IMAGING TECHNIQUES IN THE ASSESSMENT OF ENDOVASCULAR INFRARENAL ABDOMINAL AORTIC REPAIR

Summary

Introduction. Imaging is essential in the assessment of endovascular infrarenal abdominal aortic repair results. Complications include endoleaks, graft migration, kinking and infolding, stenosis, occlusion, and secondary ruptures. Examination Modalities. Contemporary imaging strategies are based on using noninvasive imaging modalities. After endovascular infrarenal abdominal aortic repair, the standard evaluation modality is computed tomography angiography, whereas additional modalities include magnetic resonance imaging, ultrasonography, and radiography. However, although an invasive imaging method, digital subtraction angiography is still performed in some patients. Computed tomography angiography provides excellent contrast, spatial resolution, and exact measurements of structures of interest, which is essential in the follow-up. Follow-up Protocol. Currently recommended follow-up protocol in the first year is contrast-enhanced computed tomography imaging at 1 and 12 months after the procedure. Conclusion. Due to its characteristics, reproducibility and availability, computed tomography angiography remains the cornerstone diagnostic modality of post-procedural assessment in patients with endovascular infrarenal abdominal aortic repair. Key words: Aortic Aneurysm, Abdominal; Blood Vessel Prostheses; Postoperative Complications; Diagnostic Imaging; Computed Tomography Angiography; Endovascular Procedures

Introduction

Radiology is a fast-growing discipline of medicine and thanks to the implementation of new technologies [1] accompanied by the technical development of materials necessary for endovascular therapy of abdominal aortic aneurysms (AAA), it has become a vital factor affecting the beginnings of endovascular aortic repair (EVAR). However, production of these personalized stent-grafts, preparations for their deployment and follow up would be impossible without highly sophisticated imaging modalities. Three-dimensional images of pathological tissues, with millimeter and sub-millimeter spatial resolution, are the cornerstone in the contemporary treatment of AAs; they may prevent their rupture, which is a surgical emergency with a high rate of mortality before the patients are admitted for treatment [2]. Practically, all available imaging modalities have their place in a dynamic protocol of pre- and post-procedural imaging. This paper reviews imaging assessment after EVAR. In the pre-procedural part, parameters that are evaluated are patient selection and procedure planning. In the post-procedural part, the most common complications and suggested follow-up protocols are discussed.

Post-Procedural Imaging

The EVAR is a relatively novel procedure [3], and as with the majority of other novel procedures, the post-procedural protocol is quite rigorous. The...
optimism associated with lower early morbidity rates compared to open aortic surgery (OAS) [4] was replaced with caution after analysis of data gathered in a longer period of time. Comparison of endovascular and open surgical approach repairs showed that a significant number of patients treated with EVAR underwent reintervention. It is also the main disadvantage of EVAR, considering that a 6-year follow-up showed a reintervention rate of 29.6% for EVAR, compared to 18.1% for OAS [5]. These data require detailed and mandatory postoperative surveillance with a goal of screening the postoperative status and especially reporting pathological phenomena leading to reintervention.

At the moment, computed tomography angiography (CTA) is the most common modality used for the assessment of EVAR, but Doppler ultrasonography (DUS), contrast-enhanced ultrasound (CEUS), magnetic resonance angiography (MRA) and plain radiography, also have their place in the follow up protocol.

Complications

Pathological phenomena, regardless of the imaging modality used, are common, so we will discuss them first.

Endoleaks

Endoleak is defined as a persistent blood flow in the aneurysm sac. It is the most common EVAR complication, and its consequences differ widely, depending on the type of endoleak [6]. Endoleaks are divided into five types, according to their location (Figure 1).

Type 1. Endoleaks at attachment sites of stent-graft. It is further subdivided into the following subtypes: 1a: proximal (aortic infrarenal), 1b: distal (iliac), 1c: on the level of the iliac occlusion.

The incidence of type 1a, proximal endoleaks, increases in anatomically difficult situations, such as short (< 15 mm) neck, large neck diameter (> 32 mm), tapered necks, increased angulations (> 60°), and landing zones with calcification, thrombus, or uneven size with incidence being reported in 0–10% of EVAR procedures [7].

Type 2. Type 2 endoleaks occur from collateral or retrograde filling the aneurysm sac by one or more of the lumbar, hypogastric, or inferior mesenteric arteries. Given the occlusion or at least partial occlusion of the aortic sac, the pressure in the sac decreases, thus enabling retrograde flow through these arteries, which are branches of the part of aorta covered with stent graft material. They are divided into two subtypes: 2a leaks through a single vessel, 2b leaks through multiple vessels. Type 2 endoleaks account for approximately 40% of all endoleaks and are reported in 20–30% of EVAR cases after 30 days, 18.9% after 1 year, and 10% over 1 year [7].

Type 3. Endoleaks develop from the graft fabric defect. They are subdivided into: 3a midgraft defects, 3b develop at junctions. Their incidence is considered to be 4% over one year [7]. Like Type 1 and Type 3 endoleaks are considered high-pressure, high-risk leaks, and always warrant urgent management [6].

Type 4. Endoleaks due to a porous endograft which is detected < 30 days after graft placement, due to fabric porosity. They present at the time of the operation on completion aortograms, when patients are fully anticoagulated [6].

Type 5. Endoleaks that are referred to as endotension which may be associated with persistent or recurrent systemic pressure in the aneurysm sac without an identifiable Type 1–4 endoleak on imaging.

Migration

Strong and pulsatile nature of aortic arterial flow combined with a pathologically changed arterial wall is ground for the development of stent-graft migration, usually toward distal parts of aorta. This can lead to endograft migration and consequent development of dangerous Type 1 endoleak and other complications, including rupture.
**Kinking and Infolding**

Change of graft material structure, may result in more or less pronounced stenosis and reduced blood flow; the reported incidence in the literature is 57% during a 4-year follow up [8] and 3.7% on average follow up after 22 months, in the more recent publications [9].

**Stenosis and occlusion**

Whether as a consequence of impaired structural integrity or non-adherence to the postoperative medical protocol, stenosis and occlusion may lead to acute ischemia in the affected lower extremity which is a state of severely impaired vitality of lower limbs due to acute occlusion of the arterial blood vessel [10].

**Secondary rupture**

Aortic rupture after EVAR is a rare, but a devastating event. It may occur due to a technical error or the inability of devices to accommodate changes in anatomy over time, or due to graft material fatigue leading to a failure [11]. Early rupture happens within 30 days after the procedure, and late more than 30 days after the procedure. Early ruptures can be avoided by meticulous pre-operative planning, improved technical performance, and the introduction of new graft designs [12]. Late ruptures are connected with endoleaks or aneurysm expansion without a detectable endoleak [11].

**Examination Modalities**

**Computed tomography angiography**

High spatial resolution, excellent contrast resolution of crucial anatomical and graft structures, and broad availability of CT machines, make CTA the most common modality in follow-up of EVAR at the moment. The difference in Hounsfield units (HU) of contrast-filled active lumen, thrombosed lumen of the aortic sac, metallic endograft structure, and the surrounding retroperitoneal fat, enable clear distinction between these structures and their detailed analysis. As with all imaging methods, there is a limit in blood vessel diameter which is detectable by CTA. Therefore, small vascular structures cannot be visualized [13]. The lack of temporal resolution can be solved by an additional later phase of contrast examination or more contemporary CT machines and dynamic CT applications [14]. Lower operator dependence, high reproducibility with the possibility to compare previous results, and no influence of patient’s body habitus make CTA optimal for EVAR follow-up.

However, exposure to ionizing radiation remains an issue, especially in the case of repeated control examinations, thus adding to the burden of patient exposure. Given that imaging is essential for EVAR follow-up, radiation exposure should be limited, particularly in light of carcinogenic potential, to a cumulative lifetime total of 400 millisieverts (mSv) [15].

Taking into account the high incidence of diabetes and renal insufficiency in patients with AAA, and the fairly high dose requirement of iodinated contrast with CTA, contrast-induced nephropathy is a major concern with these patients [16].

On non-contrast CT examination, it is possible to perform an analysis of aneurysm sac dimensions and volume. Simple measurement can give information on the maximal sac diameter (Figure 2) which in comparison to previous imaging, gives information of the aortic volume dynamics. Criteria for AAA rupture prediction are based only on the diameter of AAA [17]. Also, it is possible to use contemporary software analysis to perform volumetric analysis of the aneurysm sac by its segmentation to compare it with previous measurements. Single volume or diameter can be indirect signs of endoleak presence (in the case of diameter/volume increase) or absence (in the case of diameter/volume decrease).

Boos et al. reported that measurement of the centerline diameter and volume from the renal arteries to the iliac bifurcation of the abdominal aortic aneurysm is sufficient for the follow-up of patients who underwent EVAR, because the correlation between the measurements was nearly perfect. But in conclusion, the optimal volume (renal arteries to the iliac bifurcation) and diameter (centerline) have only moderate sensitivity (57–64%) and good specificity (64–82%) for detection of endoleaks; therefore, if possible, intravenous contrast material should be used in all patients after EVAR to achieve early detection of endoleaks [18].

Intravenous contrast administration enables analysis of arterial lumen dimensions and endoleak detection. The contrast material demonstrates endoleaks in the aneurysm sac beyond stent-graft (Figure 3). Parts of thrombus inside the sac can be partially calcified. Usually, the density of calcium formations is much higher than that of contrast, but in its development, it can be in HU range of contrast material. In that case, comparison with the pre-contrast images enables differential diagnosis of calcifications from endoleaks (Figure 4).

**Figure 2.** a) Perpendicular alignment to the longitudinal axis of the aorta; b) Measurement of the maximum aortic diameter

**Slika 2.** a) podešavanje linije preseka na ravan normalnu na pravac pružanja aorte; b) merenje najvećeg prečnika aorte
Endoleak type 2a; a) Contrast media in the aneurysm sac outside the stent graft (arrow head); b) Origin of the contrast flow from the right lumbar artery is easily seen on coronal reconstruction (arrow head)

**Figure 3.** Endoleak type 2a; a) Contrast media in the aneurysm sac outside the stent graft (arrow head); b) Origin of the contrast flow from the right lumbar artery is easily seen on coronal reconstruction (arrow head)

**Slika 3.** Propuštanje tip 2a; a) postojanje kontrasta u saku aneurizme van stent grafa (glava strelice); b) poreklo kontrastnog protoka iz desne lumbalne arterije je bolje prikazano na koronalnim rekonstrukcijama (glava strelice)

The timing of the contrast phase of the examination is essential in the detection of endoleak. Arterial enhancement of the endograft lumen and arterial leak to the aneurysm sac do not have to be visible at the same moment, either because of slower accumulation of contrast in the aneurysm sac, sometimes with possibility of recognition in the early arterial phase in endoleaks Type 1 and 3, or retrograde flow through collateral arteries in endoleak Type 2.

In the analysis of Lemkuhl et al. the maximum endoleak enhancement was reached at 22 seconds after the bolus-tracking threshold, during the phase when the bolus of contrast material had already passed the aorta. The highest endoleak detection rate was achieved later, at 27 seconds after the bolus-tracking threshold, during the phase when the mean peak enhancement of the aorta and the endoleak had already passed, and maximum contrast could be achieved between the remaining endoleak enhancement and the rapidly de-enhancing aorta. These authors reported that scan phases 3 and 6, at 12 and 27 seconds after the bolus-tracking threshold, respectively, were the most useful scan phases in patients who have undergone EVAR. The first of these phases shows the highest aortic enhancement and should be used to evaluate the aorta and its branches, detect early endoleaks, and assess the endograft anchoring and position. The second of the two phases is used to detect endoleaks [14].

Indirect methods for endoleak detection are above-mentioned analysis of aneurysm sac diameter and volume, and analysis of proximal and distal endograft junction. In an attempt to decrease the number of follow up imaging sessions, Goncalves et al. found that although large-scale confirmation of this concept is required, they firmly believe that when sufficient effective proximal and distal seal are achieved in the primary procedure, direct (Type 1 or 3) endoleaks and migration are exceedingly rare. However, the presence of an effective seal may not prevent complications in the long term (>5 years) due to late degeneration of the aortic wall [19].

Besides the evaluation of endoleaks due to excellent contrast resolution between metallic graft component and the surrounding structures, CT is used for the analysis of the structure and position of the stent-graft.

Stent migration is a complication that can lead to above mentioned dangerous high flow endoleaks Type 1 and 3. The CTA analysis of graft position and comparison with the previous findings enables migration detection and prompts to further patient management. Studies have shown that one of the main predictors of stent migration is the proximal fixation length, with each millimeter increase in length fixation, reducing the hazard of migration by 2.5% [20].

Reduced blood flow in distal arteries can be the consequence of kinking, fracture, stenosis or occlusion of endograft with each of these phenomena readily evident on CTA examination. Endograft migration, tortuosity of the aorta and iliac arteries are risk factors for these complications. Accumulation of thrombotic material on the endoluminal side of endograft is possible and leads to stenosis of the active lumen. This can be demonstrated as laminar thrombosis on the endograft material next to the bloodstream (Figure 5).

Endograft infection is a complication with an incidence of 0.5–1% of performed stent-graft procedures [21]. Infection can be diagnosed by clinical examination and laboratory analysis. On CTA images, periaortic stranding, aortic wall thickening and formation of organized collections next to the aortic wall can be appreciated. The presence of gas inside the aneurysm sac can be a sign of infection, but also in the early post-interventional imaging, it is possible to be iatrogenically deployed gas into the aneurysm sac during the intervention. In this case, analysis of inflammatory factors and if necessary a control CT are mandatory (Figure 6).

**Magnetic Resonance Imaging**

Just as CT, magnetic resonance imaging (MRI) also enables a three-dimensional analysis of the
Figure 5. Endograft stenosis: a) Two years after EVAR, there are no signs of peri-mural thrombus; b) Four years after EVAR, there is a thrombus on the medial surface of the left iliac graft (arrow)

Slika 3. Stenoza endografa: a) dve godine nakon endovaskularnog tretmana aneurizme aorte nema perimuralne tromboze; b) cetiri godine nakon tretmanu postoji perimuralni tromb na medijalnom aspektu levoj ilijskog grafa (strelica)

Figure 6. Hematoma in the left Scarpa's region and air in the aneurysm sac on early post-operative imaging two days after procedure; a and b) Hematoma in the left Scarpa's region with preserved blood flow through common femoral artery; c) Gas in the aneurysm sac, most probably due to perioperative manipulation; no other signs of infection and patient was discharged from hospital with no signs of inflammation; d) On examination two years later, there is no gas in the aneurysm sac and reduced latero-lateral sac diameter

Slika 6. Hematom u levoj Skarpovoj regiji i vazduh u aneu
rizatskom sakusu na ranom postoperativnom pregledu dva dana nakon intervencije. a i b) hematom u levoj Skarpovoj regiji sa očuvanim protokom krvi kroz femoralnu arteriju; c) gas u aneurizatskom sakusu najverovatnije kao posledica peripriceudralnog ulaska. Nije bilo drugih znakova infekcije i pacijent je otpušten iz bolnice u dobrom opštem stanju; d) na pregledu dve godine nakon intervencije detekuje se smanjenje dijametra sakusa, bez prisustva gasa.

postoperative status. Axial T1W gradient-echo sequence, followed by pre- and post-contrast T1W single-shot fast spin-echo sequence protocol, can be used. Analysis of tomograms is, as with CTA examination, performed by multiplanar reconstruction, maximum intensity projections, and by using volume rendering technique. Absence of ionizing radiation, no dependence on the operator skills and patient body habitus, with high reproducibility are obvious advantages of MRA method. However, poor demonstration of the metallic endograft components and no available MRI machines in some regions are disadvantages of this modality.

In analyzing endoleaks, MRA is equivalent to CTA in sensitivity, and in Type II endoleaks, it is superior in patients with newer generation nitinol EVAR grafts [22]. Also, in patients with impaired renal function, it is possible to perform time-of-flight imaging, but the specificity of these examinations has been documented as low as 54% in endoleak detection [23]. MRA is particularly useful in patients with nitinol stent-grafts; stainless steel and nickel alloy grafts cause a large amount of susceptibility artifact that precludes optimal evaluation by MRI [24].

Ultrasound
Ultrasound (US) is a non-ionizing and relatively cheap imaging modality that is an alternative to CTA and MRA. In detection of endoleaks, there are various modes, beginning with standard B-mode for diameter evaluation of the aneurysm sac, Doppler ultrasound, and contrast-enhanced ultrasound. Ultrasound has a high specificity for endoleaks in up to 95%, but the overall sensitivity is as low as 70%, compared to CTA as a gold standard [25, 26]. Cumulative radiation dose and renal injury associated with CTA are an issue that is being attempted to overcome by CEUS. This modality found the greatest use in detection and follow up of endoleaks. A meta-analysis that has evaluated seven trials comparing CEUS with CTA found a sensitivity of 0.98 and specificity of 0.88 of CEUS [27]. CEUS has several advantages compared to CT, including lower cost, shorter scanning time, and most importantly, absence of nephrotoxicity and radiation exposure. However, at times, the poor performance of CEUS in endoleak detection may be due to patient factors [28]. Lack of a suitable panoramic stent visualization with CEUS brings about the need to obtain concurrent radiographs when performing surveillance using CEUS, for the diagnosis of stent migration and kinking [29].

On the other hand, direct comparison with previous images is severely diminished in US evaluation compared with three-dimensional modalities such as CT and MRI, which offer multiplanar comparison and evaluation of millimetric changes in diameters of vessels analyzed. Also, there can be a discrepancy in diameters measured by different modalities with reported overestimation of the aorta diameter on ultrasound compared to CT [30], which implies surveillance using a single imaging modality.

Also, operator and patient habitus dependence and poor visualization of endograft structure are disadvantages of US as an EVAR surveillance modality.

Radiography
Radiographic analysis of blood flow is not possible, but excellent spatial resolution and possibility of analyzing the metallic structure of endograft give place to standard radiography in surveillance protocol. Stent graft kinking, fracture, migration,
and change of diameter are readily demonstrated. Even minimal endograft migration can be detected on consequently performed standard radiographs, with image overlapping and analysis of the relationship to bony landmarks. However, the impossibility of lumen analysis and three-dimensional imaging determines radiography as a supplementary surveillance modality.

Intrasac Pressure Measurement
The theoretical premise of EVAR is that a successful treatment will exclude the AAA sac from the systemic arterial pressure and circulation [31]. Imaging modalities cannot measure the pressure inside the sac, and the rationale for the success of the intervention is the measurement of diameters. It is possible to measure the intrasac pressure with guide wire mounted tip-pressure sensors. Expansion of the sac may occur in the absence of intrasac fluid accumulation and is associated with higher and more pulsatile intrasac pressure. However, in patients with intrasac fluid, expansion can occur with low intrasac pressure as well [31].

Follow-up Protocol
Currently, the recommended surveillance protocol is contrast-enhanced CT imaging performed 1 and 12 months after the procedure. Should CT imaging at one month after EVAR identify an endoleak or other abnormality of concern, postoperative imaging at six months should be added to further evaluate the proper exclusion of an aneurysm. If neither an endoleak nor aneurysm enlargement is documented during the first year after EVAR, color duplex ultrasonography may be a reasonable alternative to CT imaging for postoperative surveillance [32]. In addition to ultrasonographic surveillance, standard anteroposterior and lateral radiography should be performed; if the patient’s body habitus preclude an adequate DUS, then a non-contrast CT with plain radiographs can be substituted [33]. In case of US or radiography proven increase in the size of the aneurismal sac or signs of endoleaks, CTA evaluation is mandatory.

The extended follow-up period has led to a significant drop from the follow-up regimen, but annual imaging follow up compliance post-EVAR in the United States is significantly below recommended levels [34]. Devastating complications must be acknowledged, and their consequences treated before fatal events. Development and broader application of aneurysm pressure sensors are expected to enhance the safety of follow-up without CT, but after confirmation [35].

The regular follow-ups do not affect the surveillance or prevent complications [36], and despite clear guidelines, follow-up routines vary significantly between centers. A stratified follow-up protocol can be suggested based on the risk of complications. Most complications appear early after the procedure, so early CT is beneficial. Also, patients at risk (early endoleak, hostile anatomy, etc.) would require more frequent follow-ups.

Conclusion
Imaging is essential in the pre- and post-procedural evaluation of patients treated with endovascular aortic repair. Multiple modalities enable evaluation of morphology, selection of patients, and detection of complications. Due to its characteristics and availability, computed tomography angiography remains the cornerstone of the pre- and post-procedural assessment in patients with infrarenal abdominal aortic aneurysm.

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