Radiation exposure from reinterventions following endovascular treatment of abdominal aortic aneurysm

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Abstract

Background: Endovascular aortic repair (EVAR) has become a valuable alternative to open repair (OR) in treating abdominal aortic aneurysms (AAA), in older patients, due to a significant reduction in perioperative mortality, recovery time, and immediate complication rates. However, EVAR is associated with higher rates of complications over time and thus requires radiological surveillance, and more frequent reinterventions than OR.

Objective: Estimate the rates of reinterventions in patients treated at Oslo University Hospital, Aker, and further, the excess radiation exposure related to reinterventions after EVAR, both as a result of the intervention itself, and the increased frequency of radiological imaging surveillance.

Material and Methods: A total of 257 patients were primarily treated for an asymptomatic AAA, with bifurcated stent graft at Oslo University Hospital, Aker between 29.05.2007 and 27.11.2018. 147 of which had any complication and 58 with the need for any reintervention. We calculated the mean effective dose (ED) for the reinterventions and the cumulative radiation exposure (CRE) for the all the radiologic examinations and interventions in all the patients exceeding regular follow-up regime due to any complication.

Results: The reintervention rate in total was 22,6%, and 18,7% for endovascular reinterventions. The average first reintervention was performed 2,3 years after the EVAR procedure, and each complication required an average of 1,45 endovascular reinterventions. The mean ED of an endovascular reintervention was 46,3 mSv. The average CRE in patients with reinterventions was 123,5 mSv, and 53,1 mSv in patients treated conservatively. The mean difference between these groups constituted a difference in monthly exposure of 0,9 mSv/month.

Conclusion: Both the detection and treatment of complications following EVAR will cause a significant, additional radiation burden on patients. How much the additional radiation dose will affect the patients is not yet clear and may be subject for further research.

Acknowledgements

I want to thank Thomas Nyheim for the opportunity to work on the EVAR database at Oslo University Hospital, Aker, and thereby introducing me to this subject area. I have received impeccable mentoring in the discipline, thus gaining interest in vascular surgery. For this reason, I wanted to write about vascular surgery, and Nyheim has helped me in designing the project thesis and suggested objectives for further research.

I also want to thank Herbjørg Råen for patiently helping me extract data on radiation doses in all the patients investigated in this study, and for instructing me in the use of conversion factors for radiation doses.

Last but not least, I want to thank my supervisor Gunnar Sandbæk for accurate and prompt answers to questions, guidance, and help in building the thesis.

Innholdsfortegnelse

Abbreviations

AAA - abdominal aortic aneurysm

COPD - chronical obstructive pulmonary disease

OR – open repair

EVAR – endovascular aneurysm repair

SGI - stent graft infection

ESVS - European Society for Vascular Surgery

CTA - computed tomography angiography

PAX - plain abdominal x-ray

CRE - cumulative radiation exposures

ACR - attributable cancer risk

CVI - chronic venous insufficiency

ASA - American Society of Anesthesiologists

BMI – body mass index

DAP - dose area product

DLP - dose length product

ED – effective dose

1 Introduction

1.1 Abdominal aortic aneurysm

An aneurysm is defined as a focal dilatation of an artery of more than 50% of the original artery diameter. For the abdominal aortic aneurysm (AAA) this means a local diameter greater than 3cm. The prevalence of AAA in patients over 50 years is between 3% and 10%. Risk factors increasing the prevalence are high age, male gender, positive family history, and smoking. Most AAAs are asymptomatic before they rupture and are most often discovered incidentally during imaging studies of the abdomen indicated by other reasons. The most important risk factor for an AAA rupture is the diameter of the aneurysm. Whereas larger aneurysms are more likely to rupture several more risk factors are making it impossible to predict when an aneurysm will rupture. Other factors known to increase the risk of aneurysm rupture are rapid expansion, positive family history, hypertension, eccentric aneurysm shape, smoking, and chronical obstructive pulmonary disease (COPD). However, the risk factors can be used in combination to categorize patients into low, average, or high risk of rupture (table 1). The age and comorbidities of the patient, predicting its life expectancy together with the risk of rupture are used to assess who will yield from prophylactic repair, and who will be treated conservatively with radiological follow-up. In most cases, aneurysm repair is indicated in AAAs with a diameter of 55mm in men, and 50mm in women (1). Today there are two main procedures for AAA repair; open repair (OR) and endovascular aneurysm repair (EVAR).

	Low risk	**Average risk**	**High risk**
Diameter	<50mm	50-60mm	>60mm
Expansion	<3mm/year	3-6mm/year	>6mm/year
Hypertension	Normal blood pressure	Controlled	Poorly controlled
Family history	No relatives	One relative	Numerous relatives
shape	Fusiform	Saccular	Very eccentric
Smoking/copd	None, mild	Moderate	Severe

Table 1 shows how different risk factors can be used to categorize aneurysms into low, average, or high risk of aneurysm rupture (1).

1.2 Endovascular aneurysm repair

EVAR was introduced by Parodi in 1991 (2) but has evolved much since then. A standard EVAR device usually consists of a two-piece-stent covered with graft material to prevent leakage of blood out of the stent graft. A typical EVAR device is shown in figure 2, and the procedure is performed by inserting the main graft components folded and compressed within a delivery sheath through the lumen of an access vessel, usually the common femoral artery. Upon deployment, the endograft expands, contacting the aortic wall proximally and iliac vessels distally, “sealing” above and below the aneurysm sac, such that flow is through the stent graft rather than into the aneurysm sac. (figure 1 and 2) Some manufacturers' devices have a suprarenal “bare stent” to aid fixation. After the main body piece is inserted, one or more limb pieces are inserted, ideally to land in the common iliac arteries, and thereby preserving flow in the internal iliac arteries. The various pieces of stent graft each have radio-opaque markers on to facilitate accurate placement of the devices (3, 4). In cases where the stent graft will be placed very close to, or above the ostium of the renal arteries some variants of stent grafts with fenestrations, or even branches may be necessary to secure blood flow through essential vessels.

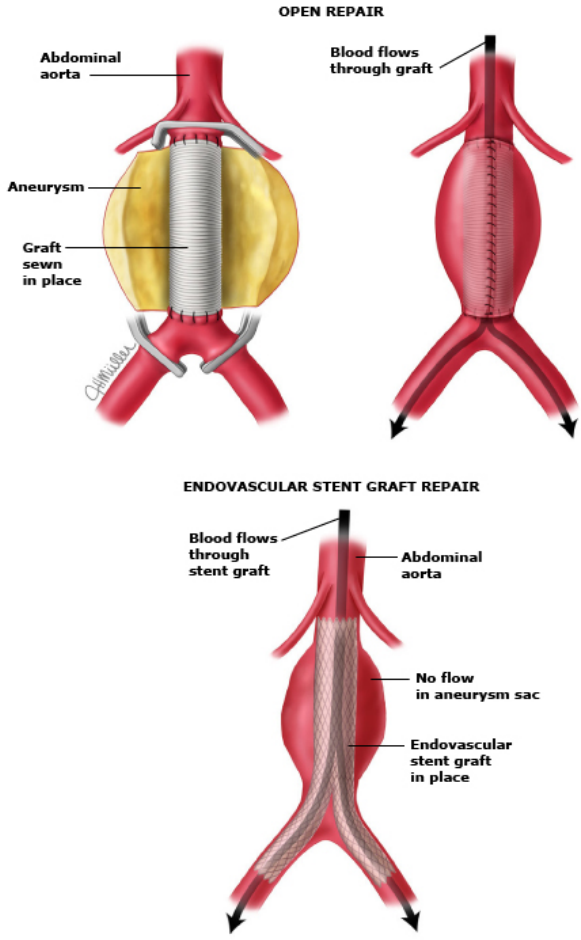

Figure 1: (Top) For open surgical repair of abdominal aortic aneurysm, the aorta is clamped, and the aneurysm sac opened. A graft is sutured into the aorta proximally and distally. A tube graft (illustrated) or a bifurcated graft is used depending upon the extent of iliac artery disease (aneurysm or stenosis). Once the graft is in place, the aneurysm sac and retroperitoneum are closed over the graft. (Bottom) For endovascular repair, the folded endograft is introduced through the femoral (or iliac) artery and, once it is adequately positioned, the self-expanding endograft is deployed. Iliac artery extensions are positioned and deployed to complete the repair (3).

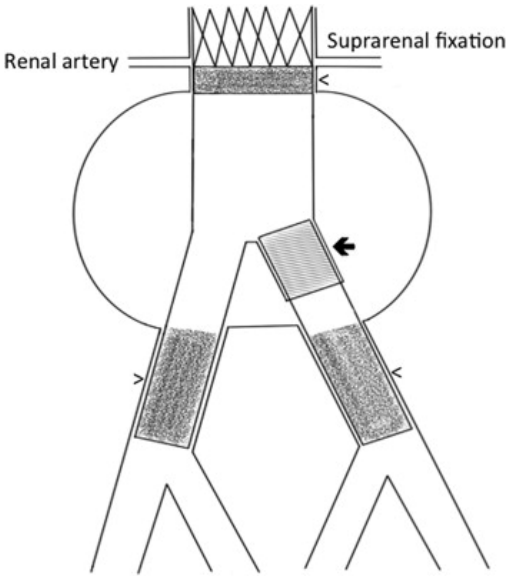

Figure 2 shows a stylized diagram of a standard bifurcated EVAR placed just below the level of the renal arteries. There are sealing zones in the infrarenal neck and common iliac arteries (arrowheads), as well as an overlap zone between the left iliac limb and the main body of the device (arrow). Note that this example has a bare-metal suprarenal fixation overlying the renal arteries to reduce the risk of migration, although not all devices have this feature (4).

EVAR has become an important alternative to OR due to a significant reduction in perioperative mortality (30-day operative mortality of 1.8% in endovascular repair and 4.3% in open repair (5)). This is mainly because EVAR does not require operative exposure of the aorta or aortic clamping (3). Furthermore, EVAR is associated with shorter recovery time and lower immediate complication rates compared to OR. A reduction in per- and postoperative complications in EVAR, compared to OR is mainly linked to bleeding, pulmonary, cardiac, bowel, and vascular complications (6). Since the introduction of EVAR, the number of deaths connected to AAA has decreased significantly. At the same time, the amount of AAA patients treated electively has increased, whereas the number of patients diagnosed and treated for ruptured AAA has decreased. This is most likely due to the ability to offer elective treatment to patients who would not otherwise be candidates for open surgical repair (3, 7).

On the other hand, the reduced adverse events in EVAR persist only through the first 2 years after repair (6), and the early benefit is completely lost in the long term. The aneurysm-related mortality is found to be substantially higher in patients treated with EVAR after 4 years of the primary intervention as the rate of graft-related complications remained. The same is true for the need for re-interventions (4). Postoperative re-intervention rates 4 years after the procedure are 1.7% for open repair and 9% in the EVAR group (8). Stent graft-related complications include most commonly endoleaks and graft thrombosis, kinking, migration, stent graft infection (SGI), growth, and rupture (9, 10).

1.3 Stent graft-related complications and reinterventions

1.3.1 Endoleaks

If the aneurysm sac is not entirely isolated blood will continue to move into the aneurysm sac, which may enable growth and rupture. The persistent blood flow within the aneurysm sac is what characterizes an endoleak. Endoleaks are classified into five types based on the position of the leak and its relation to the stent graft. Type I endoleak is characterized by persistent blood flow between the outermost part of the stent graft, and the vessel wall. Further, the type I endoleaks are divided into type Ia and Ib depending on whether the leak is in the proximal or distal anastomotic site of the stent graft. Type I endoleaks are in direct contact with the pressurized arterial circulation and require intervention. About 10% of all patients treated with EVAR require reintervention due to type I leak at the first-month follow-up examination. Methods in use for excluding the type I leak include endovascular insertion of an aortic cuff, or iliac extension to extend the sealing zones proximally or distally respectively in the type Ia or type Ib endoleak. If the problem is an incomplete expansion of the graft, balloon molding or a balloon-mounted stent can be inserted at the actual site of leak to increase the radial forces within the stent graft (4).

The most common type of endoleak, however, is the type II endoleak with rates as high as 10-25% of patients treated with EVAR (11). This type is characterized by retrograde flow of blood into the aneurysm sac through visceral and/or lumbar aortic branches. These leaks tend to cease spontaneously as the current vessel may thrombose. Treatment is therefore indicated most often only if there is an increase in aneurysm sac size as a result of an ongoing type II leak. Angiography is used to detect and catheterize the feeding artery, making it possible to embolize the artery with either microcoils, plugs, or a liquid embolic agent called Onyx.

Endoleak type III and IV are rare with modern stent graft systems. They are characterized respectively by blood flow through a graft defect caused by the separation of the graft segments, and blood flow through the graft due to porosity of the graft material itself. Endoleak type V is also called endotension and is characterized by continued expansion of the aneurysm sac without any actual leaks, visible with imaging surveillance. It is believed to be caused by persistent pressurization within the excluded aneurysm sac. Endotensions are not common and do hardly ever require intervention as they rarely result in rupture of the sac (4).

1.3.2 Graft thrombosis

Graft thrombosis involves development of thrombosis material within the graft limbs and does most often occur within the first 6 months after implantation of the stent graft. Graft thrombosis may lead to lower extremity ischemia, and a third of these patients develop acute ischemia (12). Limb occlusions are mainly caused by kinking of the stent graft, explained in chapter 1.3.3, or outflow impairment resulted by stenotic arterial disease distal to the stent graft. Treatment for graft thrombosis is necessary if the patient presents symptoms of acute ischemia, or if the thrombosis is still developing and poses a severe problem to the patient. The initial treatment option is catheter-directed thrombolysis, where the thrombolytic agent is infused through a catheter positioned inside the thrombosis material. During the infusion, that can last up to a maximum of 48 hours, angiograms are performed regularly to estimate the effect on the thrombus. Mechanically removal of the thrombus by endovascular thrombectomy is also an option. In patients with more established occlusions, resistant to endovascular treatment, surgical bypass must be considered (4).

1.3.3 Stent graft kinking

It is not entirely known what causes kinking of the stent graft, but it is believed that when the aneurysm sac decreases in size, the length of the aneurysm decreases simultaneously, making the proximal and distal anastomotic site of the stent graft come closer, compressing the stent graft and making it kink. Migration of the stent graft from one attachment site towards the other is also an explanation of stent graft kinking. Angled aortic bifurcation or tortuous iliac arteries will naturally pose a risk of intraoperative or early graft kinging (4). Fransen et al. found an incidence of 3.7% during a 2-year follow-up (13). Depending on the degree of angulation stent graft kinking can result in flow restrictions and thus cause thrombosis. Reinforcement of the graft wall by inserting a bare metal stent within the stent graft effectively reduces the kink and thereby the risk of occluding thrombosis (4).

1.3.4 Migration

Due to the constant, pulsatile flow of blood in the aorta, the stent graft is exposed to forces that pose a risk of stent graft migration. The risk is increased over time and can lead to type 1 endoleaks and thus, a risk of aneurysm growth and rupture (4). Zarins et al. reported an incidence of nearly 19% for stent graft migration during a 3-years follow-up and further found that one of the main predictors of stent migration is the length of the proximal fixation zone. They found that each millimeter increase in length of the fixation zone decreased the risk of migration by 2.5% (14). Cases of migration requiring intervention are treated by adding a stent graft extender at the site of disconnection, via an endovascular approach (4).

1.3.5 Stent graft infection

In some cases, the stent graft becomes the site of infection. SGI is a rare complication after EVAR but can be caused by both direct contamination of the stent graft during the procedure (15), indirectly during later reintervention, or via the formation of an aortoenteric fistula. SGIs are initially treated with intravenous antibiotics, but open operation with removal of the stent graft is in some cases necessary (4).

1.4 Postoperative surveillance

Lifelong radiographic surveillance is necessary to identify those patients who may need reintervention to reduce the risk of aneurysm rupture (6). The current standard surveillance protocol for EVAR, according to the European Society for Vascular Surgery (ESVS), includes serial CT angiography (CTA) and plain abdominal x-ray (PAX) at 1, 6 and 12 months and thereafter yearly (10). There have been concerns about the cumulative radiation exposures (CRE) and the following risk of cancer connected to this surveillance protocol with yearly CTA examinations. Several studies (9, 16, 17) have aimed at estimating the CRE and following cancer risks, and they all agree on an increased risk of cancer, especially associated with lower age at the time of EVAR and increasing surveillance period. However, Nyheim et al. found that the CTA surveillance alone would contribute to an attributable cancer risk (ACR) of only 0.35% and 0.65% for a 55-year-old man at 5- and 15-year follow-up respectively. For a 75-year-old man, the numbers were only 0.22% and 0.37%. Both considered to be low compared to a lifetime cancer risk of 44% (9). On the other hand, Kirkpatrick et al. found that for patients with normal CTA and no endoleak 1 month after

EVAR, no significant complications requiring intervention occurred before 3 years, and therefore proposed a less-frequent CTA surveillance (18).

Lately, ESVS has proposed new guidelines for surveillance after EVAR, intending to reduce the amount of CTA and thereby the CRE in patients treated with EVAR. The proposed protocol is illustrated in figure 3 (10). As shown, the finding of an adverse event will either produce a more frequent follow-up regime, including CTA or the need of an intervention. Absence of adverse events at both the 30 days-, and one-year post-operative examinations will according to the proposed guidelines be followed by exclusively abdominal duplex ultrasound, and PAX yearly, unless leakages, or aneurysm enlargement occurs. At Oslo University Hospital, Aker, between 2007 and 2018, the majority of patients have followed a surveillance protocol consisting of examinations at 2-3 months- and 12 months post-operative, and then yearly, including both CTA, PAX and abdominal duplex ultrasound for every examination. By the discovery of an endoleak, aneurysm enlargement, or other complications an intervention is induced, or an extra examination 6 months later, until the complication is resolved spontaneously, is stabilized or is treated with a reintervention.

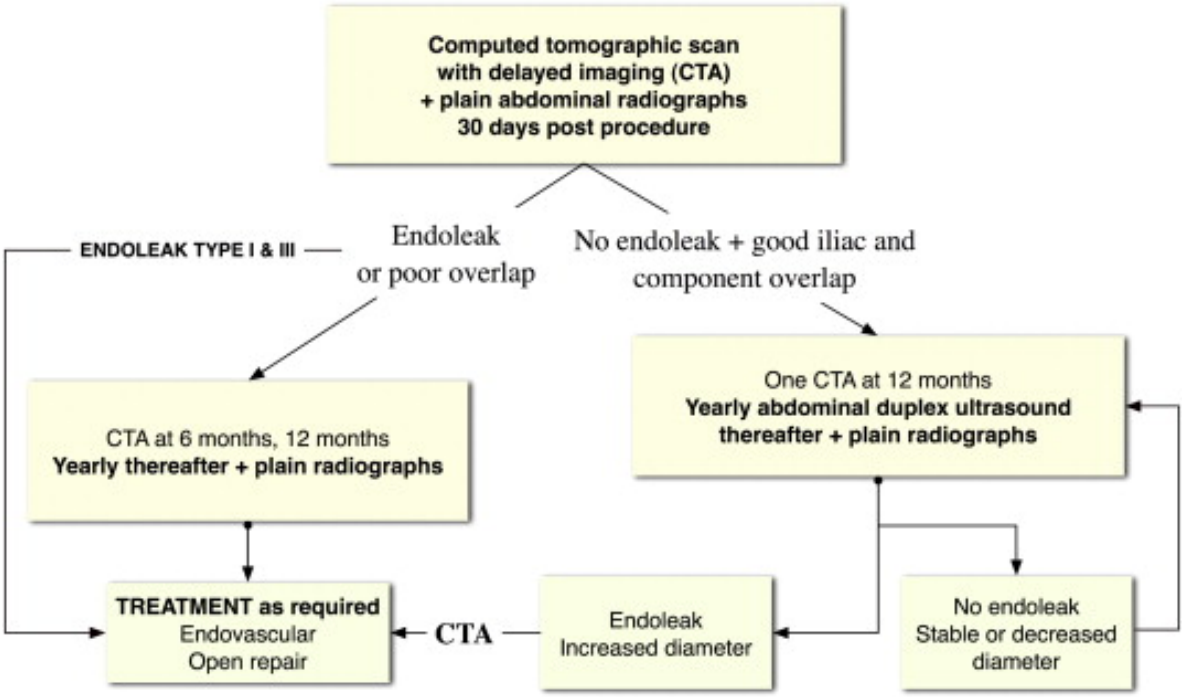

Figure 3 illustrates the new proposed guidelines suggested by ESVS (10).

1.5 Objective

Several of the stent graft specific complications are treated with endovascular interventions, demanding radiological monitoring, and also preoperative imaging. Several studies have reported the estimated radiation exposure in both the primary EVAR and the following imaging surveillance. However, there are little or no studies on the excess radiation exposure connected to the finding and treatment of the complications after EVAR. In general, there are few publications on rates of reintervention in Norway. The objective of this thesis is to estimate the rates of reinterventions in patients treated at Oslo University Hospital, Aker, and further, the excess radiation exposure related to reinterventions after EVAR, both as a result of the intervention itself, and the increased frequency of radiological imaging surveillance.

2 Method

2.1 Database and selection

At Oslo University Hospital, Aker there is developed a local database containing all the patients treated with stent grafts at the hospital from April 2007 up to and including November 2018. Per November 2018 the database contained 345 patients treated with stent grafts by the manufacturers Zenith, Endurant, and Excluder. Among the 345 patients, stent grafts were used to treat AAAs, iliac aneurysms, and new endoleaks in patients treated with EVAR before April 2007 and thus not included before.

For each patient, the database is consisting of four main aspects; clinical data, pre-operative imaging, operation data and events.

2.1.1 Clinical data

This part of the database takes aim at mapping the clinical aspects of the patient. It contains the medical history of the patient, registering if the patient suffers from diabetes, myocardial infarction, angina pectoris, heart failure, hypertension, chronic obstructive pulmonary disease (COPD) or chronic venous insufficiency (CVI). Also, information about whether the patient is a smoker, the aneurysm was symptomatic, ruptured or not, and the assessment of the American Society of Anesthesiologists (ASA) score of the patient is found. Further physical aspects like height, weight, and lung functioning is registered. Pre- and postoperative values of hemoglobin and creatinine, as well as postoperative functioning of the patient are mapped too. The setup of the clinical data page is illustrated in figure 4.

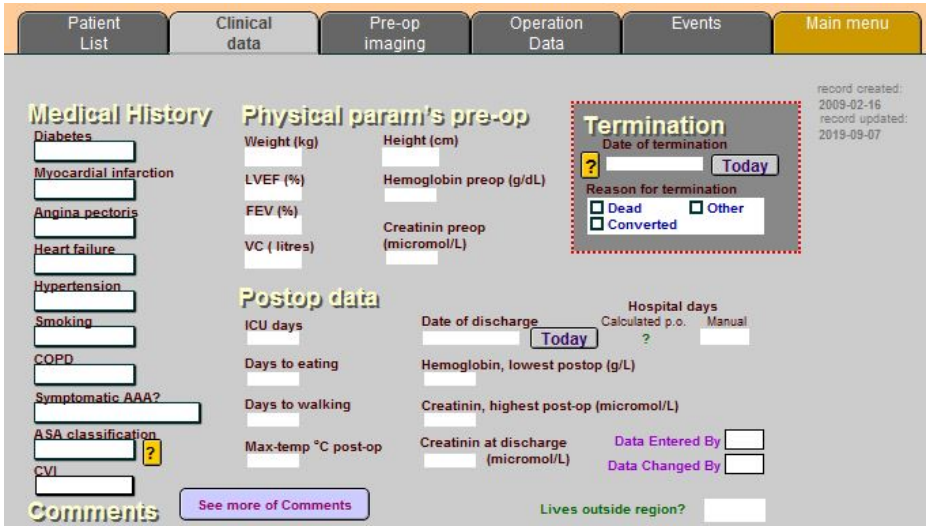

Figure 4 showing an empty scheme with all the fields making up the clinical data information on each patient.

2.1.2 Pre-operative imaging

Pre-operative imaging is vital to evaluate what kind of treatment is most suitable for the patient, and also to contemplate the results and conditions during postoperative surveillance. In the database, measures of both the AAA itself, the neck of the AAA, and the iliac arteries are enrolled. The length of the AAA, as well as the maximal and perpendicular diameter of the AAA, is registered. Additionally, the length of the neck, together with the diameter at the level of the renal arteries, 9mm below, and at the bottom of the neck is recorded. Also, the minimal diameter of the external iliac arteries, the length and maximal diameter of the common iliac arteries are registered in the database. The setup of the pre-operative imaging page is illustrated in figure 5.

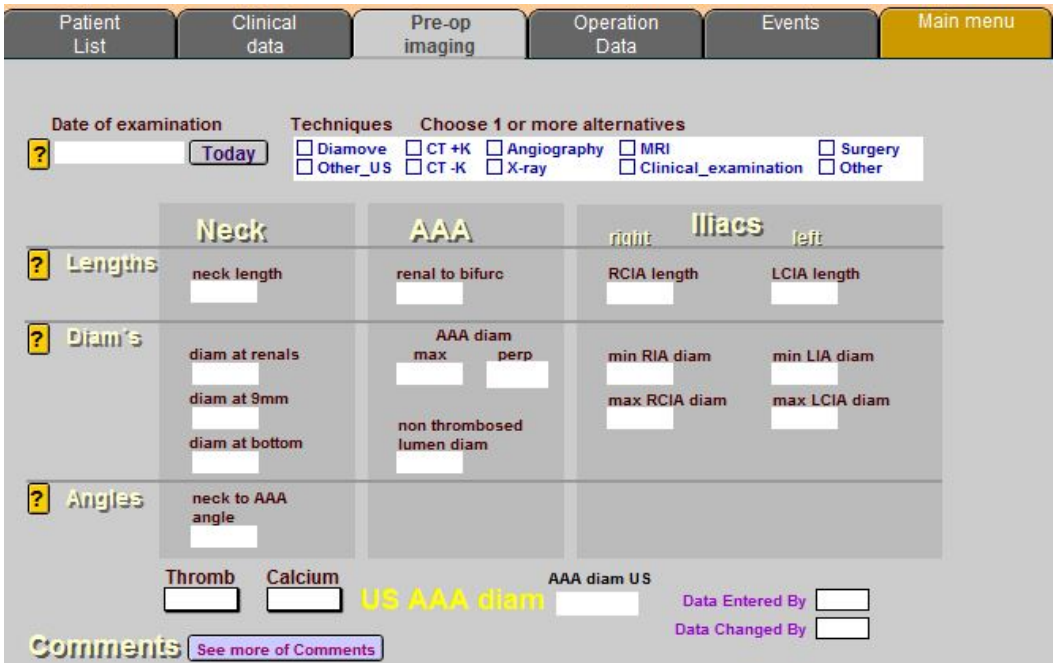

Figure 5 showing an empty scheme with all the fields making up the pre-operative imaging information on each patient.

2.1.3 Operation data

The operation data page consists of information on when and how the procedure was performed and what type of stent graft was used. It includes introducer side of the stent graft compartments, the distance of the proximal part of the stent graft relative to the renal arteries, and operation time. It also includes possible complications such as endoleaks at completion and blood loss with the needed volume of transfusion. Manufacturer, type of stent graft, with measures, possible additional extensions or other stents needed is cataloged. As the procedure is performed with radiographic surveillance, the contrast type, volume, concentration, and total dose is also registered. The setup of the operation data page is illustrated in figure 6

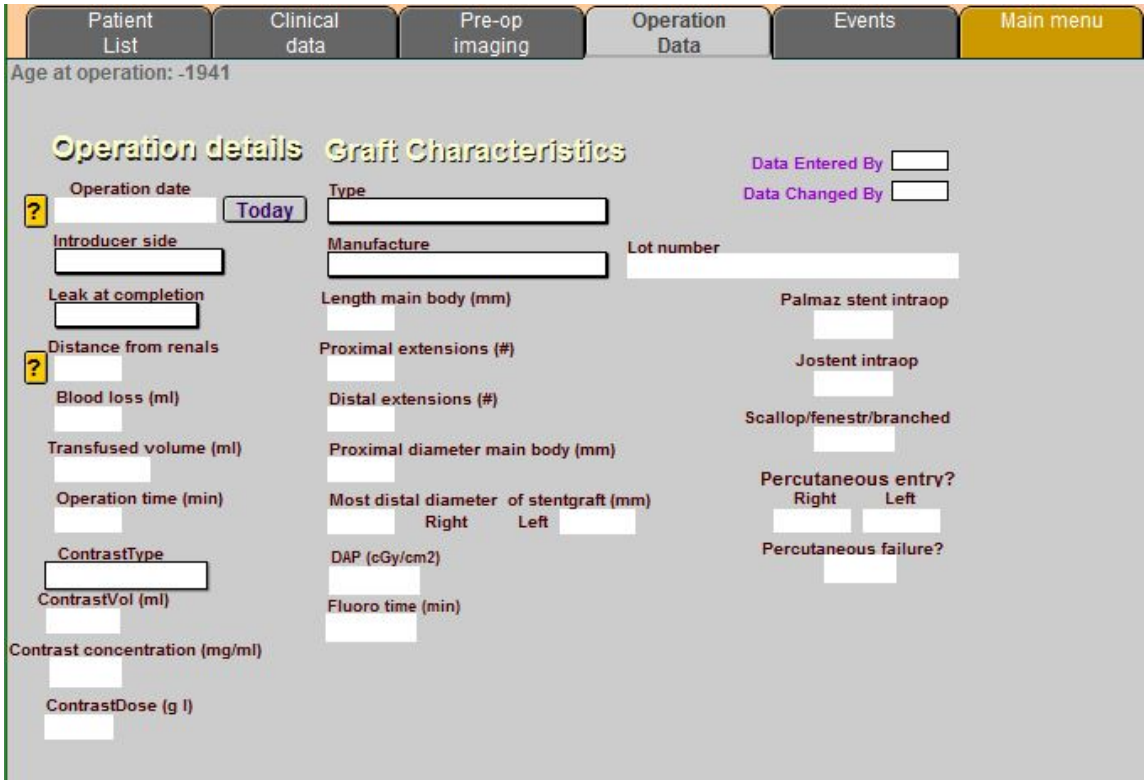

Figure 6 showing an empty scheme with all the fields making up the operation data information on each patient.

2.1.4 Events

The events-part of the database contains the radiographic surveillance procedures and is continuously updated as new follow-ups are performed. Here it is listed the date and method of the follow-up procedure, the diameters of the AAA and the neck, and the current distance of the proximal part of the stent graft from the renal arteries. Endoleaks, graft kinks, occluded renal arteries, and other adverse events are registered if found, together with the intervention if needed, and what kind of intervention performed. Every surveillance procedure is then listed chronologically. The setup of the events page is illustrated in figure 7

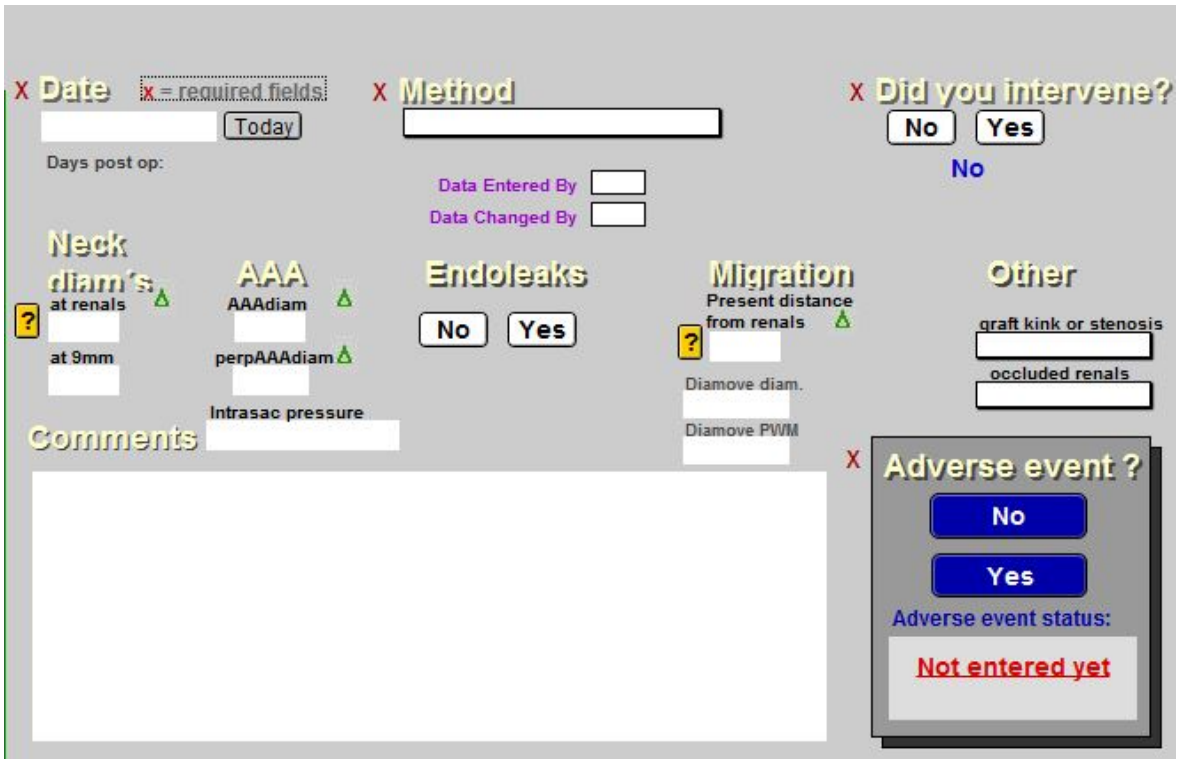

Figure 7 showing an empty scheme with all the fields to be filled in for each surveillance procedure. Complications are registered as adverse events. Type of complication, and eventual interventions are elaborated.

2.1.5 Selection

The patients included in the database are all the patients treated with stent grafts at Oslo University Hospital, Aker from April 2007 to November 2018. Most of the patients are treated with EVAR for their AAA, but some are treated for aneurysms in the iliac arteries, or as reinterventions after EVAR performed before the date of April 2007. In this study, we wanted to evaluate the additional radiation exposure in patients with reinterventions after EVAR. We wanted to observe the patients treated primarily for their AAA in the period April 2007 to November 2018. To extract the applicable patients and to make the selected group as homogenous as possible, some selection criteria were made. Guidelines suggest that EVAR is

indicated in men with AAA-diameter of 55mm or above, and 50mm or above in women. Patients with a significant amount of other risk factors for aneurysm rupture might have aneurysm repair at an earlier stage. These are found in our material. To include these patients, and to exclude patients primarily treated for aneurysms in iliac arteries, there was set a minimum limit of AAA diameter of 49mm. To exclude variations in how the procedures were performed, only asymptomatic aneurysms treated with regular bifurcated stent grafts were included. Every field in the database, described in 2.1.1-2.1.4 are searchable. A search with the including criteria AAA diameter above 49mm, asymptomatic AAA, and bifurcated graft without fenestrations and branches produce a list of 257 patients. Expanding the search to including only the patients with any adverse events, we ended up with a total of 147 patients. Of these, 58 required reinterventions.

2.2 Demographic data

A total of 257 patients were primarily treated for an asymptomatic AAA, with bifurcated stent graft, and thereby included in the material. The procedures were performed at Oslo University Hospital, Aker between 29.05.2007 and 27.11.2018. 223 of the patients (86,8%) were men, and 34 were women (13,2%). The patients were treated with stent grafts from three different manufacturers, of which 163 Zenith (63,4%), 88 Endurant (34,2%), and 6 Excluder stent grafts (2,3%). Postoperative surveillance was carried out according to the current standard surveillance protocol for EVAR, as described in chapter 1.4. However, some deviation from the standard protocol has occurred as a result of patients not attending all appointments, as well as gradually introduction of the new guidelines, explained in figure 3. Imaging surveillance has been registered from the day of operation for each patient to the date of 05.07.2019. As a result, the follow-up time varies dramatically according to when their procedure was performed. The main follow-up time was 4,02 years, with 4 patients surveilled for over 11 years, and 7 patients with no postoperative surveillance.

Causes of terminated postoperative surveillance (n=135)

Death	83 (61,5%)
Co-morbidity	34 (25,2%)
Conversion	4 (2,3%)
Lost to follow-up	14 (10,4%)

Table 2 illustrating the different causes, terminating the follow-up. 83 patients died during the time of follow-up, of which 3 are related to the AAA. 34 patients had their surveillance canceled either by own choice or by doctor´s recommendation due to age, or comorbidity, most frequently dementia. 4 patients were converted to OR due to problems unable to be solved endovascularly. 14 patients were lost to follow-up with no known cause.

Among the 58 patients who had reinterventions after the EVAR, 48 patients were men (82,8%) and 10 women (17,2%). 37 patients were treated with Zenith (63,8%), 19 with Endurant (32,8%) and 3 with Excluder stent grafts (5,2%). The mean age at the time of EVAR was 75,9 years, with the youngest patient 64 years old, and the oldest patient 89 years old. The mean follow-up time was 5,03 years in this group - two of the patients, without any follow-up and one patient with surveillance exceeding 10 years. Regarding risk factors, 49 patients had hypertension at the time of EVAR (84,5%). 11 were smokers (19,0%), and 23 were ex-smokers (39,7%). 24 patients had COPD at the time of EVAR (50,0%). The average weight in this group was 84,1kg, and the BMI was 27,1. The mean width of the AAA was 61,9 mm at the time of EVAR.

2.3 Radiation exposure assessment

2.3.1 Radiation conversion factors

The follow-up regime applied to most of the patients in this material includes, as mentioned, annual CT and PAX scans. Further, most of the reinterventions for the complications following EVAR are performed with the assistance of angiography. We have collected data on the radiation exposures registered on the different examinations and reinterventions in different patients, but these are not exact patient doses. They are calculations based on the dose the device provides for each procedure, and what part of the body is irradiated. Many parameters are included in the calculation of the exact patient dose. For instance, the distance from the x-ray generator to the skin surface of the patient, and exactly what organs are inside or outside the area being irradiated. The latter is partly taken into account in the calculations by the use of conversion factors related to the irradiated area being the abdomen/pelvis in most of these examinations. Further, the PAX imaging, and angiography both in surveillance and reintervention are calculated in dose area product (DAP) with the unit centigray per centimeter squared ($cGy * cm^2$), while for the CT scan the dose length product (DLP), with the unit milligray per centimeter (mGy*cm) is calculated.

To compare the radiation exposures originating from one type of examination to another, we have used conversion factors to obtain a universal unit, millisievert (mSv) for the total effective dose (ED) for each patient. We have used conversion factors described in the «Veileder 5, veileder om medisinsk bruk av røntgen- og MR-apparatur, revidert januar 2018, bilag 5B-5.2.3: Estimering av effektiv dose vha. overgangsfaktorer» (19). The guide utilizes a conversion factor of 0.015 to convert from $cGy * cm^2$ to mSv for CT abdomen/pelvis, and a factor of 0.0029 to convert from mGy*cm to mSv for PAX and angiography. However, the radiation exposures are not always registered for PAX, as no provision says this is necessary. Nevertheless, at Oslo University Hospital, Aker, there is an estimated average ED for PAX scans performed at the hospital of 0.4 mSv and is thereby the ED used per PAX in this study.

2.3.2 Patients selected for radiation exposure assessment

As mentioned, several other papers have investigated the CRE during radiological surveillance after EVAR. We wanted specifically to investigate the additional CRE connected to reinterventions, but also the patients with complications in general. Therefore, we have investigated all the patients with complications after EVAR, inducing either reinterventions or just a more frequent follow-up regime. Of the 147 patients with

complications, this makes up a total of 103 patients. A total of ten patients were treated with open operations, but of these, five patients were directly treated, without any extra follow-up and were not expected to have any increased CRE compared to patients without any complications. Further, four patients had a follow-up period of less than 12 months, and therefore are not suitable for comparison of CRE. Thus, we investigated the CRE in a total of 94 patients. Of these 48 (51,1%) had endovascular reinterventions, 5 (5,3%) had open surgery without any present endovascular reintervention, and 41 (43,6%) were treated conservatively with an increased amount of imaging examinations. The distribution of patients with and without interventions in the different groups of complications is shown in table 3. The patients in the open surgery group was too small to categorize further in groups according to complications.

	Type of complication	Number of patients
Reintervention (n=48)	Type I endoleak	12 (25,0%)
	Type II endoleak	15 (31,3%)
	Type III endoleak	1 (2,1%)
	Stent graft migration	2 (4,2%)
	Stent graft thrombosis	6 (12,5%)
	Stent graft infection	2 (4,2%)
	Stent graft kink	8 (16,7%)
	Arterial dissection	2 (4,2%)
Conservative (n=41)	Type II endoleak	27 (65,9%)
	Type V endoleak	4 (9,8%)
	Others	10 (24,4%)
Open (n=5)	Others	5 (100%)

Table 3 shows how the different patients are distributed among the different complication types.

2.4 Statistics

The patients with reinterventions were divided into groups according to table 3. Further, all patients were registered with follow-up time in months, and total radiation exposure carried out by surveillance alone, reinterventions alone, total CRE, number of reinterventions, and time from EVAR to reintervention for each patient. Moreover, the weight, height, and BMI were registered for each patient. We calculated the mean number of endovascular

reinterventions and the mean time from EVAR to first reintervention per group of complications. Further, we calculated the mean radiation dose from reinterventions in each group. At last, the mean total CRE was calculated in each group, but since the duration of follow-up was so variable, the total radiation exposures cannot be compared without controlling for this factor. Therefore, the CRE divided by number of months of follow-up was calculated in the individual patient. Then the mean CRE/months of follow-up was calculated in each group of complications.

To compare the differences in CRE/months of follow-up between the patients with and without reinterventions, SPSS was used to run a t-test. Since we were comparing two separate patient groups, an "independent two-sample t-test or student´s t-test was performed to determine whether the population means were significantly different.

3 Results

3.1 Reintervention rates

We wanted to investigate the rates of reinterventions after EVAR at Oslo University Hospital, Aker. As mentioned in the method, of the 257 patients included in this material, 58 (22,6%) had reinterventions during the period of follow-up (4 years mean follow-up time). 10 (17,2%) of the interventions were carried out by open procedures, without any present endovascular reinterventions. Causes for these open reinterventions included type I and II endoleaks, stent graft infections, stent graft thrombosis, and the stent graft covering other blood vessels, including the renal arteries, and the internal iliac arteries.
Of the remaining 48 (18,7%) patients with endovascular reinterventions, there was an average of 1,45 reinterventions per patient. The total amount of endovascular reinterventions in this period was thereby 70. The different complications needed a varying number of reinterventions. The distribution of the mean number of reinterventions is illustrated in figure 8. Further, the timing of the reinterventions was dramatically varying between the patient groups, but also within the groups. Table 4 is showing the average time from EVAR to reintervention in the different patient groups. Stent graft thrombosis, and -kinks seem to occur and get treated rather early after the EVAR procedure, while stent graft infection occurs many years later.

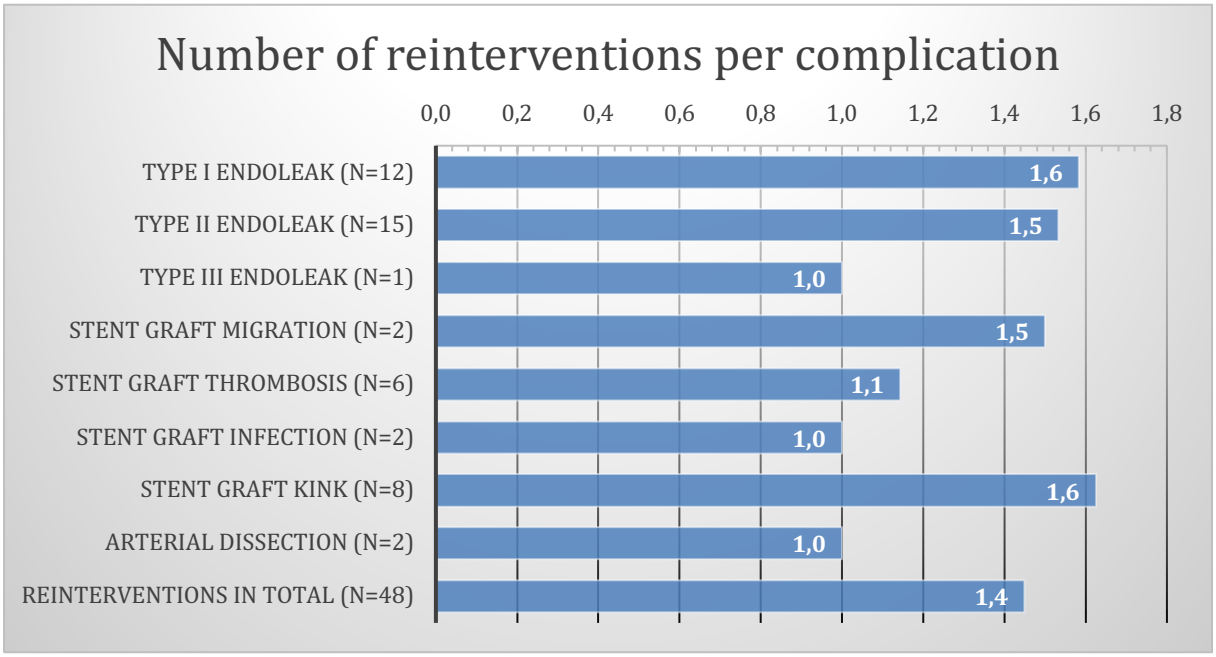

Figure 8, showing the mean number of reinterventions in each patient group. The patient group with stent graft kinks had the highest reintervention rate, with an average of 1,63. The groups with type III endoleaks, infections, and arterial dissections had their complications eliminated with only one endovascular reintervention.

Type of complication	Time in years from EVAR to reintervention
Type I endoleak (n=12)	2,8 (0,1-8,3)
Type II endoleak (n=15)	2,6 (0,4-5,9)
Type III endoleak (n=1)	2,0
Stent graft migration (n=2)	3,4 (0,2-6,7)
Stent graft thrombosis (n=6)	0,4 (0,03-1,3)
Stent graft infection (n=2)	9,1 (8,7-9,5)
Stent graft kink (n=8)	0,7 (0,2-2,3)
Arterial dissection (n=2)	2,4 (0,2-4,5)
Total endovascular reintervention (n=48)	2,3 (0,03-9,5)

Table 4, showing the average time from EVAR to reintervention in the different patient groups. Range of reintervention time within each group in parenthesis, showing there are significant variations also within each patient group.

3.2 Radiation exposure

3.2.1 Reintervention doses

A total of 48 patients had endovascular reinterventions du to any complication after EVAR. A variety of procedures are used in treating the different complications, some more advanced and time-consuming than others. As seen in 3.1, many of the patients needed more than one endovascular reintervention. As a result, the CRE is dramatically varying between the patient groups and within the groups. The mean total radiation exposure from reinterventions are illustrated in figure 9. The average reintervention dose among all the patients was 46,3 mSv.

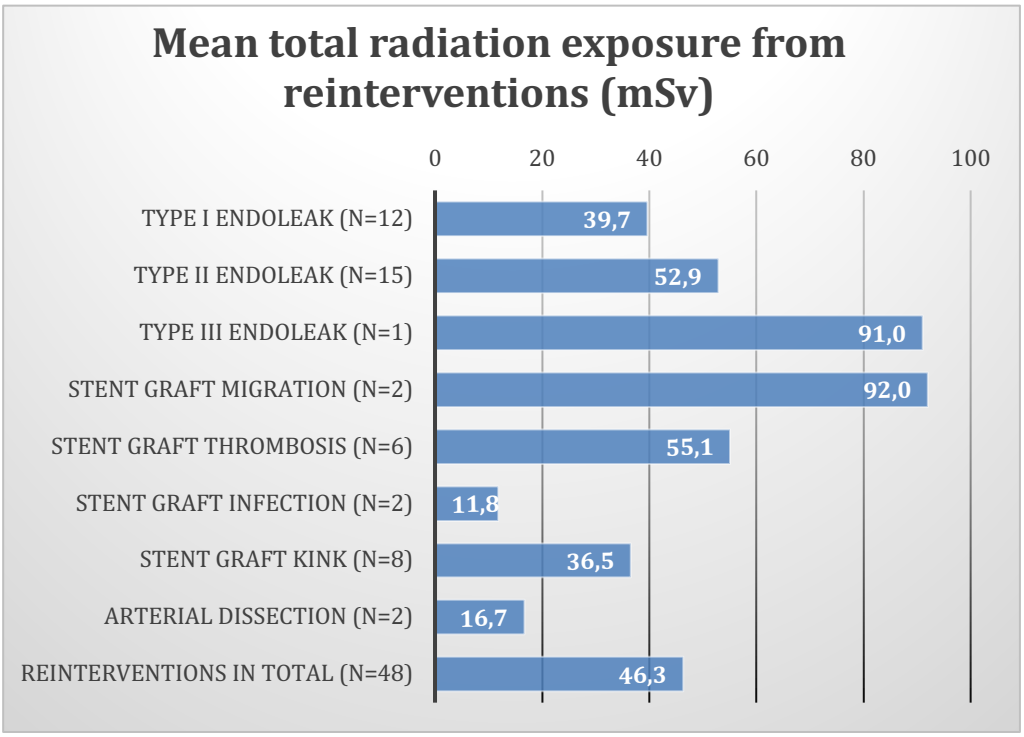

Figure 9 illustrates the average CRE (mSv) from reinterventions.

3.2.2 Total radiation dose

The average CRE, including both follow-up and the reinterventions itself, was 123,5 mSv, in the group with reinterventions, and 53,1mSv in the group without reinterventions, but more frequent follow-up regime. Since the duration of follow-up is so variable, we cannot compare the total radiation exposure without controlling for this factor. Therefore, the CRE per number of months of follow-up in the individual patient was calculated, as mentioned in 2.4. The mean radiation exposure per month is illustrated in figure 10.

The 48 patients with endovascular reinterventions had a significantly higher mean radiation exposure per month, of 0,9 mSv/month (std error diff: 0,2, 95% confidence interval: 0,5-1,3) than the 41 patients treated conservatively with only more frequent follow-up.

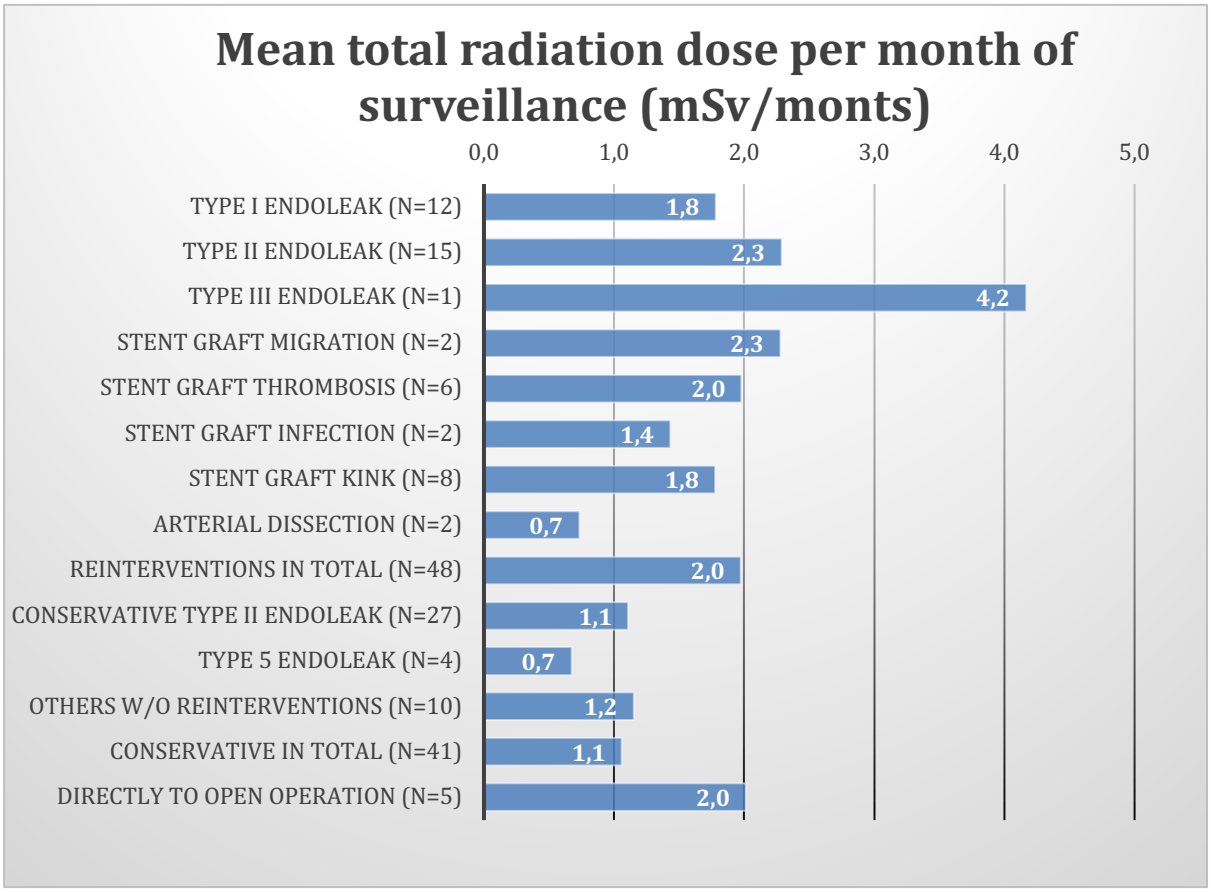

Figure 10 illustrates the average CRE (mSv) divided by follow-up time in each patient group.

4 Discussion

As seen in the results, both follow-up time, reintervention rates, and effective doses from reinterventions and follow-up examinations are heavily varying between the different patient groups, and between the different patients within the groups. Thereby many of the patient groups in this study are too small to compare to each other. For instance, we had only one patient treated with endovascular reintervention for a type III endoleak, and only two treated endovascularly for stent graft migration, one of which had an ED from the reintervention of 152,9 mSv, about five times higher than the other (31,1 mSv). On the other hand, comparing the patients with endovascular reinterventions with the patients only having more frequent, or extra examinations, there is seen a significantly increased total radiation exposure per time unit of 0,9 mSv/month in the group with endovascular reintervention. The difference is not far from doubled (2,0 mSv/month vs. 1,1 mSv/month)

Nyheim et al. investigated the ED, and CRE during follow-up after EVAR, and calculated an average ED for each CTA scan. According to their research, an average CT abdomen/pelvis will involve an ED of 8 mSv (9). To compare the patients with reinterventions, and more frequent follow-up examinations in our material, with patients without any complications or extra examinations, we can use this average ED of 8 mSv to estimate the dose per month in these patients. The average follow-up time for the patients without re-intervention was four years, thereby 48 months. According to the standard follow-up regime at Aker, which for the most patients involves one CTA scan 2-3 months after EVAR, then at 12 months and then annually (9), a four years long follow-up period will constitute a total of five examinations including CTA and PAX, assuming no complications found, which are already eliminated in this patient group. Assuming an ED of 8 mSv form each CTA scan, and 0,4 mSv from each PAX, as mentioned in 2.3.1, these patients will have a CRE of 42 mSv in four years, and thereby an average radiation exposure per month of 0,9 mSv/month. This exposure is lower than for the group with conservative treatment but extra examinations (1,1 mSv/month), and less than half compared to the group with endovascular reinterventions (2,0 mSv/month).

Of the 257 patients included in this study, we found a reintervention rate of 22,5%. Schermerhorn et al., on the other hand, reports a rate of only 9% in four years (8), which was the average follow-up time among the 257 patients in this study. Columbo et al. found a reintervention rate of 16% in three years (20). The mean follow-up time among the 58

patients with reintervention in our study was 5,03 years, which could explain the difference in reintervention rates. Nevertheless, as shown in table 3, the average time from EVAR to reintervention in our selection was only 2,3 years, which makes it appear that reintervention rates in this study are high, compared to other studies. Different procedures during EVAR, more careful examinations, or lower threshold for reintervention might explain the difference.

4.1 Disruptive factors

Some factors may disturb the results of this study. First of all, the routines in the follow-up regime have changed gradually at Oslo University Hospital, Aker over the period of the study. The changes involve less use of CTA scans in patients without any complications, or aneurysm growth, according to the new guidelines, proposed by ESVS, mentioned in 1.4. While some of the patients treated in 2007-2010 had an extra 6- or 18-months examination without even having any complications found at any present examinations. The results of these gradual changes in follow-up routines make the difference in CRE in patients with or without complications less significant in the patients treated in the early years of this study, and perhaps more significant in the latter part, and in the future. Maybe we could have eliminated the difference in follow-up routines by excluding the patients treated before the introduction of the new guidelines. However, this would make the patient material in this study even smaller and make the basis for comparison even less. Furthermore, the changes were introduced gradually and at different times in one patient to another. At the same time, some examinations may have been more or less inconclusive, and the individual doctor has had to consider whether or not new examinations were needed. Some patients have not always met to their appointment or have been lost to follow-up for some time before being reentered to the follow-up regime. For this reason, it is difficult to point out which patients having followed one regime or the other. Also, some patients may have a CRE lower than what one would expect according to the length of their follow-up.

There are also factors contributing to different ED for each examination and or reintervention for each patient, for instance, whether the CTAs are performed with or without contrast, and what kind of CTA-scan has been used. We have not investigated the distribution of these factors in this study and cannot exclude or verify that they are disturbing the results of the study. Further, Ector et al. suggest that body mass index was a more important determinant of ED than total fluoroscopy time in patients treated with pulmonary vein isolation for atrial

fibrillation (21) This may not apply to follow-up after EVAR, but it should be considered a potential disruptive factor. Table 5 shows the distribution of the patient groups of our study in different BMI categories. It might seem that higher BMI is connected to higher ED, thus might be considered a disruptive factor in this study. Perhaps the effect of BMI on radiation exposure in EVAR follow-up and reintervention could be subject to later research.

BMI	Conservative	Endovascular reintervention	Total
18,5-24 ,9 (n=38)	0,91 mSv	1,78 mSv	1,37 mSv
25-29,9 (n=34)	1,18 mSv	1,78 mSv	1,48 mSv
> 30 (n=17)	1,02 mSv	2,50 mSv	2,15 mSv

Table 5. Distributing both the patients with and without endovascular reintervention into the BMI categories "normal weight," "overweight," and "obese" appears to illustrate that increasing BMI might be associated with increasing effective dose.

Several studies have aimed at estimating the radiation exposure obtained from follow-up after EVAR, but there are little or no studies on the excess radiation exposure connected to the finding and the treatment of the complications after EVAR, and there are few Norwegian publications on rates of reintervention. Therefore, we have little data to compare with and substantiate the findings of this project. Nevertheless, it seems certain that both the detection and treatment of complications following EVAR will cause an additional radiation burden on patients, both with current follow-up regimens and perhaps even more with future guidelines. How much the additional radiation dose will affect the patients is not yet clear and may be subject to further research.

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