CHAPTER 1

General introduction
1.1 Abdominal aortic aneurysm

An aneurysm is described as a permanent localized dilation of an artery having at least a 50 per cent increase in diameter compared to the expected normal diameter of this artery [1]. Aneurysms of the main artery in the abdomen (aorta) are called abdominal aortic aneurysms (AAA). The most common site of these aneurysms is below the renal arteries (infrarenal).

AAAs become an increasing health care problem, because of the proportional increase of ageing population. The major risk factors of AAAs are age, male sex, a history of smoking and a first-degree family history of AAA. The prevalence of AAAs is about 4% to 9% in men and 1% in women [2–7].

Most AAAs are asymptomatic. However, AAA rupture is associated with high mortality rates [8, 9]. The majority of patients with AAAs will not die from their aneurysms [10, 11]. Hence the surgical decision regarding aneurysm surgery is complex. The risk of aneurysm rupture has to be balanced against the risk of operation. Aneurysm repair is undertaken only when the risk of rupture is considered high. The risk of aneurysm rupture is related to the size of the AAA, expansion rate of the aneurysm and gender of the patient [12]. The threshold of aneurysm surgery remains a point of discussion but varies between 5.0 and 5.5 cm in diameter [13–16].

1.2 Treatment of abdominal aortic aneurysms

AAAs are treated with either the conventional open aneurysm repair or the endovascular aneurysm repair. During conventional open aneurysm surgery the aorta is approached transperitoneally or left retroperitoneally. After clamping the aorta proximally and distally the aneurysm sac is opened and the aneurysm sac thrombus is removed. The backbleeding side branches are oversewed. A tube graft or bifurcated graft is sewed by end-to-end anastomosis in the aorta. Subsequently, the circulation is reestablished by declamping. The aneurysm wall is closed around the prosthesis. Finally, the retroperitoneum and abdominal wall are closed. Clearly, this is a very invasive treatment.

A self-fixing synthetic blood vessel, i.e. endovascular stent-graft was first described in 1986 by Volodos et al. [17]. Later, in 1991, endovascular aneurysm repair (EVAR) is introduced by Volodos et al. and Parodi et al. as a less invasive treatment of AAAs [18, 19]. During the endovascular procedure two incisions are made in the groin to expose the femoral arteries. However, some endovascular specialists prefer a percutaneous approach to the femoral arteries. The endovascular stent-graft is loaded in a special delivery system and is placed under fluoroscopy via the femoral and iliac arteries inside the abdominal aortic aneurysm. Catheters and guidewires are used to position the stent-graft correctly. The radial force of the
stent-graft maintains the graft apposition to the vessel wall. Currently, most commercial available stent-grafts use extra barbs at the top-stent to prevent stent-graft migration.

### 1.3 Open versus endovascular aneurysm repair

Randomized trials are performed to compare open aneurysm repair with EVAR [20–23]. The EVAR-1 trial and DREAM-trial concluded that endovascular aneurysm repair results in decreased time spent in the operation theatre and hospital stay. Moreover, after combining the results of these studies the operative mortality rate of open repair is 5.8% and of EVAR is 1.9%, resulting in a risk ratio of 3.1 [21, 22]. On the basis of these data EVAR seems preferable to open aneurysm surgery.

The DREAM and EVAR-1 trial published the results after 4 and 2 years after randomization, respectively [20, 23]. The EVAR-1 trial concluded that the difference in aneurysm mortality at 4 years was significant (EVAR 4% vs Open 7%). However, the all-cause mortality at 4 years after randomization was similar in the EVAR and open repair group. The number of complications and re-interventions in the EVAR-group increased, whereas complications and re-interventions were rare in open repair patients [23]. The peri-operative survival advantage with EVAR as compared to open repair was limited to the first postoperative year in the DREAM-trial [20]. The EVAR-2 trial was performed to identify whether EVAR improves survival compared to no intervention in patients unfit for open repair of AAAs. However, findings of this study showed no survival benefit from EVAR in patients unfit for open repair [24].

The long-term results and durability of EVAR are uncertain. Therefore, the future has to show if EVAR will replace the conventional aneurysm repair.

### 1.4 Complications after EVAR

An important complication after EVAR is the occurrence of endoleaks and endotension. An endoleak is defined by the persistence of blood flow outside the lumen of the stent-graft within the aneurysm sac or an adjacent vascular segment being treated by the stent-graft [25]. Endoleaks occur approximately in 20% of the patients treated by EVAR [26]. Endotension is defined as a state of significant pressure in the aneurysm sac without any evidence of an endoleak as identified by imaging techniques [27]. Endoleaks and endotension are associated with increased risk of aneurysm rupture due to persistence of high aneurysm sac pressures [28].

Stent-graft migration is another well recognized complication after EVAR [29]. Migration of the stent-graft could result in endoleaks. Therefore, patients who underwent EVAR are subjected to intensive follow-up programs to detect endoleaks, endotension and stent-graft migration.
1.5 The problem

Computer Tomography (CT) with contrast, ultrasound (US), angiography, Magnetic Resonance Angiography (MRA) and plain abdominal radiography are used during follow-up after EVAR [30, 31]. CT is considered the ”gold-standard” for the detection of endoleak, endotension and stent-graft migration [28, 32]. During follow-up programs patients are assessed through clinical observation and contrast enhanced CT scans at 1, 3, 6, 12 and 18 months after the operation and thereafter at yearly intervals for the rest of their life. This lifelong follow-up results in increasing burden on hospital logistics and costs [33]. CT also has several patient-related adverse effects. Patients are exposed to ionizing radiation and contrast material, which is nephrotoxic and can cause allergic reaction.

CT is associated with false positive and false negative diagnoses of endoleaks [28]. Sometimes it is difficult to distinguish calcification from leaked contrast material. Mischaracterized calcium in mural thrombus causes false-positive diagnosis. A second pitfall is that some of the endoleaks are seen only after some delay, because they arise from low flow through collateral pathways [30]. Furthermore, CT is a random picture of the aneurysm sac. Theoretically, endoleaks could occur during the time between two successive CT scans. Hence, patients are exposed to increased risk of aneurysm rupture without knowing it.

CT is an imaging tool and provides direct evidence of the presence of blood flow from the circulation into the aneurysm sac (endoleak). However, it gives no information about the direction of flow in an endoleak. Distinction between in- and outflow channels from the aneurysm sac is difficult to make. This is especially important for the treatment of endoleaks through collateral vessels, because in-flow and outflow channels pressurize and depressurize the aneurysm sac, respectively.

The follow-up by CT is complex. Endoleak detected by CT demonstrates only that the aneurysm has not been completely isolated from the circulation. If an endoleak is diagnosed it often leads to a dilemma what to do because the risk of rupture can not be unambiguous estimated from the images, because the risk of aneurysm rupture depends on the aneurysm wall strength and the aneurysm wall stress, which is directly related to the aneurysm sac pressure. The aneurysm sac pressure is evaluated only indirectly by measuring the AAA size during follow-up. Information about the exact aneurysm sac pressure after EVAR seems important, because not all endoleaks on CT seem to have clinical consequences [28]. On the other hand the absence of an endoleak detected by means of CT does not exclude the possibility of high pressure in the aneurysm sac and the persistent risk of rupture. Therefore, it is difficult to predict whether and when re-intervention is justified, solely based on CT. Hence the patient is left in uncertainty during follow-up.

Since aneurysm rupture occurs if the aneurysm wall stress exceeds the strength of the aneurysm wall [34] and the aneurysm wall stress is directly related to the
aneurysm sac pressure, it seems more attractive to measure aneurysm sac pressure during follow-up. Non-invasive wireless pressure sensors are being developed. Continuous aneurysm sac pressure measuring could reduce the number of CT scans during follow-up and could be a valuable test during follow-up after EVAR to predict the need and moment of re-intervention [35]. This will probably improve the patient- and economical burden of endovascular aneurysm repair. Furthermore, continuous aneurysm sac pressure measuring by wireless sensors in the aneurysm sac has an extra advantage over CT. Continuous monitoring of aneurysm sac pressure is possible 24 hours each day; it is not a random indication such as a CT.

From a biomechanical point of view aneurysm sac pressure measurement is not straightforward. The aneurysm sac is filled with solid thrombus, which possibly hampers the pressure measurements. This thesis contributes to the development of the rationale of pressure monitoring in the aneurysm sac as follow-up method after EVAR. The aim of this thesis is to evaluate the possible pitfalls of aneurysm sac pressure measurements.

1.6 Outline of the thesis

The studies in this thesis discuss several aspects of aneurysm sac pressure measurements. The relation of endoleak to aneurysm sac pressure is not clear. A review of literature about aneurysm sac pressure measurement is given in Chapter 2. Results of different studies are compared and the present knowledge about determinants of aneurysm sac pressure are discussed.

A validated artificial perfusion model is needed to perform in-vitro studies in a controlled way. Construction and validation of an artificial perfusion model are described in Chapter 3. In Chapter 4 the mechanical properties of fibrinous aneurysm sac thrombus are investigated. These mechanical properties are used to develop aneurysm sac thrombus analogues. Validation of a thrombus analogue is also described in this chapter.

In literature, aneurysm sac pressure measurements are performed with fluid filled and non-fluid filled pressure devices. In Chapter 5 the accuracy of both measuring techniques is evaluated.

In Chapter 6, the effect of sensor motion on the pressure measurement is assessed. The easiest way to introduce a wireless sensor into the aneurysm sac is by attaching it to the outside of the stentgraft. However, pulsatile wall motion of the stentgraft, depending on stent compliance, may result in sensor motion and consequently may affect the result of the pressure measurement.

To interpret pressure measurements in a thrombus, we have to learn about the effect of the thrombus on pressure transmission. In Chapter 7 we clarify the effect of intraluminal thrombus on the pressure transmission.
Finally, in Chapter 8 the effect of the direction of pressure measurement on the measured pressure level is investigated. Since forces in a solid material are not identical in all directions, pressure measurements in solid fibrinous thrombus could be hampered.
References


