mask was adjusted (repeat registration).

Milestone 5. Milestone 5 consists of deployment of the main body until release of the contralateral leg. During deployment, a short DSA was performed to again verify the exact EVAR positioning before full deployment. For cannulation of the contralateral leg, angulation was not necessary.

The correct wire position was checked inside the contralateral leg using a compliant balloon ("bulb sign"; 46 mm; Reliant; Medtronic). After length assessment according to retrograde DSA, the contralateral leg extension was deployed.

Milestone 6. Milestone 6 consists of full deployment of the main body. Measuring, positioning, deployment, and modeling of the ipsilateral leg (identical to the method used for the contralateral leg). Due to the long distal landing zones and favorable anatomical conditions, angulations were not needed to display hypogastric arteries.

Milestone 7. Milestone 7 consists of completion angiography under reduced parallax compensation of 10° craniocaudally with the proximal stent graft markers in one line (Fig 3).

A type Ia endoleak was detected, most likely due to slight crimping of the main body. Balloon modulation was repeated in the proximal landing zone, and a second completion DSA was performed. Parallax correction was avoided because detection of a type Ia endoleak was the only objective (Fig 3).

Changing from 10° craniocaudally to 0° helped to reduce the dose from the previous DSA of 0.53 Gy*cm^2 to 0.28 Gy*cm^2 within the second completion DSA. With these adjustments, we were able to confirm that no endoleak persisted. At this final checkpoint, the total dose was reached (DAP, 2.39 Gy*cm^2; fluoroscopy time, 14 minutes, 4 seconds; Fig 4).

Exam Protocol

Patient Info:

[redacted]

Patientenlage: HFS 09-Sep-21 09:47:41

4	DSA		FIXED	DSA xxCARE 4 NEW STY	7s	4F/s	09-Sep-21 13:21:17		
A	67kV	241mA	83.1ms	115cm micro 0.9Cu 42cm	0.32Gycm²	2.4mGy	2LAO	14CRA	28F
5	DSA		FIXED	DSA xxCARE 4 NEW STY	3s	4F/s	09-Sep-21 13:25:38		
A	69kV	245mA	85.1ms	115cm micro 0.9Cu 42cm	0.13Gycm²	1.0mGy	2LAO	14CRA	10F
9	DSA		FIXED	DSA xxCARE 4 NEW STY	2s	4F/s	09-Sep-21 13:43:27		
A	67kV	239mA	84.2ms	115cm micro 0.9Cu 32cm	0.07Gycm²	0.7mGy	0LAO	0CRA	9F
12	DSA		FIXED	DSA xxCARE 4 NEW STY	2s	4F/s	09-Sep-21 13:56:22		
A	67kV	238mA	80.9ms	115cm micro 0.9Cu 32cm	0.05Gycm²	0.6mGy	0LAO	0CRA	8F
20	DSA		FIXED	DSA xxCARE 4 NEW STY	11s	4F/s	09-Sep-21 14:16:16		
A	68kV	242mA	77.2ms	115cm micro 0.9Cu 42cm	0.53Gycm²	3.3mGy	2LAO	10CRA	42F
22	DSA		FIXED	DSA xxCARE 4 NEW STY	7s	4F/s	09-Sep-21 14:22:13		
A	67kV	238mA	73.3ms	115cm micro 0.9Cu 42cm	0.28Gycm²	1.7mGy	2LAO	0CRA	26F

Aufsummierte Strahlungsdaten 09-Sep-21 14:48:21

Untersuchender Arzt : Dr Hakimi Aufnahmen: 6

Summe Fluoro: 00:14:04	Max.Hauteintrittsdosis: 12mGy	Summe:	2.39Gycm² 16.9mGy
A Fluoro: 00:14:04	1.00Gycm² 7.2mGy	Summe:	2.39Gycm² 16.9mGy

Fig 4. Radiation dose examination protocol. The final dose area product (DAP) was 2.39 Gy*cm^2. The fluoroscopy time was 14 minutes, 4 seconds.

DISCUSSION

To the best of our knowledge, this case documents the lowest DAP used in a standard EVAR procedure available in the literature. Due to the optimal conditions of the patient's anatomy (ie, low body mass index, straight renal arteries, a suitable proximal landing zone, no tortuosity), this very low result could be achieved. This case also shows that an ULD is possible despite a surgically urgent second completion DSA, because the ULD did not compromise the imaging quality. However, the second DSA was only responsible for 0.28 Gy*cm^2. Possibilities still exist to further reduce the DAP, such as changing the frame rate from four frames per second to two frames per second. Device selection could influence the procedural steps. A trimodular device enables collimation during the initial DSA run and main body deployment. It also has wider variability regarding iliac extension selection.

Minimizing dose exposure is not only relevant for patient safety but is also a major topic in occupational health.[13,14] However, the reporting of dose levels in the literature varies greatly. The parameters and units used for radiation dose reporting vary between institutions and device manufacturers, leading to reporting disparities.[15,16] Furthermore, a wide range of dose levels for standard EVAR has been reported.[17-19] A recent literature review reported the imaging environment and technologies, good clinical practice, and team experience as three factors to explain the wide variations in DAP for EVAR.[20] To enhance good clinical practice in our institution, we developed the Lucerne EVAR milestone approach, not only to standardize the EVAR procedures, but also to benchmark the dose levels and standardize reporting.[7]

Regarding standard EVAR, although the definition includes a variety of anatomical and perioperative details, only 60% of AAAs are suitable for a standard EVAR procedure.[21] Complex EVAR procedures are likely to be associated with a higher DAP and intraoperative deviations from the initial plan.[22] Additionally, the working environments and imaging systems for vascular surgeons differ between institutions significantly. Both conditions contribute to difficult comparisons of dose levels. As a result, granularity is low between reported procedures, and investigators of recent studies are calling for universally adopted reporting standards.[23,24]

CONCLUSIONS

This case report shares our lowest radiation dose within the scientific community to establish which dose levels are currently achievable under suitable conditions for a standard EVAR procedure (ULD benchmarking). With regard to occupational health issues and radiation protection of patients and staff, dosages can be decreased with high procedural quality maintained. With this result, we would like to encourage institutions to concern themselves with knowledge of the technical parameters of their imaging systems, standardize their procedures, and establish ALARA principles as a key competence for endovascular surgery education and training.

DISCLOSURES

Y.B. is Director for Global Clinical Marketing Surgery at Siemens Healthineers. D.S. is Director for Clinical Marketing Vascular Surgery at Siemens Healthineers. M.H. is a consultant for Siemens Healthineers and a member of an advisory board for Siemens Healthineers. A.R. reports no conflicts.

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REFERENCES

1. Greenhalgh RM, Brown LC, Kwong GP, Powell JT, Thompson SG, EVAR trial participants. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. *Lancet*. 2004;364:843–848.
2. Lederle FA, Freischlag JA, Kyriakides TC, et al. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. *JAMA*. 2009;302:1535–1542.
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. Hertault A, Maurel B, Sobocinski J, et al. Impact of hybrid rooms with image fusion on radiation exposure during endovascular aortic repair. *Eur J Vasc Endovasc Surg*. 2014;48:382–390.
5. Strahlenschutz Bf; 2023 Accessed August 12, 2023. https://www.bfs.de/SharedDocs/Downloads/BfS/DE/fachinfo/ion/drw-roentgen.pdf;jsessionid=E098ADE919322EA7C86093C244296EE9.2_cid374?__blob=publicationFile&v=11.
6. Modarai B, Haulon S, Ainsbury E, et al. Editor's choice - European society for vascular surgery (ESVS) 2023 clinical practice guidelines on radiation safety. *Eur J Vasc Endovasc Surg*. 2023;65:171–222.
7. Hakimi M, Reeg A, Celi de la Torre JA, et al. *Lucerne milestone approach for benchmarking and education – towards ultra low dose EVAR*. 2024.
8. Hakimi M. *SYMPOSIUM: EVAR imaging innovations for a safer treatment "Ultra low dose EVAR: first results"*. LINC; 2021. Accessed August 12, 2023. https://www.leipzig-interventional-course.com/archive/linc-2021/faculty-list/.
9. Isselbacher EM, Preventza O, Hamilton Black J 3rd, et al. 2022 ACC/AHA guideline for the diagnosis and management of aortic disease: a report of the American Heart association/American College of Cardiology Joint Committee on clinical practice guidelines. *Circulation*. 2022;146:e334–e482.
10. Moll FL, Powell JT, Fraedrich G, et al. Management of abdominal aortic aneurysms clinical practice guidelines of the European society for vascular surgery. *Eur J Vasc Endovasc Surg*. 2011;41(Suppl 1):S1–S58.
11. Werncke T, Kemling M, Tashenov S, et al. Impact of a contrast-to-noise ratio driven and material specific exposure control on image quality and radiation exposure in angiography. *Phys Med Biol*. 2021;66:065020.
12. Schulz CJ, Bockler D, Krisam J, Geisbusch P. Two-dimensional-three-dimensional registration for fusion imaging is noninferior to three-dimensional- three-dimensional registration in infrarenal endovascular aneurysm repair. *J Vasc Surg*. 2019;70:2005–2013.
13. Kirkwood ML, Guild JB, Arbique GM, Anderson JA, Valentine RJ, Timaran C. Surgeon radiation dose during complex endovascular procedures. *J Vasc Surg*. 2015;62:457–463.
14. Patel AP, Gallacher D, Dourado R, et al. Occupational radiation exposure during endovascular aortic procedures. *Eur J Vasc Endovasc Surg*. 2013;46:424–430.
15. Efthymiou FO, Metaxas VI, Dimitroukas CP, Kakkos SK, Panayiotakis GS. Kerma-area product, entrance surface dose and effective dose in abdominal endovascular aneurysm repair. *Radiat Prot Dosimetry*. 2021;194:121–134.
16. Tuthill E, O'Hora L, O'Donohoe M, et al. Investigation of reference levels and radiation dose associated with abdominal EVAR (endovascular aneurysm repair) procedures across several European Centres. *Eur Radiol*. 2017;27:4846–4856.
17. Mandigers TJ, Fulgheri I, Pugliese G, et al. Patients' radiation exposure during endovascular abdominal aortic aneurysm repair. *Ann Vasc Surg*. 2024;98:115–123.
18. Martínez LI, Esteban C, Riera C, Altés P, Llagostera S. Endovascular infrarenal aortic aneurysm repair performed in a hybrid operating room versus conventional operating room using a C-arm. *Ann Vasc Surg*. 2020;69:366–372.
19. Zurcher KS, Naidu SG, Money SR, et al. Dose reduction using digital fluoroscopy versus digital subtraction angiography in endovascular aneurysm repair: a prospective randomized trial. *J Vasc Surg*. 2020;72:1938–1945.
20. Hertault A, Bianchini A, Amiot S, et al. Editor's choice - comprehensive literature review of radiation levels during endovascular aortic repair in cathlabs and operating theatres. *Eur J Vasc Endovasc Surg*. 2020;60:374–385.
21. Excellence NIfHaC. *Abdominal aortic aneurysm: diagnosis and management*. 2020.
22. Locham S, Faateh M, Dhaliwal J, Nejim B, Dakour-Aridi H, Malas MB. Outcomes and cost of fenestrated versus standard endovascular repair of intact abdominal aortic aneurysm in the United States. *J Vasc Surg*. 2019;69:1036–10344.e1.
23. Mezzetto L, D'Oria M, Lepidi S, et al. A scoping review on the incidence, risk factors, and outcomes of proximal neck dilatation after standard and complex endovascular repair for abdominal aortic aneurysms. *J Clin Med*. 2023;12:2324.
24. Patel SR, Ormesher DC, Griffin R, et al. Editor's choice - comparison of open, standard, and complex endovascular aortic repair treatments for Juxtarenal/short neck aneurysms: a systematic review and network meta-analysis. *Eur J Vasc Endovasc Surg*. 2022;63:696–706.

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