# RADIATION EXPOSURE IN ENDOVASCULAR PROCEDURES - AN ASSESSMENT BASED ON EXAMINATIONS PERFORMED AT SAHLGRENSKA UNIVERSITY HOSPITAL

M.Sc. thesis

Roham D. Ebrahimi

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<td>Program and/or course:</td>
<td>Medical Physicist Programme</td>
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<td>Supervisor:</td>
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Abstract

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**Supervisor:** Charlotta Lundh and Anja Almén

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**Keyword:** Endovascular aortic repair, image-guided procedure, ionizing radiation

**Purpose:** The aim of this study was to investigate how DAP and skin dose was affected by different parameters from the X-ray equipment during endovascular aortic repair (EVAR) and thoracic endovascular aortic repair (TEVAR), assess effective- and organ doses and also explore the possibilities to optimize radiation use during these procedures.

**Theory:** EVAR is an image-guided procedure, where X-ray equipment is used for guidance through the patient’s anatomy. It is a minimally invasive technique used to diagnose and treat diseases. EVAR is performed on patients suffering from abdominal aortic aneurysm (AAA). An aneurysm on the abdominal aorta results in an increase in the aorta’s diameter of over 50%. The aneurysm can also occur in the thoracic aorta. The procedure is then called TEVAR. By placing a stentgraft, a self-expanding metallic mesh, in the anatomy, the blood can flow as usual and the damaged aorta is excluded from the circulation. During these procedures high doses of ionizing radiation are used. The difference in dose between the patients is very high. By analysing this difference and find a way to optimize the radiation use, EVAR and TEVAR can be performed in a much more standardized way.

**Method:** This study is based on 38 patients that underwent EVAR and 14 patients that underwent TEVAR at Sahlgrenska University Hospital’s hybrid operating room. The 38 EVAR patients and 14 TEVAR patients were divided into two groups. The first group was the one that had DICOM Structured reports and the second group was the one that did not have any dose reports, but only had information such as total dose area product (DAP), total fluoroscopy time and patient weight available. Examination of DAP and skin dose during EVAR and TEVAR was made for each specific patient that had a DICOM Structured report. From the DAP values received, an estimation of effective- and organ doses was done in PCXMC.

**Result:** The mean [min; max] total DAP for EVAR patients was 280 [1050; 27] Gycm² and 330 [1200; 23] Gycm² for TEVAR patients. The mean skin dose for EVAR patients was 630 [170; 1300] mGy and 720 [310; 1400] mGy for TEVAR patients. The mean effective dose was estimated to 32.0 ± 19.0 mSv for EVAR and 66.0 ± 21.0 mSv for TEVAR. The mean dose to stomach, the highest organ dose during EVAR, was 100.2 ± 63.0 mGy and the thymus, the highest dose during TEVAR, received a mean dose of 250 ± 170 mGy.

**Conclusion:** This study indicates that exposure mode and fluoroscopy time are the parameters that affect the patient dose the most. However, further analysis is required to establish this. The DAP values and effective doses varied very much between patients in this study and the values were high compared to doses presented in other studies. Due to the lack of collected reports a routine must be established in order to follow the radiation use and to optimize the endovascular procedures done at Sahlgrenska University Hospital.
Table of content

1. Introduction ................................................................................................................................. 5
   1.1 X-ray equipment for image-guided procedures ................................................................. 6
   1.2 Radiation risk during image-guided procedures ................................................................. 7
   1.3 Endovascular aneurysm repair (EVAR) ........................................................................... 7
2. Aims ............................................................................................................................................... 12
3. Material and Methods ................................................................................................................... 13
   3.1 Patients included in the study ............................................................................................ 13
   3.2 Equipment ........................................................................................................................... 14
   3.3 Exposure and 3D dose simulation - EVAR ................................................................... 15
   3.4 Fluoroscopy dose simulation - EVAR ........................................................................... 15
   3.5 Exposure, 3D and fluoroscopy dose simulation - TEVAR .............................................. 17
   3.6 Conversion factors for EVAR and TEVAR .................................................................... 18
4. Results .......................................................................................................................................... 19
   4.1 EVAR ................................................................................................................................. 19
   4.2 TEVAR ............................................................................................................................... 22
   4.3 Effective dose and organ doses for EVAR ....................................................................... 26
   4.4 Effective dose and organ doses for TEVAR ................................................................... 27
5. Discussion and Conclusion ......................................................................................................... 28
Acknowledgments .......................................................................................................................... 31
Reference list .................................................................................................................................... 32
Appendix .......................................................................................................................................... 35
# List of abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAA</td>
<td>Abdominal aortic aneurysm</td>
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<tr>
<td>AEC</td>
<td>Automatic exposure control</td>
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<td>AVM</td>
<td>Arteriovenous malformation</td>
</tr>
<tr>
<td>CAU</td>
<td>Caudal</td>
</tr>
<tr>
<td>CNS</td>
<td>Central nervous system</td>
</tr>
<tr>
<td>CRA</td>
<td>Cranial</td>
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<tr>
<td>D</td>
<td>Absorbed dose</td>
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<tr>
<td>DAP</td>
<td>Dose area product</td>
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<td>DSA</td>
<td>Digital subtraction angiography</td>
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<td>E</td>
<td>Effective dose</td>
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<tr>
<td>EVAR</td>
<td>Endovascular aortic repair</td>
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<tr>
<td>Gy</td>
<td>Gray</td>
</tr>
<tr>
<td>IAK</td>
<td>Incident air kerma</td>
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<tr>
<td>IR</td>
<td>Interventional radiology</td>
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<tr>
<td>IRP</td>
<td>Interventional reference point</td>
</tr>
<tr>
<td>IVC filter</td>
<td>Inferior vena cava filter</td>
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<tr>
<td>LAO</td>
<td>Left anterior oblique</td>
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<tr>
<td>PCI</td>
<td>Percutaneous coronary intervention</td>
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<tr>
<td>RAO</td>
<td>Right anterior oblique</td>
</tr>
<tr>
<td>Sv</td>
<td>Sievert</td>
</tr>
<tr>
<td>TEVAR</td>
<td>Thoracic endovascular aortic repair</td>
</tr>
<tr>
<td>TIPS</td>
<td>Transjugular intrahepatic portosystemic shunt</td>
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1. Introduction

Interventional radiology (IR) is a medical speciality that uses image-guidance for diagnoses and treatment. It is a minimally invasive technique that is time effective compared to open surgery. When image-guided procedures are executed, the patient is often stung in the groin. From there a catheter is led up in the anatomy to the region of interest. The guidance through the anatomy is done with an X-ray system that shows live images of the anatomy through a screen that the operators use during the procedure. Since these image-guided procedures are minimally invasive their use is increasing around the world. During these image-guided procedures the X-ray equipment provides different imaging techniques. Fluoroscopy is a technique that is used for guidance through the anatomy by providing live images. 3D rotation is used to get good overview before the start of the different procedures and high quality exposure is used during and after the procedures. The expected benefits with minimally invasive procedures are less injury to the body, faster recovery and that the patient does not require long stays at the hospital. Today intervention is used in e.g cardiology, endovascular surgery, and neuroradiology [1]. Image-guided procedures are becoming more common around the world and so is the need of more interventional rooms to perform the procedures. The most advanced interventional room available is the hybrid operation room. In hybrid operating rooms the X-ray equipment is combined with the sterility of an operation room. These rooms are used for more complex and acute procedures. If necessary, operators can perform open surgery in combination with the minimal invasive procedure. Therefore it is necessary that the environment is sterile.

With image-guided technique, diseases can be cured without the use of open surgery. This technique, however, uses ionizing radiation for guidance and imaging. Some of the highest doses, related to X-ray imaging, are found in image-guided procedures. Although interventional procedures is time effective and is less demanding for the patient, compared to open surgery, the daily use of these procedures has led to increasing patient- and staff doses [2-5]. As the use of ionizing radiation procedures increases around the world it is equally important to increase the radiation protection for the patient and the staff.
1.1 X-ray equipment for image-guided procedures

Image-guided procedures are usually performed in angiographic suites using a C-arm. The suite showed in figure 1 is a typical examination room. The X-ray equipment is constructed as a C with an X-ray tube and a detector that can be rotated in any preferable direction. In order to describe the direction, a reference system is used. When the C-arm is rotated towards the left shoulder of the patient it is named LAO (left anterior oblique), RAO (right anterior oblique) when the C-arm is rotated towards the right shoulder of the patient, CAU (caudal) when the C-arm is tilted towards the feet of the patient and CRA (cranial) when the C-arm is tilted towards the patient’s head [6]. In order to specify a direction the first two is combined with the latter two. The operator determines the angulation of the tube.

![Figure 1: An example of a C-arm commonly used at image-guided procedures.](image)

The X-ray equipment is used for image guidance during the procedure. The operator mainly uses fluoroscopy to navigate through the anatomy of the patient. Fluoroscopy uses relatively low dose pulsed radiation. The image quality is good enough to e.g. see when the catheters are in the right position. The pulsed fluoroscopy can be used in different ways. The difference depends on the dose per pulse and number of pulses used from the operator. Pulsed fluoroscopy images have breaks between the taken images. Depending on the number of pulses, for a time interval, the break can either be very short or long. However, the images on the screen are seen as a live image and the breaks can affect the images if there is rather rapid motion in the anatomy. Pulsed fluoroscopy has the advantage over continuous fluoroscopy that the radiation dose, to patient and operators, is lower [3,7]. Other than fluoroscopy, the system delivers 3D images and exposure series. These imaging techniques usually have higher doses than fluoroscopy, aiming at producing images with diagnostic quality.

The exposure technique commonly used in vascular procedures is called digital subtraction angiography (DSA). DSA is used to visualize the blood vessels by subtracting all the anatomical structures around the vessels that is of interest. An image is taken before the contrast media is injected into the vessels. A series of images is then taken during the distribution of the contrast media in the vessels while a subtraction of the anatomical structures from the first image is performed in real time. The contrast medium used in most cases is iodine (which has higher density compared with the surrounding structure). The images are showing only the resulting contrast filled vessels without disturbing anatomical structures [8]. This way the staff can see the vessels in detail and it helps them with e.g. stent placement. There are different types of exposure modes (DSA modes) that vary in image quality and dose. These different modes are preprogramed in the system and are selectable for the operator. When 3D is performed, the C-arm is rotated automatically and takes images in different projections. The intraoperative 3D images are sometimes
matched with a CT that is taken preoperatively. This is called image fusion and helps the operators before and during the procedure with stent placement [9].

During the procedure a pedal is used for pulsed fluoroscopy or angiographic series (high dose images). With the help of the pedal, the operator can irradiate and have both hands free to e.g. insert catheters into the patient’s vessels.

Fluoroscopy systems can be divided into two categories, depending on the detector type. The first category is image intensifier systems, which are rarely used anymore, and the second one is flat-panel detector systems. The flat-panel detector systems can be divided into two different classes. The first one is direct conversion (X-ray photons are converted to electric charge directly) and the second one is based on indirect conversion. Indirect conversion converts X-ray photons to light by the use of a phosphor material that absorbs the X-rays photons and produces light. This light interacts with a photodiode electrode and creates the electric charge that is used by the system to produce an image.

In the X-ray machine a number of programmes specifying some technique factors and image reconstruction are set and used specifically for different procedures. Parameters such as tube voltage, tube current and filtration are controlled and varied by the system’s automatic exposure control (AEC). The purpose of the AEC is to deliver consistent radiation to the detector regardless of the patient thickness in different parts of the body. This is achieved by adjusting the parameters for different exposure situations mentioned above. However, the parameters cannot vary out of the programmed range. There is a preprogrammed range for all the parameters that are controlled by the AEC. Therefore these parameters are altered with the purpose to produce adequate image quality, regardless of patient thickness. Parameters that are not automatically controlled by the system but controlled by the operator are rotation of the C-arm and fluoroscopy mode/exposure mode.

1.2 Radiation risk during image-guided procedures

During image-guided procedures there may be a risk of tissue damage, for example skin burns and circulatory disease regarding the patient and also eye cataract for the operators if they are not properly protected [10]. These tissue damages are called deterministic effects and are noticed after exceeding a threshold dose. The threshold dose for circulatory disease can be as low as 0.5 Gy to the heart and brain [11]. The threshold dose for skin erythema is 2 Gy [12]. There is also a risk of stochastic effects i.e - cancer induction. For stochastic effects the risk increases with dose without any threshold. It is essential for the whole procedure that the operator, together with the staff, plans the imaging in advance as much as possible. This way the dose to the patient can be kept to a minimum. Generally, for patient protection, it is important that the operator rotates the x-ray equipment (this way the risk of skin injury is decreased), keeps the distance between the detector and the patient as close as possible, uses the lowest dose per pulse (and only increase the dose per pulse when necessary), keeps the fluoroscopy time as low as possible and uses as few exposures as possible [11].

1.3 Endovascular aneurysm repair (EVAR)

Endovascular aneurysm repair (EVAR) is an endovascular procedure practised in order to treat abdominal aortic aneurysm (AAA). The aorta is the biggest artery in the body and the main blood vessel that supplies blood to abdomen, pelvis, legs and the smaller arteries. An abdominal aortic aneurysm occurs when an area of the aorta is enlarged and becomes like a balloon. If the aneurysm grows fast one might feel pain but usually the aneurysm itself does not come with any symptoms. If the aneurysm is ruptured it can cause life-threatening damage. The cause of the disease is unknown but there are some risk factors such as smoking, high blood pressure, heredity and increasing age. Patients with AAA are treated with EVAR or open surgery. Approximately ten percent of the patients with AAA require open surgery. Open surgery is recommended during acute conditions, e.g when the aneurysm has ruptured or is growing fast. This is one major reason why a hybrid suite is required, for its sterility if the operators have to change to open surgery [13].
EVAR procedures use image-guided technique and are minimally invasive. The operator cuts the patient in the groin, to get access to the femoral artery. From the femoral artery a long tube, called a catheter, is led up via the iliac artery to the aneurysm. The operator is guided with the help of fluoroscopy up to the dysfunctional/damaged aorta. Attached to the catheter is a stent graft. A stent is a tube that is placed in the anatomy to create a passage for blood to go through vessels, in this case the aneurysm. The placement must be done with great care because of the risk of blockade of the renal arteries. When the stent is placed the pressure reduces in the abdominal aorta and reduces the risk of rupture dramatically.

The benefit of an EVAR compared to open surgery is that the patient spends less time in the hospital because there is no need for opening the chest or abdomen to execute the procedure. This decreases the risk of damaging the body’s main arteries, veins and nerves. Studies have shown that the 30-day operative mortality is reduced with two-thirds when the aneurysm is repaired using EVAR instead of open surgery [14,15]. Even though there are multiple benefits with EVAR, it is however one of the most dose-requiring procedures using image-guidance. A study by Weerakkody et al. [16] showed that skin damage of 2 Gy was exceeded in 29 % of the procedures performed. This indicates that EVAR requires high doses.

The aneurysm can occur in the thoracic aorta as well and is then called thoracic aortic aneurysm (TAA). The treatment for TAA is called thoracic endovascular aortic repair (TEVAR). Usually this procedure requires more advanced methods compared to EVAR, because of the complexity of the blood circulation to the upper body and cerebral arteries, leading to the brain [17].

It is challenging to determine the radiation dose from EVAR and TEVAR since all the patients vary from each other. The lack of standardized treatment routines makes it hard to determine dose to operator and patient. In the present study both EVAR and TEVAR were examined.
1.4 Patient dose during image-guided procedures

Patient doses are monitored in two ways by the X-ray equipment during image-guided procedures. The first one is an estimation of skin dose and is measured as incident air kerma (IAK). IAK is determined in the interventional reference point (IRP). The IRP is located 15 cm from the isocenter in the direction of the X-ray tube [7]. This is illustrated in figure 2. Since the IRP does not change when the table height is adjusted, the skin dose can both be overestimated and underestimated. The IAK value is an indication of the dose to the skin, i.e. an indication of deterministic risk. The unit for IAK is Gray (Gy).

![Digital Detector](image)

**Figure 2**: A schematic view of a fluoroscopy system using flat-panel detector technique.

The second dose estimate is the dose-area-product (DAP) with the unit Gycm². DAP is defined as the absorbed dose multiplied with the irradiated area. The DAP value provides the operator with a simple dose estimation during a procedure. DAP gives an indication of stochastic risk, but the quantity that is used to estimate the stochastic risk of the patient is effective dose. Effective dose is used to estimate the stochastic risk of the patient and is determined using equation 1:

\[ E = \sum D \times w_T \times w_R \]  

(1)

where D is the absorbed dose in each organ, \( w_R \) is a weighting factor that depends on the different radiation type (e.g. x-ray, protons, alpha particles etc.) and \( w_T \) is a weighting factor for specific organs. For example, the human bone marrow has a weighting factor of 0.12 and the skin has a weighting factor of 0.01. Sensitive tissues/organs have higher value on the weighting factors than less sensitive tissues/organs. The unit of effective dose is Sievert (Sv). The risk of cancer is estimated to increase with 5.5 % per Sievert. This estimation is derived from the survivors of the atom bomb dropped over Hiroshima and Nagasaki [11]. If one is to get an estimation of stochastic risk, one must convert the DAP value to E [18].

Table 1 illustrates the weighting factors for the different organs [19].
Table 1: The table shows the different weighting factors for the different organs. The last row (Rest) is a summation of all the remaining organs [19].

<table>
<thead>
<tr>
<th>Organs</th>
<th>Weighting factors</th>
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<tbody>
<tr>
<td>Bone Marrow, colon, stomach, lungs,</td>
<td>0.12</td>
</tr>
<tr>
<td>breasts</td>
<td></td>
</tr>
<tr>
<td>Gonads</td>
<td>0.08</td>
</tr>
<tr>
<td>Bladder, liver, esophagus, thyroid</td>
<td>0.04</td>
</tr>
<tr>
<td>Salivary glands, brain, skin, bone</td>
<td>0.01</td>
</tr>
<tr>
<td>surface</td>
<td></td>
</tr>
<tr>
<td>Remainder</td>
<td>0.12</td>
</tr>
</tbody>
</table>

X-ray as image guidance is used, as mentioned, for many different procedures. DAP and estimated skin dose values from different procedures are presented in Table 2. The order of presentation in the table is determined after the highest DAP value.

Table 2: Data for a variety of image-guided procedures taken from previous studies. Procedures #1, #2, #4 and #5 are taken from Miller et. al. [7]. Procedure #3 is taken from Howells et. al. [20]. Procedure #6 is from Walsh et. al. [21]. Procedures #7 and #10 are taken from Pantos et. al. [22]. Procedure #8 is from Geijer et. al. [23]. Lastly, Procedure #9 is from Jones et. al. [24].

<table>
<thead>
<tr>
<th>#</th>
<th>Procedure Description</th>
<th>Total Cases</th>
<th>Fluoro Time (min)</th>
<th>DAP (Gycm²)</th>
<th>Est. skin dose (Gy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>Embolization/head AVM</td>
<td>177</td>
<td>92.5</td>
<td>2.6 - 314</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>Aneurysm</td>
<td>149</td>
<td>75.0</td>
<td>15.2 - 401</td>
<td>283</td>
</tr>
<tr>
<td>2</td>
<td>TIPS creation</td>
<td>135</td>
<td>38.7</td>
<td>3.5 - 153</td>
<td>335</td>
</tr>
<tr>
<td>3</td>
<td>TEVAR</td>
<td>232</td>
<td>10</td>
<td>1.5 - 130</td>
<td>194</td>
</tr>
<tr>
<td>4</td>
<td>Renal angio</td>
<td>103</td>
<td>21.6</td>
<td>4.1 - 87</td>
<td>190</td>
</tr>
<tr>
<td>5</td>
<td>IVC filter</td>
<td>279</td>
<td>13.4</td>
<td>1.4 - 34</td>
<td>108</td>
</tr>
<tr>
<td>6</td>
<td>EVAR</td>
<td>111</td>
<td>18.5</td>
<td>-</td>
<td>85.6</td>
</tr>
<tr>
<td>7</td>
<td>PCI</td>
<td>5294</td>
<td>15</td>
<td>1.4 - 172</td>
<td>78.3</td>
</tr>
<tr>
<td>8</td>
<td>EVAR</td>
<td>24</td>
<td>28</td>
<td>-</td>
<td>72</td>
</tr>
<tr>
<td>9</td>
<td>EVAR</td>
<td>320</td>
<td>29.4</td>
<td>-</td>
<td>46.8</td>
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<tr>
<td>10</td>
<td>Coronary angio</td>
<td>9100</td>
<td>4.7</td>
<td>0.3 - 57.0</td>
<td>39.9</td>
</tr>
</tbody>
</table>

The procedures in table 2 vary in nature and concern a variety of anatomical structures. Arteriovenous malformation (AVM) is an abnormal connection between the arteries and veins that occurs in the central nervous system (CNS). Aneurysm occurs when part of an artery wall weakens. This weakness widens the artery wall and increases the risk of blood leakage. Transjugular intrahepatic portosystemic shunt (TIPS) is a procedure that creates a new connection between the portal vein and the hepatic vein. During an inferior vena cava (IVC) filter procedure a filter is placed in the vena cava to prevent blood clots to travel up to the lungs. Percutaneous coronary intervention (PCI) is a procedure where the narrowed coronary arteries in the heart are widened [25]. Coronary angiography is a procedure where the coronary arteries in the heart are diagnosed [26,27]. EVAR and TEVAR are described in section 1.3.

Dose restrictions for patients do not exist as it does for staff members performing the procedure, but an assessment between benefit and risk has to be performed. As long as the benefit of the procedure is greater than the risk of radiation damage, one could go ahead with the procedure. But all procedures should be executed with as low dose as possible, the ALARA (as low as reasonably achievable) principle is applicable.
[28]. There is however some standardised procedures that have reference doses. An example is coronary angiography. In Sweden the reference dose for a coronary angiography procedure is 80 Gy cm$^2$ [29]. The reason that some procedures do not have reference doses is due to the lack of standardized work. Procedures such as TIPS and placement of IVC filter, EVAR and TEVAR are difficult to execute applying one specific protocol and therefore it is hard to establish reference doses for these procedures.
2. Aims

The aims of this work were to

- survey DAP and skin dose during EVAR and TEVAR procedures
- assess organ doses and effective doses during the procedures
- evaluate how these dose parameters are affected by specific parameters (e.g. fluoroscopy time, angulation and exposure mode) and
- explore possibilities to optimize radiation use during these procedures.

This study is part of a project aiming at developing safe and efficient use of X-ray imaging during image guided procedures. This work was a pilot study adding basic knowledge of technical parameters used and radiation dose to patients, in order to be able to investigate the associated radiation risks.
3. Material and Methods

3.1 Patients included in the study

This study is based on collected data from 38 patients undergoing an EVAR procedure from 2015-01-22 to 2016-03-10. The collected data are from two different sources.

1. DICOM Structured report (report received from the X-ray system)
2. Medical records

In figure 4 an illustration of a DICOM Structured report is shown. The information received from the DICOM Structured report was total fluoroscopy time, DAP from fluoroscopy, DAP and skin dose given from exposures, technical settings (such as kV, mA, frames/s), exposure time and the angle of the gantry when exposure was used.

![Figure 4: An illustration of a DICOM Structured report.](image)

38 patients undergoing EVAR, during 2015-01-22 to 2016-03-10, were included in this study. Only 12 patients had a useable DICOM Structured report. The reason for this was technical and practical issues. Table 3 shows what type of information the patients had and the number of available patients in the study.

| Table 3: An illustration of what information the different patients had. |
|------------------|------------------|
| **Total patients** | **38** |
| Useable DICOM Structured report | 12 |
| Data from Medical records | 26 |

In the medical records, information such as fluoroscopy time, total DAP (exposure and fluoroscopy was not separated), patient weight and height were available. The patients with information from medical records were used to examine how the total DAP differed with patient weight.

This study is also based on 14 patients undergoing a TEVAR procedure from 2015-01-08 to 2016-03-03. In this group, 4 had a useable DICOM Structured report. The rest of the patients had medical records with weight, height, fluoroscopy time and total DAP.
3.2 Equipment

The patients were treated in Sahlgrenska University Hospital’s hybrid operating room. Figure 5 shows the hybrid room at Sahlgrenska University Hospital. The X-ray equipment in a hybrid room is not mobile as it is in ordinary operating suites. The C-arm in the hybrid room is a robot that is controlled by a remote.

![Figure 5: A hybrid operating room where the high technology X-ray equipment is combined with the sterile operating environment. This allows surgeons to perform invasive and minimally invasive procedures.](image)

The X-ray equipment in the hybrid operating room at Sahlgrenska University hospital is a Siemens Axiom Artis Zeego (Siemens Healthcare, Erlangen, Germany) with a flat panel detector system with the dimensions 30×40 cm² of the indirect conversion type. The system provides the operator with DAP, with the unit μGycm², and IAK with the unit mGy. The total filtration of the system is 3.9 mm aluminium. Copper is used as added filtration varies between 0.1 – 0.9 mm. Table 12 in appendix shows the different DSA protocols used during procedures. The system can also produce rotational 3D images that are sometimes used in the beginning of the treatment, as mentioned in section 1.1.
3.3 Exposure and 3D dose simulation - EVAR

The effective dose and organ doses were assessed using the Monte Carlo programme – PCXMC 2.0 (STUK (Radiation and Nuclear Safety Authority), Helsinki, Finland) [30]. The exposure data from both exposure and 3D rotation was used in the simulations.

Dose simulations were performed for 10 out of the total 38 patients included in the study. The exclusion was made because PCXMC requires all the information that the DICOM Structured report provides. Parameters such as angulation of the X-ray tube, patient weight, patient height, filtration and X-ray tube voltage varied during the procedures for each patient and were used in the dose simulations. Figure 6 illustrates the position of the radiation field and also which parts of the anatomy that were included. Parameters such as field size, exposure area, focus-source-distance (FSD) and number of photons were kept constant during the simulations. The field size was set at 30×30 cm² on the patient target and this “reference” size was obtained from exposure images that were available from the procedures. The starting position for exposure, 3D and fluoroscopy was at posterior anterior (PA) position for each simulation. The exposure area was chosen in the pelvis area up to the kidneys (where the aortic aneurysm normally is located).

![Image](image_url)

**Figure 6:** The position and the field size when exposure was used for patients that underwent EVAR. The right image illustrates the anatomy that is included. The main organs that are seen are the kidneys, bladder, spine and the liver.

The FSD was set at 65 cm. This information was obtained from the DICOM Structured report for each patient and did not vary. The number of simulated photons was set to 20,000. The effective- and organ doses was obtained by using the DAP value from each exposure. By summing the dose from each exposure the total effective dose was obtained for each procedure and the same was made for organ doses.

For those treatments including 3D rotation, the effective dose estimation was made by dividing the rotation in 16 projections and then simulating each projection as an exposure [31]. The field size and FSD was the same as for the exposures. The 16 projections were divided with an even angular interval of 12°.

3.4 Fluoroscopy dose simulation - EVAR

The effective- and organ doses from fluoroscopy were also assessed using PCXMC. Parameters such as patient weight, height, FSD, field size and exposure area was identical as for the simulations described in section 3.3. The fluoroscopy DAP was presented as one total DAP value and not in detail as for the exposures. Due to this, each fluoroscopy simulation was made using one angulation. The angulation for fluoroscopy simulation was chosen as the mean of all angulations used during the exposures for each
patient, given in detail in the DICOM Structured report. Figure 7 illustrates the field size and a specific angulation for a patient.

![Image](image.png)

Figure 7: The position and the field size when fluoroscopy was used for patients that underwent EVAR. The right image illustrates the anatomy that is included. In this case the mean of all the different angulations from the exposures was used.

The chosen tube voltage was set to 70 kV and the filtration was set to 0.2 mm Cu. These parameters were not varied since this information was not available from the DICOM Structured report. The only available information was the general pre-set protocol used for all procedures using fluoroscopy. The standard tube voltage and filtration was the ones chosen for simulation.
3.5 Exposure, 3D and fluoroscopy dose simulation - TEVAR

The dose simulation for patients undergoing TEVAR was similar to patients undergoing EVAR. Organ doses for 3 patients were assessed. Figure 8 illustrates the field position and field size. The dimension of the field size was $25 \times 15 \text{ cm}^2$ and these dimensions were obtained from images from the procedure. The area of exposure was chosen in the thorax area. The remaining parameters were identical as in the EVAR simulations mentioned in section 3.3.

![Figure 8](image.png)

Figure 8: The position and the field size when exposure was used for patients that underwent TEVAR. The right image illustrates the anatomy that is included. The main organs that are seen are the heart, lungs and liver.

Field size, exposure area and FSD was identical for fluoroscopy simulation as the exposure simulation for TEVAR. Tube voltage and filtration was set at 70 kV and 0.2 mm Cu, identical as the fluoroscopy simulation for EVAR. Figure 9 illustrates the field and specific angulation for a specific patient.

![Figure 9](image.png)

Figure 9: The position and the field size when fluoroscopy was used for patients that underwent TEVAR. The right image illustrates the anatomy that is included. In this case the mean of all the different angulations from the exposures was used.
3.6 Conversion factors for EVAR and TEVAR

Factors to convert DAP values to effective dose is sometimes used for standardized X-ray examinations e.g. conventional lung X-ray. The purpose of conversion factors is to get a tool to estimate radiation risk from a radiation dose value easily obtained during the treatment. By converting DAP directly to effective dose one can get an estimation of risk without the need to calculate organ doses for each patient. In this study, conversion factors for EVAR and TEVAR were derived. By dividing the obtained effective doses from simulations for each patient with the obtained DAP from the same patient, the conversion factor can be derived for this kind of treatment. The conversion factor is then, if the procedure is performed similarly for different patients, applicable to other patients. Specific calculations of organ doses are not needed for individual patients to get an estimation of the effective dose, the radiation risk. The unit for the conversion factor \( k \) is \( \text{mSv/Gycm}^2 \). The conversion factor was calculated using the calculated effective dose for the 10 EVAR patients and 3 TEVAR patients. Separate conversion factors were calculated for exposure, fluoroscopy and 3D.
4. Results

4.1 EVAR

In most cases where DSA was used the tube voltage was between 66 and 119 kV. The 3D rotation during the examination was performed with high tube voltage between 106 and 116 kV. In most of the cases where DSA were used the tube current normally varied between 300 and 500 mA but sometimes the value could reach 700-800 mA. Detailed information about all the used parameters during each procedure are shown in the appendix, table 8. The tube voltage, tube current, exposure time, number of collected images per exposure, weight, filtration, DAP received from each specific exposure and tube angulation is included in the table.

Figure 10 illustrates an example of when the different exposures were made for one representative patient. In this example the DAP is plotted against the elapsed time of the procedure for DSA and 3D exposures. It can be seen that it took 1 hour and 40 minutes from the start of the procedure to make the first exposure in this example. Fluoroscopy was most likely used in between the exposures and also in between “start” and the first exposure. In the appendix the remaining procedures are presented. The other procedures showed a similar pattern.

![Figure 10: An illustration of DAP values against elapsed time for patient 1. The labels shown above the dots include the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.](image-url)
Figure 11 illustrates when the different exposures were made for the same patient, as shown in figure 10. In this example the estimated skin dose is plotted against the elapsed time for DSA and 3D. The labels shown above the dots include the time for each DSA run and also the gantry angulation.

In table 4 the mean [min, max] fluoroscopy time, total DAP, procedure time, DAP from exposure, DAP from fluoroscopy, skin dose from exposure, skin dose from fluoroscopy and total skin dose are given for EVAR procedures. Fluoroscopy time and total DAP are data collected from all 38 patients. Procedure time, DAP from fluoroscopy, DAP from exposures, skin dose from fluoroscopy and total skin dose are collected from the DICOM Structured report available for 12 patients. In appendix, table 10, detailed data on the weight, fluoroscopy time and total DAP for each patient undergoing EVAR is given.

Table 4: The mean [min, max] is illustrated for different parameters during EVAR. The fluoroscopy time and total DAP is taken from 38 patients. Procedure time, DAP from exposure, DAP from fluoroscopy, skin dose from exposures, skin dose from fluoroscopy and total skin dose is taken from 12 patients.
Figure 12 illustrates the distribution of total DAP from fluoroscopy, exposure and 3D for each patient. The dose contribution from the different imaging technique varied between the patients. However, generally, exposure was the main contributor to dose for the patients receiving the highest doses.

Figure 12: Illustrations of the total DAP given from fluoroscopy, exposure and 3D during EVAR procedures.

Figure 13 illustrates the total skin dose given from fluoroscopy, exposure and 3D for each procedure. In this case, fluoroscopy was the main skin dose distributor.

Figure 13: Illustrations of the total skin dose given from fluoroscopy, exposure and 3D during EVAR procedures.
In figure 14 the weight of the patient is plotted against total DAP for 36 patients. Two out the total 38 patient’s weights were unknown and therefore missing. No correlation between DAP and weight could be seen during the present study.

![Graph](image)

**Figure 14:** An illustration of the weight plotted against total DAP from 36 patients.

### 4.2 TEVAR

Figure 15 illustrates when the different exposures (DSA and 3D) were made for one patient that underwent TEVAR. In this example the DAP is plotted against the elapsed time. In Appendix the same result, for all patients, are presented.

![Graph](image)

**Figure 15:** An illustration of DAP values against elapsed time during a TEVAR procedure for patient 52. The labels shown above the dots include the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 16 illustrates when the different exposures were made during the procedure for one patient. In this example the skin dose is plotted against the elapsed time for DSA and 3D.

![Image of Figure 16]

**Figure 16**: An illustration of IAK values against elapsed time during a TEVAR procedure for patient 52. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

In table 5 the mean [min,max] fluorotime, total DAP, procedure time, DAP from exposure, DAP from fluoroscopy, skin dose from exposure, skin dose from fluoroscopy and total skin dose is given for TEVAR procedures. Fluoroscopy time and total DAP illustrates data collected from all 14 patients. Procedure time, DAP from fluoroscopy, DAP from exposure, skin dose from exposure, skin dose from fluoroscopy and total skin dose is collected from 4 patients. In appendix, table 11, the weight, total DAP and fluoroscopy time are illustrated for all the patients undergoing TEVAR.

**Table 5**: The mean [min,max] is illustrated for different parameters during TEVAR. The fluoroscopy time and total DAP is taken from 14 patients. Procedure time, DAP from exposure, DAP from fluoroscopy, skin dose from exposures, skin dose from fluoroscopy and the total skin dose is taken from 4 patients.

<table>
<thead>
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</tbody>
</table>
Figure 17 illustrates the total DAP from each imaging technique for 4 patients that had a useable DICOM Structured report. There was a significant difference in total DAP between the patient receiving the lowest and the highest DAP. The largest DAP contributor varied between the different patients.

Figure 17: An illustration of the DAP from each imaging technique during TEVAR procedures.
Figure 18 illustrates the estimated skin dose from each imaging technique. The highest skin dose was received from exposure for the patients receiving highest skin dose, this was also the case for EVAR.

![Figure 18: An illustration of the total skin dose given from each imaging technique.](image)

In figure 19 the total DAP is plotted against weight for 13 patients. One patient had an unknown weight and was excluded. The figure illustrates that there are no correlation between DAP and weight in the present study.

![Figure 19: An illustration of the weight against the total DAP from 13 patients undergoing a TEVAR](image)
4.3 Effective dose and organ doses for EVAR

Figure 20 illustrates the effective dose received from exposures (red colour), fluoroscopy (light blue colour) and 3D (dark blue). The difference between the patients receiving the highest and the lowest effective dose was almost a factor of 10.

Figure 20: The effective dose received from exposures and fluoroscopy for the 10 patients. Two patients were excluded due to unknown weight.

In table 6 the mean effective dose and mean absorbed dose to organs, along with the standard deviation and median dose, can be seen for the 10 patients included in the calculations. The table illustrates the received doses from exposure and fluoroscopy separately, in addition to the total given radiation dose. Two patients had an unknown weight and were excluded. The organs shown in the table were the ones that received highest absorbed dose during the dose simulations.

Table 6: The table illustrates the mean effective dose (mSv) and mean absorbed dose to organs (mGy) with the standard deviation and the median dose with matching range values [minimum; maximum] from exposures, fluoroscopy and the total given radiation dose for the 10 patients that was simulated. The organs with the highest dose are shown in the table.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>E [mSv]</th>
<th>Colon [mGy]</th>
<th>Spine [mGy]</th>
<th>Bone Marrow [mGy]</th>
<th>Liver [mGy]</th>
<th>Stomach [mGy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>18.0±12.0</td>
<td>37.0±25.0</td>
<td>33.0±33.0</td>
<td>7.9±6.8</td>
<td>23.0±15.0</td>
<td>56.0±44.0</td>
</tr>
</tbody>
</table>

Fluoroscopy

| Mean     | 14.0±10.6 | 30.0±30.4   | 13.0±15.0   | 4.2±2.9            | 20.6±18.0   | 44.0±32.0     |
| Median   | 14[2; 37]  | 30.4[6.2; 83] | 15[2.8; 34] | 4.5[0.71; 10.8]   | 18[2.7; 61] | 40[6.4; 100] |

Total

| Mean     | 32.0±19.0 | 67.0±39.0   | 47.0±34.0   | 12.0±8.0           | 43.0±27.0   | 100.2±63.0    |
| Median   | 33[7.6; 60.1] | 73[14; 104] | 41.0[8.1; 140] | 10.1[3.2; 31]    | 50[9.1; 80] | 99[18; 201]  |

A mean conversion factor value was estimated by taking the mean value from the 10 patients. The mean conversion factor was 0.24±0.03 for fluoroscopy, 0.17±0.02 for exposure and 0.19±0.02 for total dose. If the conversion factor was applied on the patient that received the highest DAP (1050 Gycm²) the resulting effective dose was approximately 200 mSv for EVAR.
4.4 Effective dose and organ doses for TEVAR

Figure 21 illustrates the effective dose received from exposures (light blue colour), 3D (dark blue) and fluoroscopy (red colour) for each patient. The difference in effective dose between the patient receiving the lowest and the highest dose was little more than a factor 2.

![Figure 21: The effective dose received for 3 patients undergoing TEVAR.](image)

In table 7 the mean effective dose and mean absorbed dose to organs, along with the standard deviation and median dose from exposures, fluoroscopy and total given radiation can be seen for the 3 patients that were simulated. The organs shown in the table were the ones that received the highest dose.

Table 7: The table illustrates the mean effective dose and mean absorbed dose to organs (both in mSv and mGy) with the standard deviation and the median dose with matching range values [minimum; maximum] from exposure, fluoroscopy and total given radiation for 3 patients that were simulated. The choice of organs was based on the highest dose received.

<table>
<thead>
<tr>
<th>Exposure</th>
<th>E [mSv]</th>
<th>Heart [mGy]</th>
<th>Spine [mGy]</th>
<th>Lungs [mGy]</th>
<th>Liver [mGy]</th>
<th>Thymus [mGy]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>42.0 ± 21.0</td>
<td>105.0 ± 61.0</td>
<td>68.0 ± 55.0</td>
<td>80.0 ± 54.0</td>
<td>78.0 ± 72.0</td>
<td>150.0 ± 107.0</td>
</tr>
</tbody>
</table>

Fluoroscopy

| Mean     | 24.0 ± 6.6 | 65 ± 39 | 19.0 ± 4.4 | 34 ± 11 | 29 ± 11 | 104 ± 66 |

Total

| Mean     | 66.0 ± 21.0 | 170 ± 92 | 87.0 ± 53 | 110 ± 55 | 107 ± 84 | 250 ± 170 |
| Median   | 80[36; 82] | 110[96; 300] | 74[30; 160] | 106[50; 180] | 73[26; 220] | 170[110; 490] |

A mean conversion factor value was calculated. The mean conversion factor for was 0.37 ± 0.10 for fluoroscopy, 0.31 ± 0.07 for exposure and 0.33 ± 0.09 for total dose. If the conversion factor was applied on the patient that received the highest DAP (1300 Gycm²) the resulting effective dose was 400 mSv.
5. Discussion and Conclusion

The purpose of this study was to survey DAP and skin dose during EVAR and TEVAR and investigate how different parameters affected the dose parameters, assess organ doses and effective doses and also explore the possibilities to optimize radiation use during endovascular procedures. In this study it was difficult to establish a clear connection between the studied parameters such as fluoroscopy time, exposure/fluoroscopy mode, tube voltage, tube current and filtration, and DAP value. Parameters such as tube voltage, tube current and filtration varied during procedures, due to the AEC. However, which parameter that affect the DAP the most cannot be concluded in this study and further analysis is required.

It is important for operators to use the lowest dose and still get a good result in the images. This often requires a compromise between dose and image quality. The most critical parameter, when it comes to keeping the doses low, is the choice of exposure mode and the setup of the modes. These different setups are preprogrammed by the supplier and can be changed if necessary. Unfortunately a change is difficult to do during a treatment and this optimization work has to be done in advance. Thus, optimization work has to be performed in a structured way in the clinic. It is also not always possible to use the exposure mode that provides the lowest dose to the patient because of the complexity of the procedure.

In the appendix, tables 9 and 10, it can be seen that the total DAP differed very much between the different patients. The mean total DAP was 280 Gycm² for EVAR and this is much higher than mean values in other EVAR studies shown in table 2. The mean total DAP for TEVAR, in this study, was 330 Gycm² and this is also higher than the mean DAP from the TEVAR study shown in table 2. Compared to the other studies that are presented in table 2, the total DAP presented in this study is as high as TIPS and embolization. This result strengthens the fact that EVAR and TEVAR are high dose-requiring procedures, especially at Sahlgrenska University hospital. An explanation why these procedures are higher in this study compared to other studies cannot be given at this stage. A more detailed examination of the operator’s work and DAP is needed before drawing any conclusions about why the DAP values is as high as they are at Sahlgrenska University hospital.

In this study an attempt of finding a correlation between patient weight and total DAP was made. It can be seen in figure 14 and figure 20 that the R²-value is 0.029 and 0.049, respectively. This indicates that the correlation between weight and total DAP is weak. The major reason for this is that other parameters, for example fluoroscopy time, also affect the total DAP. It is important to note that all the procedures are different, some patients have more complications than others, and some procedures take longer time to complete than others. An example of this can be seen in table 10 (Appendix) where a patient weighing 58 kg have a fluoroscopy time of 110 minutes and a total DAP of 263 Gycm² while a patient weighing 107 kg have a fluoroscopy time of 10 minutes and a total DAP of 67 Gycm². This clearly shows that the fluoroscopy time affects total DAP and that some procedures require less time than others regardless of the patient weight.

Looking at the skin dose that the patients receive from this study it can be seen that the mean total skin dose for EVAR was 630 [170; 1300] mGy and 720 [310; 1400] mGy for TEVAR. These values are well below the risk for erythema, but it should be known that this is doses received after only one procedure. If the patients receive a mean skin dose of 630 mGy after one procedure and needs a reintervention, because the stent is misplaced or is leaking, there is a risk of exceeding the dose limit for erythema of 2 Gy. If the skin dose is compared with the treatments presented in table 2, it can be seen that the skin dose is lower than some extreme procedures. The skin dose in this study is similar to the other EVAR and TEVAR studies presented in table 2. However, it is assumed that the patients receiving the highest doses were not included in the study (see below).

The estimation of effective dose and organ dose was made from the DAP values received from fluoroscopy and exposure. As mentioned, the assessment was made with PCXMC. By simulating every single exposure for each patient, the estimation of effective dose and organ dose was made. For those patients that received 3D imaging, the estimation was made by dividing the rotation in 16 projections and then simulate each projection as an exposure. Svalkvist et al. [30] showed that the error, in the worst-case scenarios, was less
than 20% for 16 projections. When the simulation for fluoroscopy was made, it was done as one exposure. This was because parameters such as tube voltage, tube angulation and filtration were not known from the DICOM Structured reports for fluoroscopy. When simulation was done for fluoroscopy those parameters were chosen from the X-ray machine’s manual. This introduces uncertainties in the estimated organ doses and effective doses. The overall uncertainties were not easy to estimate and no attempt was made in the study.

It can be seen from the tables 6 and 7 that the dose values were below the threshold for acute effects on the organs for patients that underwent EVAR. Even if different organs have different threshold doses, none of the organs during EVAR simulations were in the risk zone for acute effects. However, TEVAR patients had high organ doses to both the heart and the thymus. As presented earlier in this study, the threshold dose for circulatory disease is estimated to be as low as 0.5 Gy to the heart and brain. The mean total absorbed dose to the heart for TEVAR patients was 170 mGy. This is below the threshold but it is enough to be alert.

From the same simulations that provided the organ doses for each patient, the effective dose of each procedure was also obtained. PCXMC uses equation 1 [32] to provide the effective dose for each simulation. The mean total effective dose for EVAR patients was 32 mSv and 66 mSv for TEVAR. Compared to a chest radiograph procedure (0.1-0.15 mSv) and CT scans (1-10 mSv) [33], the obtained effective doses in this study are high.

The main limitation of this study was the collection of data. Out of 47 patients undergoing EVAR, 9 patients were excluded due to no information. This study only included 38 patients undergoing EVAR. Out of the 38 patients, 12 patients had a DICOM Structured report where only 10 patients had all the useable information for this study (two patients had unknown weight). The rest of the EVAR patients had data from medical records. The reason why the majority of the patients did not have useable reports was due to technical reasons. This resulted in an exclusion of the patients receiving the highest doses. Patients undergoing TEVAR had the same issue. For better dose supervision in the future, a routine must be established when it comes to saving all the dose reports. In this way more patient doses can be evaluated and an attempt to optimize these procedures can be done more effectively. The most extreme DAP values and skin doses are from the patients that did not have a useable DICOM Structure report, but only had information from the medical records. This means that the DAP- and skin dose values presented in this study are underestimations, since the highest dose patients were not examined in detail.

As mentioned earlier, dose area product (DAP) is a dose quantity that describes the total dose delivered to the patient by the X-ray tube. It is defined as absorbed dose multiplied with the irradiated area. The benefits with DAP are that it is an easy quantity to measure during image-guided procedures and that it provides an indication of stochastic risk. To get an estimation of stochastic risk, DAP have to be converted to effective dose. Since DAP only is an indication it would be more optimal if the system would give the operators a direct value of the effective dose. Many studies, including this study, have calculated conversion factors ($k = \frac{E}{DAP}$) in order to get a direct estimation of stochastic risk. In this study, this conversion factor was derived by dividing the obtained effective dose (received from simulation) and the total DAP given from each procedure. Since there were few patients that were simulated the obtained conversion factor is associated with a great uncertainty. However if the conversion factor were applied the effective dose for EVAR would be as high as 200 mSv and 400 mSv for TEVAR. This is very high doses when it comes to X-ray imaging.

The limitation in the estimated skin dose is that the value can be both over- and underestimated. This is because the IRP is a general fixed point. It does not take into account the patient size. With different patient size, the entrance skin point is not located at the same exact point for all patients.

It can also be seen, from tables 6 and 7, that the variation in received organ doses is large for both EVAR and TEVAR due to among other things the variation in DAP. The small number of patients included in this study makes it difficult to analyse the organ doses further. The number of patients presented in the tables are 10 and 3, respectively.

Out of the three different imaging techniques, the largest uncertainty from simulation was fluoroscopy due to the lack of information when fluoroscopy was used during procedures and because it was simulated as...
one exposure. It would be more precise if the dose reports had fluoroscopy information as detailed as exposure information. In this way, estimation of effective- and organ dose from fluoroscopy can be done with more precision.

In conclusion, the study indicates that the exposure mode and the fluoroscopy time are the parameters that affect the patient dose the most during endovascular procedures. Since this is only an indication further analysis is required to conclude that those are the parameters that affect the patient dose the most. From the estimations done from this study, the organ doses do not exceed the assumed threshold for deterministic effects. The largest limitation of the study was the limited data and the lack of detailed information from fluoroscopy. The DAP values and skin dose varied very much between the patients that underwent both EVAR and TEVAR. The DAP values and effective doses in this study are high compared to other endovascular procedures despite the fact it was realized that patients with the highest doses were excluded from this study. In the future a routine must be established to save all the dose reports from all of the procedures in order to overcome the shortcomings of this study. This will improve the received information and it would be easier to find ways to standardize the ionizing radiation use during these procedures.
Acknowledgments

I would like to thank my supervisors Charlotta Lundh and Anja Almén for their support, feedback and guidance throughout this thesis! You have always been available for questions and feedback whenever I wanted and needed it. I have learned so much from you two during these months. I hope to work with you two in the future.

Lastly I would like to thank my family for their love and never ending support. Nothing would be possible if I did not have you in my life.

Thank you!
Reference list


Appendix

In table 8 the technical parameters for EVAR procedures are illustrated along with the patient weight. The examinations included in table 8 are the ones with useable DICOM Structured reports. Patient 31 and 37 had an unknown weight. The numbering of patients in table 8 follows the DICOM Structure report’s order. For example patients in between patient 1 and patient 5 are patients with only medical report information. Since those are excluded the numbering is as shown. An explanation of the different DSA modes is shown in table 12.

Table 8: All the technical parameters collected from the DICOM Structured report during EVAR procedures. The value before the tube angle is how many degrees the tube is rotated.

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<td>15.6</td>
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<td>582</td>
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<td>62.5</td>
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<td>CARE DSA low</td>
<td>76</td>
<td>772</td>
<td>50.1</td>
<td>29</td>
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<td>25.9</td>
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<td>797</td>
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<td>25</td>
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<td>42</td>
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<td>109</td>
<td>13 CRA</td>
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<td>8.0</td>
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<td></td>
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<td>5.8</td>
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<td>73</td>
<td>797</td>
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<td>39</td>
<td>0.1</td>
<td>24.6</td>
<td>48 LAO</td>
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<td></td>
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<tr>
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<td>350</td>
<td>50.0</td>
<td>27</td>
<td>0.1</td>
<td>10.2</td>
<td>20 CRA</td>
<td></td>
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<td>797</td>
<td>49.2</td>
<td>23</td>
<td>0.1</td>
<td>12.6</td>
<td>25 LAO, 26 CAU</td>
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<td>787</td>
<td>50.2</td>
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<td>0.1</td>
<td>10.5</td>
<td>26 LAO, 31 CAU</td>
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<td>778</td>
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<td>19 CRA</td>
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<td>50.0</td>
<td>38</td>
<td>0.1</td>
<td>15.9</td>
<td>19 CRA</td>
<td></td>
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<td>Patient 27</td>
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<td></td>
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<td></td>
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<td>CARE DSA</td>
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<td>433</td>
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<td>9</td>
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<td>1.0</td>
<td>16 LAO, 3 CRA</td>
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</tr>
<tr>
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<td>519</td>
<td>36.2</td>
<td>74</td>
<td>0.0</td>
<td>96.9</td>
<td>48 LAO, 3 CRA</td>
<td></td>
</tr>
<tr>
<td>DSA 7.5 F/s</td>
<td>93</td>
<td>510</td>
<td>36.3</td>
<td>93</td>
<td>0.0</td>
<td>103</td>
<td>48 LAO, 3 CRA</td>
<td></td>
</tr>
<tr>
<td>Patient 31</td>
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<td></td>
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<td></td>
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<td>50.0</td>
<td>25</td>
<td>0.1</td>
<td>9.8</td>
<td>7 LAO, 10 CRA</td>
<td></td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>71</td>
<td>797</td>
<td>50.0</td>
<td>16</td>
<td>0.1</td>
<td>6.4</td>
<td>20 LAO, 25 CAU</td>
<td></td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>71</td>
<td>798</td>
<td>50.0</td>
<td>23</td>
<td>0.1</td>
<td>9.1</td>
<td>30 RAO, 19 CAU</td>
<td></td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>70</td>
<td>375</td>
<td>45.0</td>
<td>37</td>
<td>0.1</td>
<td>13.7</td>
<td>1 RAO</td>
<td></td>
</tr>
<tr>
<td>Patient 37</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSA Extra low</td>
<td>66</td>
<td>438</td>
<td>36.2</td>
<td>30</td>
<td>0.3</td>
<td>3.9</td>
<td>5 LAO, 9 CRA</td>
<td></td>
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<tr>
<td>DSA Extra low</td>
<td>66</td>
<td>441</td>
<td>33.7</td>
<td>24</td>
<td>0.3</td>
<td>2.3</td>
<td>5 LAO, 3 CRA</td>
<td></td>
</tr>
<tr>
<td>DSA Extra low</td>
<td>68</td>
<td>429</td>
<td>36.2</td>
<td>15</td>
<td>0.2</td>
<td>2.5</td>
<td>24 RAO, 3 CRA</td>
<td></td>
</tr>
<tr>
<td>DSA Extra low</td>
<td>68</td>
<td>441</td>
<td>33.3</td>
<td>36</td>
<td>0.3</td>
<td>4.5</td>
<td>1 LAO, 3 CRA</td>
<td></td>
</tr>
<tr>
<td>Patient 38</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>xCARE DSA low</td>
<td>74</td>
<td>405</td>
<td>9.5</td>
<td>30</td>
<td>0.6</td>
<td>0.5</td>
<td>27 LAO, 9 CRA</td>
<td></td>
</tr>
<tr>
<td>xCARE DSA low</td>
<td>79</td>
<td>360</td>
<td>33.4</td>
<td>27</td>
<td>0.3</td>
<td>2.3</td>
<td>27 LAO, 9 CRA</td>
<td></td>
</tr>
<tr>
<td>xCARE DSA low</td>
<td>79</td>
<td>357</td>
<td>37.4</td>
<td>21</td>
<td>0.3</td>
<td>2.0</td>
<td>27 LAO, 13 CRA</td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>106</td>
<td>458</td>
<td>4.4</td>
<td>248</td>
<td>0.0</td>
<td>26.9</td>
<td>113 RAO</td>
<td></td>
</tr>
<tr>
<td>Patient 41</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>72</td>
<td>361</td>
<td>50.1</td>
<td>27</td>
<td>0.1</td>
<td>13.0</td>
<td>4 CRA</td>
<td></td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>71</td>
<td>365</td>
<td>50.1</td>
<td>21</td>
<td>0.1</td>
<td>7.9</td>
<td>8 LAO, 4 CRA</td>
<td></td>
</tr>
</tbody>
</table>
In table 9 the technical parameters for TEVAR procedures are illustrated along with the patient weight. The illustrated patients are the ones with useable DICOM Structured reports. Patient 49 had an unknown weight.

Table 9: All the technical parameters during collected from DICOM Structured reports during TEVAR procedures.

| Patient 42 | CARE DSA low | 72 | 798 | 50.0 | 27 | 0.1 | 25.2 | 31 RAO, 19 CAU |
| Patient 42 | CARE DSA low | 71 | 364 | 50.1 | 38 | 0.1 | 17.5 | 1 RAO, 1 CAU |
| CARE DSA low | xCARE DSA low | 82 | 350 | 31.8 | 30 | 0.2 | 2.7 | 11 LAO |
| CARE DSA low | CARE DSA low | 74 | 349 | 50.0 | 20 | 0.1 | 3.1 | 11 LAO |
| CARE DSA low | CARE DSA low | 75 | 347 | 50.0 | 26 | 0.1 | 4.1 | 11 LAO |
| CARE DSA low | CARE DSA low | 75 | 345 | 50.0 | 26 | 0.1 | 4.1 | 11 LAO |
| CARE DSA low | 3D | 110 | 464 | 4.7 | 248 | 0.0 | 40.0 | 113 RAO |
| Patient 43 | CARE DSA low | 79 | 738 | 50.3 | 30 | 0.1 | 19.3 | 40 LAO, 1 CAU |
| Patient 43 | CARE DSA low | 79 | 742 | 50.2 | 29 | 0.1 | 14.9 | 40 LAO, 1 CAU |
| Patient 44 | CARE DSA low | 76 | 343 | 50.1 | 29 | 0.1 | 9.6 | 16 CRA |
| Patient 44 | CARE DSA low | 70 | 797 | 50.0 | 20 | 0.1 | 8.9 | 13 LAO, 16 CRA |
| Patient 44 | CARE DSA low | 76 | 341 | 50.0 | 22 | 0.1 | 5.9 | 4 RAO, 19 CAU |
| Patient 44 | CARE DSA low | 79 | 329 | 50.1 | 19 | 0.1 | 4.5 | 2 LAO, 24 CAU |
| Patient 44 | DSA | 74 | 601 | 80.2 | 39 | 0.0 | 105 | 2 LAO, 12 CAU |

In table 10 the total fluoroscopy time is shown along with the patient’s weight and total DAP during EVAR procedures. In section 4, table 4, the mean [min,max] of these data are illustrated.
Table 10: Data from 38 EVAR procedures showing fluoroscopy time, weight and total DAP. The total DAP also includes dose from exposures.

<table>
<thead>
<tr>
<th>Fluoroscopy time [min&amp;s]</th>
<th>Weight [kg]</th>
<th>Total DAP [Gycm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>33 m 11 s</td>
<td>54</td>
<td>52,6</td>
</tr>
<tr>
<td>110 m</td>
<td>58</td>
<td>262,7</td>
</tr>
<tr>
<td>31 m 54 s</td>
<td>62</td>
<td>26,8</td>
</tr>
<tr>
<td>18 m 13 s</td>
<td>63</td>
<td>61,9</td>
</tr>
<tr>
<td>14 m 15 s</td>
<td>65</td>
<td>38,9</td>
</tr>
<tr>
<td>157 m</td>
<td>65</td>
<td>1045,1</td>
</tr>
<tr>
<td>28 m 59 s</td>
<td>69</td>
<td>258,1</td>
</tr>
<tr>
<td>29 m</td>
<td>78</td>
<td>148,5</td>
</tr>
<tr>
<td>14 m 14 s</td>
<td>80</td>
<td>69,4</td>
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<tr>
<td>9 m 54 s</td>
<td>80</td>
<td>65,2</td>
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<td>38 m 23 s</td>
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<td>83</td>
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<td>815,7</td>
</tr>
<tr>
<td>21 m 3 s</td>
<td>89</td>
<td>140,9</td>
</tr>
<tr>
<td>53 m 1 s</td>
<td>89</td>
<td>188,8</td>
</tr>
<tr>
<td>21 m 31 s</td>
<td>90</td>
<td>343,4</td>
</tr>
<tr>
<td>28 m 26 s</td>
<td>90</td>
<td>144,6</td>
</tr>
<tr>
<td>23 m 3 s</td>
<td>90</td>
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<tr>
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<td>360,4</td>
</tr>
<tr>
<td>61 m</td>
<td>92</td>
<td>709,8</td>
</tr>
<tr>
<td>31 m</td>
<td>95</td>
<td>193,3</td>
</tr>
<tr>
<td>57 m</td>
<td>95</td>
<td>269,0</td>
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<td>33 m 5 s</td>
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<tr>
<td>10 m 24 s</td>
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<td>38 m 34 s</td>
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<td>37 m 18 s</td>
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<td>117</td>
<td>309,2</td>
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<tr>
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</tr>
<tr>
<td>16 m 57 s</td>
<td>Unknown</td>
<td>47,52</td>
</tr>
</tbody>
</table>
Figure 22 illustrates the received DAP for patient 5 when the different exposures are made during the procedure.

Figure 22: An illustration of DAP values against elapsed time for patient 5. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 23 illustrates the received DAP for patient 14 when the different exposures are made during the procedure.

Figure 23: An illustration of DAP values against elapsed time for patient 14. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 24 illustrates the received DAP for patient 20 when the different exposures are made during the procedure.

Figure 24: An illustration of DAP values against elapsed time for patient 20. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 25 illustrates the received DAP for patient 31 when the different exposures are made during the procedure.

Figure 25: An illustration of DAP values against elapsed time for patient 31. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 26 illustrates the received DAP for patient 37 when the different exposures are made during the procedure.

Figure 26: An illustration of DAP values against elapsed time for patient 37. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 27 illustrates the received DAP for patient 38 when the different exposures are made during the procedure.

Figure 27: An illustration of DAP values against elapsed time for patient 38. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 28 illustrates the received DAP for patient 41 when the different exposures are made during the procedure.

Figure 28: An illustration of DAP values against elapsed time for patient 41. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 29 illustrates the received DAP for patient 42 when the different exposures are made during the procedure.

Figure 29: An illustration of DAP values against elapsed time for patient 42. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 30 illustrates the received DAP for patient 43 when the different exposures are made during the procedure.

Figure 30: An illustration of DAP values against elapsed time for patient 42. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 31 illustrates the received DAP for patient 44 when the different exposures are made during the procedure.

**Patient 44**

![Graph showing DAP values against elapsed time for patient 44. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.]

Figure 31: An illustration of DAP values against elapsed time for patient 44. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 32 illustrates the received skin dose, measured as IAK, to patient 5 when the different exposures are made during the procedure.

**Patient 5**

![Graph showing skin dose against elapsed time for patient 5. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.]

Figure 32: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 1. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 33 illustrates the received skin dose, measured as IAK, to patient 14 when the different exposures are made during the procedure.

Figure 33: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 14. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 34 illustrates the received skin dose, measured as IAK, to patient 20 when the different exposures are made during the procedure.

Figure 34: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 20. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 35 illustrates the received skin dose, measured as IAK, to patient 31 when the different exposures are made during the procedure.

![Patient 31 graph](image)

**Figure 35:** An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 31. The labels shown above the dots include the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 36 illustrates the received skin dose, measured as IAK, to patient 37 when the different exposures are made during the procedure.

![Patient 37 graph](image)

**Figure 36:** An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 31. The labels shown above the dots include the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 37 illustrates the received skin dose, measured as IAK, to patient 38 when the different exposures are made during the procedure.

Figure 37: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 38. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 38 illustrates the received skin dose, measured as IAK, to patient 41 when the different exposures are made during the procedure.

Figure 38: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 41. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 39 illustrates the received skin dose, measured as IAK, to patient 42 when the different exposures are made during the procedure.

![Figure 39](image)

Figure 39: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 42. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 40 illustrates the received skin dose, measured as IAK, to patient 43 when the different exposures are made during the procedure.

![Figure 40](image)

Figure 40: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 43. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 41 illustrates the received skin dose, measured as IAK, to patient 44 when the different exposures are made during the procedure.

Figure 41: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 44. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

In table 11 the total fluoroscopy time, weight and Total DAP is illustrated for the patients undergoing TEVAR.

Table 11: Data from 13 TEVAR procedures showing weight, fluoroscopy time and total DAP. The total DAP also includes dose from exposures.

<table>
<thead>
<tr>
<th>Fluoroscopy time [min&amp;s]</th>
<th>Weight [kg]</th>
<th>Total DAP [Gycm^2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>47 m 23 s</td>
<td>62</td>
<td>120,2</td>
</tr>
<tr>
<td>42 m 13 s</td>
<td>70</td>
<td>192,1</td>
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<tr>
<td>125 m</td>
<td>75</td>
<td>638,1</td>
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<td>23 m 28 s</td>
<td>76</td>
<td>265,9</td>
</tr>
<tr>
<td>22 m 39 s</td>
<td>78</td>
<td>85,3</td>
</tr>
<tr>
<td>130 m</td>
<td>78</td>
<td>573,4</td>
</tr>
<tr>
<td>6 m 28 s</td>
<td>80</td>
<td>22,8</td>
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<td>16 m 13 s</td>
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<td>263,5</td>
</tr>
<tr>
<td>19 m 25 s</td>
<td>83</td>
<td>224,4</td>
</tr>
<tr>
<td>10 m 24 s</td>
<td>85</td>
<td>222,5</td>
</tr>
<tr>
<td>184 m</td>
<td>90</td>
<td>1242,6</td>
</tr>
<tr>
<td>14 m 38 s</td>
<td>92</td>
<td>384,7</td>
</tr>
<tr>
<td>41 m 2 s</td>
<td>108</td>
<td>230,8</td>
</tr>
<tr>
<td>22 m 6 s</td>
<td>Unknown</td>
<td>128,87</td>
</tr>
</tbody>
</table>
In table 12 all the different exposures are being shown. The exposures varied between 7 different DSA modes. A short explanation is shown.

### Table 12: A short explanation of each DSA mode used in procedures that were investigated in this thesis.

<table>
<thead>
<tr>
<th>DSA</th>
<th>This exposure is a standard mode where the frame rate is varied from the operator. Each frame provides the operator with 3 μGy/pulse.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSA 7.5 F/s</td>
<td>The same as the first presented DSA with the exception that the exposure is fixed with 7.5 Frames/s.</td>
</tr>
<tr>
<td>CARE DSA</td>
<td>The same as the first. Only difference is that this mode has more filtration</td>
</tr>
<tr>
<td>CARE DSA low</td>
<td>This is a further dose-reduced mode where the dose per pulse is 0.8 μGy/pulse.</td>
</tr>
<tr>
<td>DSA Extra low</td>
<td>An even lower dose mode where the dose per pulse is 0.36 μGy/pulse.</td>
</tr>
<tr>
<td>xCARE DSA xlow</td>
<td>0.2 μGy/pulse.</td>
</tr>
</tbody>
</table>

Figure 42 illustrates the received DAP for patient 46 when the different exposures are made during a TEVAR procedure.

![Diagram](image)

**Patient 46**

**Figure 42:** An illustration of DAP values against elapsed time for patient 46. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 43 illustrates the received DAP for patient 49 when the different exposures are made during a TEVAR procedure.

Figure 43: An illustration of DAP values against elapsed time for patient 49. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 44 illustrates the received DAP for patient 53 when the different exposures are made during a TEVAR procedure.

Figure 44: An illustration of DAP values against elapsed time for patient 53. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 45 illustrates the received skin dose, measured as IAK, to patient 46 when the different exposures are made during a TEVAR procedure.

Figure 45: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 46. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.

Figure 46 illustrates the received skin dose, measured as IAK, to patient 49 when the different exposures are made during a TEVAR procedure.

Figure 46: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 49. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.
Figure 47 illustrates the received skin dose, measured as IAK, to patient 53 when the different exposures are made during a TEVAR procedure.

Figure 47: An illustration of the received skin dose, measured as IAK, against the elapsed time to patient 53. The labels shown above the dots includes the time for each DSA run in seconds, and the angle, in degrees, of the X-ray tube is shown.