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on behalf of the
European Society
of Vascular Medicine

Aneurysms and dissections

What is new in the literature of 2019/2020 – a European Society of Vascular Medicine annual review

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Review

Aneurysms and dissections

What is new in the literature of 2019/2020

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Summary: More than 6,000 publications were found in PubMed concerning aneurysms and dissections, including those Epub ahead of print in 2019, printed in 2020. Among those publications 327 were selected and considered of particular interest.

Abbreviations

[18F]FLT	fluorine-18-fluorothymidine
AA	aortic aneurysm
AAA	abdominal aortic aneurysm
AD	aortic dissection
AIDI	anti-inflammatory diet index
AKI	acute kidney injury
Ang II	angiotensin II
apolipoprotein E	apoE
AR	androgen receptor
ASI	maximal aortic diameter/body surface area
AUC	area under the curve
AVF	arteriovenous fistula
A-VNC	arterial VNC
BAPN	β-aminopropionitrile
BD	Behçet's disease
BEVAR	branched endovascular aortic repair
CAG	cycloastragenol
CDU	colour-coded ultrasound
CEtUS	contrast-enhanced tomographic 3-D ultrasound
CEUS	contrastenhanced ultrasound
ChEVAR	chimney technique
CI	confidence intervall
CIN	contrast-induced nephropathy
CSF	cerebrospinal fluid
CT	computed tomography
CTA	computed tomography angiography
CTD	connective tissue disease
CV	cardiovascular
CVA	cerebrovascular accidents
CVD	cardiovascular disease
DAP	dose area product
DECTA	dual-energy CTA
DM	diabetes mellitus
DUS	duplex ultrasound
EACTS	European Association for Cardio-Thoracic Surgery
ED	exposure dose
ER	enhancement ratio
ERK	extracellular signal-regulated kinase
ESVS	European Society for Vascular Surgery
EVAR	endovascular aortic repair
F/BEVAR	fenestrated/branched endovascular aortic repair
FAERS	US Food and Drug Administration Adverse Event Reporting System
FEVAR	fenestrated endovascular aneurysm repair
FMD	fibromuscular dysplasia
GA	general anaesthesia
GBE	Ginkgo biloba extract
GCA	giant cell arteritis
GFAp	glial fibrillary acidic protein
GFR	glomerular filtration rate
GLP-1	glucagon-Like Peptide-1
HR	hazard ratio
hsCRP	highsensitivity C reactive protein
IBD	iliac branch device
IF	image fusion
IFU	instructions for use
IgG4	immunoglobulin G4
IHE	in-hospital event
IL18r	IL18 receptor
IL6R	interleukin-6 receptor
IMA	inferior mesenteric artery
ISMAD	isolated superior mesenteric artery dissection
LA	licochalcone A
LA	local anaesthesia

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LMP7	low-molecular mass protein 7
lncRNA	long noncoding RNA
LSA	left subclavian artery
LVV	large vessel vasculitis
MAA	mycotic aortic aneurysms
MEK	mitogen-activated protein kinase
miRNA	microRNAs
MIS2ACE	minimally invasive staged segmental artery coil embolisation
MMP	matrix metalloproteinase
MRDR	maximal rate of diastolic recoil
MRI	magnetic resonance imaging
MRSD	maximal rate of systolic distension
mSv	milliSievers
n-3 PUFA	omega-3 PUFA
NCC	Na-Cl co-transporter
NFL	neurone-specific enolase
NSQIP	National Quality Improvement Program
OR	open aortic aneurysm repair
PAA	popliteal artery aneurysm
PET	positron emission tomography
PKG	proteinkinase G
PMSG	physician-modified fenestrated stent graft
PSD	peak skin dose
PSV	peak systolic velocity
pt	patient
PTA	percutaneous transluminal angioplasty
pts	patients
PUFA	polyunsaturated fatty acid
PVAT	perivascular adipose tissue
QALY	quality adjusted life years
RA	regional anaesthesia
RAA	renal artery aneurysm
rAA	ruptured aortic aneurysms
rAAA	ruptured AAA
RCCA	right common carotid artery
RCT	randomised clinical trial
rEVAR	ruptured endovascular aortic repair
rOR	rupured open aortic aneurysm repair
rTAA	ruptured thoracic aortic aneurysms
rTAAA	ruptured thoracoabdominal aneurysms
SAM	segmental arterial mediolysis
SCI	spinal cord ischemia
SECTA	single-energy CTA
SES	socioeconomic status
SGLT-2	sodium-glucose cotransporter 2
SLE	systemic lupus erythematosus
SRY	Y chromosome
TAA	thoracic aortic aneurysms
TAAA	thoracoabdominal aortic aneurysm
TAAD	type A aortic dissections
TAB	temporal artery biopsy
TAC	transverse aortic constriction
TAD	thoracic aortic dissection
TAK	Takayasu's arteritis
TBAD	type B aortic dissection
TEVAR	thoracic endovascular aortic aneurysm repair
TGF-β	transforming growth factor β
TNC	true noncontrast
TOF	tetralogy of Fallot
TPFAA	true profunda femoris artery aneurysm
TS	Turner syndrome
USPSTF	US Preventive Services Task Force
VAA	visceral arterial aneurysm
VEGF	vascular endothelial growth factor
VMC	virtual monochromatic
VNC	virtual noncontrast
VQI	Vascular Quality Initiative
V-VNC	venous VNC

Epidemiology

Data on prevalence of aneurysm in different vascular territories are scarce and the majority of publications focus on aortic aneurysm. In 2019 ESVS guidelines for the management of aortic and iliac aneurysm from the European Society of Vascular Surgery have been published [1]. In these guidelines a slight decrease of aneurysm prevalence has been described probably caused by change in smoking habits. This is supported by the results from a recent publication [2]. In this retrospective study, the 10-year outcomes of an abdominal aortic aneurysm (AAA) screening program by a regional Veterans Affairs health care system was evaluated. Overall 10-year rate of AAA was 6.3%. More small aneurysms (3.0–4.4 cm) and less large aneurysms ($\geq$ 5.5 cm) were detected in the last 5 years compared with the first 5 years of the screening program.

Management of AAA has undergone considerable advances over the last two decades. Bartek et al. evaluated AAA-related mortality trends in Washington State over a 21-year period and to assess variation in AAA-related mortality by sex, race, and county over the same time period [3]. Death certificate records were obtained from the Washington State Department of Health death certificate records from 1996 to 2016 were analysed. Of the 1,014,039 deaths occurring in Washington State during the study period, 4,438 (0.4%) had AAA listed as an underlying or associated cause of death (66.1% male; 94.8% white; mean age at death, 79.4 ± 9.3 years). In 64.1% of the cases, AAA was listed as the underlying cause of death. AAA-related mortality rates decreased by 62.1% over the 21 years from 5.8 to 2.2 deaths per 100,000. Notably, there was a statistically significant decrease in ruptured AAA-(rAAA)-related mortality rate (from 3.2 to 0.95 per 100,000, a decrease of .12 deaths/100,000/year). Men had a significantly steeper decrease in age-standardized AAA-related mortality rate with a 55% decrease (from 6.5 to 3.0 per 100,000) versus a 41% decrease (2.4 to 1.4 per 100,000) among women. Men were younger than women at the time of death (78.1 ± 9.4 years vs. 81.9 ± 8.6 years, respectively; $P < .001$). White individuals had a significantly steeper decrease in age-standardised AAA-related mortality rate with a 53% decrease (from 5.3 to 2.5 per 100,000) compared to a 13% decrease among

nonwhite individuals (from 1.5 to 1.3 per 100,000). Thus, age-standardised AAA-related mortality rate has decreased in Washington State between 1996 and 2016, with a notable decrease in the rAAA-related mortality rate. The decrease in AAA-related mortality rate varied in relation to sex and race. In addition, rAAA-related mortality rates differed between counties. These observations are a first step toward regional population assessments. Future work to understand the sources of variation can influence public health interventions on a state level.

Ruptured aortic aneurysms (rAAs) are associated with high mortality. The purpose of the study of Abdulameer et al. was to describe the trends of deaths due to rAAs in the United States. A retrospective review of the national death certificate data from the U.S. National Vital Statistics System was performed to identify deaths due to rAAs in the United States between 1999 and 2016. A total of 104,458 deaths due to rAAs occurred during the study period [4]. The overall age-adjusted incidence of fatal rAA was 23.3 per 1 million (rAAA, 15.1; ruptured thoracic aortic aneurysms (rTAA), 3.1; ruptured thoracoabdominal aneurysms (rTAAA), 0.4; and unspecified site, 4.8). The annual incidence of rAA decreased by 68% from 40.0 (1999) to 12.8 (2016) per 1 million (rTAA by – 67% from 5.5 to 1.8 and rAAA by – 70% from 26.3 to 7.89 per 1 million; P < .001 for all comparisons). These trends were consistent across age groups, sexes, and races. There was a significant seasonal variation in rAA mortality, with higher deaths in winter months compared with summer months. Interestingly, only 57% of rAAA deaths occurred in men $\geq$ 65 years. Thus, the incidence of fatal rAA, rTAA, and rAAA drastically decreased in the United States between 1999 and 2016, a trend that was consistent across age groups, sexes, and races. A significant percentage of fatal rAAAs occurred in patients (pts) who are not eligible for the current screening program which should have impact on revisions of current guidelines. Importantly, a problem is the high co-prevalence of aneurysms in different vascular beds and the complete detection of those aneurysms.

A current publication reports data from 10,471 Danish men aged 65–74 years. Pts were screened using computed tomography angiography (CTA) scans for prevalence of TAA and AAA [5]. Thoracic aortic aneurysm was diagnosed in the ascending aorta (diameter > 45 mm) in 4.5%, in the arch (>40 mm) in .5% and in the descending aorta (diameter > 35 mm) in 2.2%. AAA (diameter > 30 mm) and iliac aneurysms (diameter > 20 mm) were diagnosed in 5.1% and 2.3%, respectively. In a recent publication from Sweden a total of 19,820 65-year old men have been screened for abdominal, iliac and popliteal aneurysms between 2006 and 2017 [6]. The prevalence of AAA (diameter > 30 mm) was .9% (N = 173) and of subaneurysmal aortic dilatation (diameter 25–29 mm) it was 1.1% (N = 149). In these men, popliteal aneurysms (diameter > 12 mm or 1.5 times larger than the distal superficial femoral artery) were found in 14.2%.

There is also a high co-prevalence of other aneurysms or manifestations of atherosclerosis in pts with aortic aneurysm [7]. In a retrospective cross-sectional study, CTA scans of 933 pts with AAA, including thoracoabdominal aortic aneurysms (TAAAs) were evaluated. Pts were compared according the location of aneurysm: solely infrarenal AAA or with the suprarenal aneurysm component. There was a higher prevalence of common iliac artery aneurysms (44.6% vs. 30.6%, P = .013), internal iliac artery aneurysms (28.4% vs. 18.0%, P = .03), common femoral artery aneurysms (13.5% vs. 4.4%, P < .001), visceral artery aneurysms (5.4% vs. 1.2%, P = .019), renal artery stenosis (20.3% vs. 5.2%, P < .001), renal atrophy (6.7% vs. 1.1%, P = .004), and severe chronic kidney disease (14.1% vs. 1.8%, P < .001) in pts with suprarenal aneurysm component compared to those with infrarenal AAA only.

Visceral arterial aneurysms and pseudoaneurysms are very rare entities but have high mortality because of their risk for rupture. Recently the prevalence of visceral artery aneurysm was reported from a structured review of the literature [8]. The most common location are aneurysms of the splenic or hepatic arteries. The incidence is approximately 0.01% to 2% and aneurysms most commonly involve the splenic artery (60%), followed by the hepatic, superior mesenteric, gastric, celiac, pancreaticoduodenal, gastroduodenal, inferior mesenteric and renal arteries.

Pathophysiology

The most common cause of aneurysm is atherosclerosis, in particular if aorta or extremity arteries are affected and typical cardiovascular risk factors can be identified. In 274 consecutive male pts aged $\geq$ 60 years consecutively attending a cardiology department the prevalence of AAA was 8.8%. A majority of pts with AA presented with ischemic heart disease (Odds Ratio (OR): 4.3, p = .012), dyslipidemia (OR: 5.0, p = .04), arterial hypertension (OR: 4.1, p = .04), and a longer history of smoking (OR: 1.0; p = .04) [9]. Also, obesity can be linked with AAA development [10].

Current smoking is associated with an increased aneurysm growth rate and smoking cessation is probably associated with an approximately 20% reduction in growth rate, as well as 50% reduction in the risk of aneurysm rupture [1]. A current study evaluated the pathophysiological mechanism of this association in thoracic aortic aneurysm and dissections [11]. Aneurysms are characterised by progressive disorganisation of the aortic wall matrix, including elastin, a highly immunogenic molecule. Cigarette smoking was associated with loss of self-tolerance and induction of elastin-specific autoreactive T- and B-cell responses in pts with TAA and thoracic aortic dissection (TAD) [11].

True visceral aneurysms are mostly caused by atherosclerosis (32%), although medial degeneration or dysplasia (24%) and abdominal trauma (22%) also represent a frequent cause [6]. On the other hand, false visceral aneurysms commonly result from local degenerative conditions such as pancreatitis, cholecystitis or infections.

In all types of aneurysms, risk of rupture is strongly correlated with aneurysm growth. Women have higher rupture risk compared to men [12]. A recent analysis showed in pts with TAA that aneurysm growth is more than twice as fast in women than men [13]. In addition, aortic stiffness is associated with greater aneurysm growth in women, but not in men.

The delayed development of AAA in women compared with men might be secondary to a protective effect from endogenous estrogens. The role of postmenopausal hormone therapy remains unclear. The aim of the study was to evaluate the effect of female sex hormones compared with other risk factors associated with AAA through a long-term study of a large female cohort. The prospective cohort study included 20,024 postmenopausal women from the Norwegian Nord-Trøndelag Health Study [14]. A total of 201 cases of AAA were identified during a median follow-up period of 18 years (295,554 person-years; 1995–2014). The effect of female sex hormones on the risk of incident AAAs in women, as evaluated by the serum concentrations of estradiol and the use of postmenopausal hormone therapy, is clinically less important than the strong associations found with smoking, hypertension, and coronary heart disease.

Along with these findings, prominent Y chromosome loss in tissue specimens from male AAAs was observed in pts, which was correlated to age, lower level of sex-determining region of the Y chromosome (SRY) gene expression and free testosterone [15]. Similarly, testosterone depletion and androgen receptor (AR) blockade precede AAA formation, and conversely, testosterone administration could suppress AAA formation by regulating macrophage-mediated inflammatory responses. This anti-inflammatory action of testosterone/AR on AAA formation might provide a mechanistic insight into the vascular protective actions of testosterone and suggest that its proper administration or selective AR modulators might be novel therapeutic strategies for this aortic pathology [16].

Fashandi et al. demonstrated in a mouse model that female mice had decreased AAA rupture rates (16% vs. 46%; P = .029) [17]. Female mice expressed fewer elastin breaks (P = .0079) and decreased smooth muscle cell degradation (P = .0057). Also, multiple cytokines were decreased in the female group. Gelatin zymography demonstrated significantly decreased pro-matrix metalloproteinase 2 in female mice (P = .001). Male mice fed a high dose phytoestrogen diet failed to decrease AAA rupture. Female mice undergoing oophorectomy did not have accelerated aortic rupture. These data are the first to attempt to tease out hormonal effects on AAA rupture and the possible role of gender in rupture.

Women with Turner syndrome (TS) are at increased risk of aortic dissection (AD), which is related to ascending aortic diameter. However, the relation between aortic diameter and outcome was not well determined. Duijnhouwer et al. evaluated the prevalence of aortic dilatation, the growth rate of the aorta and the risk of aortic complications in 268 women with TS, having median age of 28.7 (IQR: 21.3–39.7) years [18]. Aortic dilatation was present in 22%. Whereas aortic dilatation is common in large adult TS cohort, AD, related mortality and preventive aortic surgery are rare. Growth hormone treatment in childhood was associated with aortic dimensions.

The negative correlation between diabetes and AAAs is well described. D'cruz et al. demonstrated in a meta-analysis of 5 population cohort studies and five case-control studies involving 1,006,360 pts a statistically significant inverse association between diabetes mellitus (DM) and TAAs (OR: .77; 95% CI, .61–.98), similar to that of AAA [19]. Further research is required into the potentially protective mechanisms that DM may confer and whether there is biologic plausibility to exploit these mechanisms further to prevent aneurysm expansion and rupture.

Perivascular adipose tissue (PVAT) is thought to play a role in vascular homeostasis and in the pathogenesis of large vessel diseases, including AAA. Herein, the hypothesis that locally restricted transcriptional profiles characterize PVAT surrounding AAA was tested, indicating specific dysfunctions associated with the disease. A microarray-based investigation of the PVAT transcriptome in 30 pts with AAA, comparing the adipose layer of the dilated abdominal aorta with that of the not-dilated aortic neck in each patient. Substantial differences in PVAT gene expression clearly distinguishing the dilated from the not-dilated aorta were found, which increased in number and magnitude with increasing AAA diameter. Comparisons with other adipose depots (omental or subcutaneous fat) confirmed that gene expression changes are locally restricted. Both innate and adaptive immune-response genes along with genes related to cell-death pathways, metabolic processes of collagen, sphingolipids, aminoglycans, and extracellular matrix degradation were strongly overrepresented in PVAT of AAA compared with PVAT of the not-dilated aorta. This suggests that AAA is an immunologic disease with an underlying autoimmune component [20].

Current research supports the link between inflammation and aneurysm growth. The group of Paige E et al. aimed to investigate the clinical association between the IL6R-Asp358Ala variant and AAA growth and to assess the effect of blocking the IL-6 signaling pathway in a mouse model of aortic aneurysm rupture or dissection [21]. The results of this mouse model support the concept that IL-6 trans-signaling is relevant to aneurysm growth.

The role of inflammation is further supported by experimental data from mice by Liu et al. Inflammatory cytokine interleukin-18 (IL18) has two receptors: IL18 receptor (IL18r) and Na-Cl co-transporter (NCC). In human and mouse AAA lesions, IL18 colocalizes to its receptors at regions rich in adipocytes, suggesting a role of adipocytes in promoting IL18 actions in AAA development. Authors demonstrated that Interleukin-18 uses both IL18r and NCC to promote AAA formation [22]. Lesion adipocyte and perivascular adipose tissue contribute to AAA pathogenesis by releasing leptin and FABP4 that induce IL18, IL18r, and NCC expression and promote IL18 actions.

Suehiro et al. demonstrated that deletion of interleukin-18 attenuates abdominal aortic aneurysm formation in mice by enhancing osteopontin expression, macrophage recruitment, and metalloproteinase activation [23].

Since the discovery of the familial nature of TAA and TAD almost 2 decades ago, the understanding of the genetics of this disorder has undergone a transformative amplification. To date, at least 37 TAD-causing genes have been identified and an estimated 30% of the pts with familial nonsyndromic TAD harbor a pathogenic mutation in one of these genes. In the review of Faggion Vinholo et al., an update summarizing the genes associated with TAD and the ensuing clinical implications for endovascular intervention is given [24]. Molecular genetics will continue to bolster this burgeoning catalog of culprit genes, enabling the provision of personalised aortic care.

Immunoglobulin G4 (IgG4)-related disease is a systemic chronic fibroinflammatory disease that can affect almost every organ of the body. IgG4-related periaortitis/periarteritis is a newly recognised subset of IgG4-related disease, and its characteristics and prognosis remain unclear. We investigated the clinical characteristics and prognosis of IgG4-related periaortitis/periarteritis. Akiyama et al. investigated 248 pts with IgG4-related periaortitis/periarteritis [25]. All studies reported the condition in elderly pts, and male predominance was observed. The infrarenal abdominal aorta and iliac arteries were the most commonly affected sites. Most reports showed the serum C-reactive protein elevation in this disease entity, in contrast to non-vascular IgG4-related disease. Although corticosteroid treatment was effective, this disease can be life-threatening secondary to myocardial infarction, AD, and aneurysmal rupture.

The molecular roles of noncoding RNAs in AA development appear to vary significantly between TAAs and AAAs. Some microRNAs (miRNA – a non-coding RNA subspecies) appear to contribute to AA pathophysiology, with some showing major potential for use as biomarkers or as therapeutic targets. Studies of long noncoding RNAs (lncRNAs) are more limited, and their specific contributions to disease development and progression largely remain unexplored. The reviews of Wu et al. and Spin et al. aim to summarise and discuss the most current data on lncRNAs and their mediation of AA pathophysiology [26].

In the search for alternative methods of diagnosing, monitoring, and treating AAA noncoding RNAs-short noncoding RNAs (microRNAs) and long-noncoding RNAs-are emerging as new fundamental regulators of gene expression. Researchers and clinicians are aiming at targeting these microRNAs and long noncoding RNAs and exploit their potential as clinical biomarkers and new therapeutic targets for AAAs. While the role of miRNAs in AAA is established, studies on IncRNAs are only beginning to emerge, suggesting their important yet unexplored role in vascular physiology and disease. Kumar et al. review the role of noncoding RNAs and their target genes focusing on their role in AAA and discuss the animal models used for mechanistic understanding of AAA as well as the potential role of microRNAs and IncRNAs as clinical biomarkers and therapeutics [27].

Studies have found that the TGF-β/Smad pathway and aneurysm formation appear linked. For example, the TGF-β signaling pathway was significantly activated in aneurysm development and AD. Aneurysms are, however, not mitigated following knockdown of TGF-β signaling pathway-related genes. Incidence and mortality rate of ruptured thoracic aneurysms increase with the downregulation of the classical TGF-β signaling pathway. In a review, Tingting et al. summarise recent findings and evaluate the differential role of classical and non-classical TGF-β pathways on AA [28]. It is postulated that the TGF-β signaling pathway is necessary to maintain vascular function, but over-activation will promote aneurysms whereas over-inhibition will lead to bypass pathway over-activation and promote aneurysm occurrence.

Large animal models to study AAAs have been sparse so far. Shannon et al. created a reproducible, clinically significant infrarenal AAA model in swine. To achieve this, Cullen et al. used a combination of balloon angioplasty, elastase and collagenase, and a lysyl oxidase inhibitor, called β-aminopropionitrile (BAPN), to create clinically significant infrarenal AAs, analogous to human disease [29].

Segmental arterial mediolysis (SAM) is a rare but serious nonatherosclerotic, noninflammatory vasculopathy of unknown etiology that often results in dissection, aneurysm, occlusion, or stenosis of, primarily, the abdominal arteries. Current literature lacks consensus on diagnostic criteria and management options for SAM. The review of Sheik et al. summarises 143 cases and aims to advance appropriate recognition and management of SAM [30]. Pts with SAM were most commonly men (68%) in their 60 s. Abdominal pain (80%) and intraabdominal bleeding (50%) were the most common presenting symptoms. CT was the most frequently used imaging method (78%), and histology was available in 44% of cases. The most commonly affected vessels were the superior mesenteric (53%), hepatic (45%), celiac (36%), renal (26%), and splenic (25%) arteries with aneurysm (76%), dissection (61%), and arterial rupture (46%). Treatments included coil embolization (28%), abdominal organ surgery (24%), open arterial repair (21%), and medical management (20%). Case-specific treatment modalities yielded symptom relief in the vast majority (91%) of pts, with a mortality rate of 7%.

Salmonella infection is most common in pts with infected AA. When the aortic wall is heavily atherosclerotic, the intima is vulnerable to invasion by Salmonella. By using THP-1 macrophage-derived foam cells to mimic atherosclerosis, Chu et al. investigated the role of three Salmonella enterica serotypes – Typhimurium, Enteritidis, and Choleraesuis – in foam cell autophagy and inflammasome formation [31].

AA and AD are rare complications of systemic lupus erythematosus (SLE). The incidence, etiology, risk factors, and outcomes of this entity were largely unknown. Publications of aortic aneurysm or dissection due to SLE published between 2000 and 2017 were reviewed and a total of

36 articles reporting a single case or case series involving 40 pts were collected [32]. The pts showed an absolute female dominance at a mean aneurysm age of 44.6 years. Steroid use was 13.3 ± 9.4 years prior to admission for management of AA or AD. AA occurred more commonly in abdominal than other segments of the aorta, whereas AD did not show any location predilection. Pts with open aortic operations showed a higher mortality rate than other groups; however, no statistical significance was reached. Overall, SLE pts had significant risks for developing aortic aneurysm and dissection. Hypertension, long-term steroid use, and aortic pathological changes related to SLE seemed to be predominant risk factors for the occurrence of aortic aneurysm and dissection. Upon diagnosis, a surgical, interventional, or hybrid treatment should be performed to prevent severe sequelae and sudden deaths.

Aortic dilation and aortic valve disease are known long-term complication of tetralogy of Fallot (TOF), but the risk of AD and the indications for prophylactic aortic surgery were unknown in this population. One purpose of the study by Egbe et al. was to determine the incidence of progressive aortic dilation and AD in pts with TOF in 453 consecutive pts (37 ± 13 years, men 216 (49%)) between 1990 and 2017. AA was present in 312 (69%) based on normative data; progressive aortic dilation occurred in 40 (9%), and there was no case of aortic dissection. Significant aortic valve disease-AA occurred in 52 (12%) pts; and 15 of them (29%) underwent aortic surgery without any surgical mortality [33].

For the better understanding of pathophysiology and natural course of AAAs longitudinal research is needed that combines biomarkers with clinical and imaging data measured over multiple time points. Therefore, a multicentre biobank, databank and imagebank has been established in the Netherlands: the "Pearl Abdominal Aortic Aneurysm" (AAA bank) [34].

Similarly, the Munich Vascular Biobank collects biological tissue samples to validate diagnostic and therapeutic strategies for translational and clinical research including personalised medicine [35].

Impact of medical management on aneurysm growth

Up to now no specific class of drug has been shown to be effective to stop aneurysm growth [1]. Nevertheless, treatment of arterial hypertension is crucial for the development and growth of aneurysm. A current meta-analysis of 21 cohort studies including 28,162 cases with showed a strong association between hypertension and development of AAA [11]. In particular, pts with Marfan syndrome and poorly controlled hypertension are at increased risk for growth and rupture of TAA. In a recent publication the current evidence about anti-hypertensive treatment are summarised [36]. Although limited evidence ß-blockers seems to be superior in these pts compared to other anti-hypertensive medications. Pts with diabetes have a slower aneurysm growth rate than pts without diabetes, which has recently been suggested to be related to the treatment with metformin [1, 37]. Metformin represses the pathophysiology of AAA by inhibiting the activation of PI3 K/AKT/mTOR/autophagy pathway [38]. In a prospective cohort observational study performed in three cities in Australia, Colledge et al. investigated 1,080 pts with a mean (SD) initial AAA diameter of 46.1 (11.3) mm, followed for a mean (SD) of 2.5 (3.1) years. Pts with diabetes who were prescribed metformin (adjusted HR 0.63), but not pts with diabetes who were not prescribed metformin (adjusted HR 1.15), had a lower incidence of AAA events compared with those without diabetes. Authors concluded that a randomised controlled trial is needed to definitively test whether metformin reduces AAA related clinical events in pts with small AAAs who do not have diabetes [39]. In a nationwide analysis of 13,834 diabetic Veterans Affairs pts between 2003 and 2013, prescription for metformin was associated with decreased AAA enlargement. The unadjusted mean rate of AAA growth was 1.2 ± 1.9 mm/year for pts prescribed metformin compared with 1.5 ± 2.2 mm/year for those without ($P < .001$), a 20% decrease [40]. This effect remained significant when adjusted for variables relevant on AAA progression. Also, SGLT-2 (sodium-glucose cotransporter 2) inhibitors have emerged as powerful pharmacological tools for type 2 diabetes mellitus treatment. Beyond their glucose-lowering effects, recent studies have shown that SGLT-2 inhibitors reduce cardiovascular events and have beneficial effects on several vascular diseases such as atherosclerosis; however, the potential effects of SGLT-2 inhibition on AAA remain unknown. Ortega et al. evaluated the effect of oral chronic treatment with empagliflozin-an SGLT-2 inhibitor-on dissecting AAA induced by Ang II (angiotensin II) infusion in apoE (apolipoprotein E)-/-mice. Pharmacological inhibition of SGLT-2 by empagliflozin inhibited AAA formation. SGLT-2 inhibition might therefore represent a novel promising therapeutic strategy to prevent AAA progression [41]. Epidemiological evidence supports a reduced prevalence of TAA and AAA in pts with diabetes. The mechanisms underlying this negative association are unknown. In the narrative review of Krizhanovskii et al. the available evidence for effects of Glucagon-Like Peptide-1 (GLP-1) on experimental aneurysm development is summarized and the potential role of GLP-1 in aneurysm formation based on available data from pre-clinical and clinical studies discussed [42].

The study of Yamagashi et al. was conducted as a pooled analysis of original data from 8 cohort studies, comprising a total of 366,048 community-based men and women who had no history of cardiovascular disease or cancer [43]. A nonlinear inverse association was found between fish intake and total aortic disease. Compared with persons who ate fish 1–2 times/week, persons who seldom ate fish had higher mortality from total aortic disease (multivariable-adjusted pooled HR = 1.93). Higher mortality was not seen in those who ate fish 1–2 times/month. A similar

pattern was observed for AD. VEGF-A and its receptors contribute to experimental AAA formation by suppressing mural angiogenesis, matrix metalloproteinase (MMP) and vascular endothelial growth factor A (VEGF-A) production, myeloid cell chemotaxis, and circulating monocytes. Pharmacological inhibition of receptor tyrosine kinases by sunitinib or related compounds may provide novel opportunities for clinical aneurysm suppression [44]. A new therapeutic approach has been tested by a group from Australia [45]. Inflammation and abnormal redox status are believed to be key pathogenic mechanisms for AAA. A correlation between inflammation and aberrant fatty acid profiles has been suggested. In this small placebo-controlled study, the effect of omega-3 PUFA (n-3 PUFA) supplementation on erythrocyte fatty acid content was examined in a cohort of 30 pts with AAA. After a treatment period of 12 weeks n-3 PUFAs improved fatty acid profiles and ameliorate factors associated with inflammation in AA pts. Zhou et al. demonstrated in mice that rapamycin suppressed TAA and TAD formation, probably by inhibition of mechanistic target of rapamycin signaling and reduction of inflammatory cell infiltration and MMP 9 production. Targeting of the mechanistic target of rapamycin signaling pathway using rapamycin may be a favorable modulation for the clinical treatment of TAD [46]. Horimatsu et al. report that niacin blunts aortic inflammation and matrix degradation, thereby suppressing AAA formation [47]. These effects are independent of the niacin receptor GPR109A and mimicked by nicotinamide, which does not induce flushing. Thus, niacin protects against AAA formation independent of GPR109A, most likely by serving as an NAD + precursor. Supplementation of NAD + using nicotinamide-related biomolecules may represent an effective and well-tolerated approach to preventing or treating AAA. Zhang et al. developed a peptide vaccine named ATRQβ-001, which was proved to retard signal transduction initiated by angiotensin II (Ang II) [48]. Ang II was implicated in AAA progression. In mice, ATRQβ-001 vaccine prevented AAA initiation and progression in both Ang II and calcium phosphate-induced AAA models. And the beneficial effects were played beyond decrease of blood pressure. Gamboge is the dry resin secreted by Garcinia hanbaryi Hook.f, with the function of promoting blood circulation and anti-cancer effects, detoxification, hemostasis and killing insects. It is also used for the treatment of cancer, brain edema and other diseases. Gambogic acid is the main effective constituent of Gamboge. Liu et al. demonstrated that Gambogic acid prevents angiotensin II induced AAA through inflammatory and oxidative stress dependent targeting of the PI3 K/Akt/mTOR and NF κB signaling pathways in mice [49]. Licochalcone A (LA), a chalcone derived from liquorice, exhibits multiple biological activities, including anti-oxidation and anti-inflammation. In mice, LA attenuated AngII-induced AAA by modulating the miR-181b/SIRT1/HO-1 signaling. LA might be a potential medical therapy for small AAA [50]. The Asp358Ala variant (rs2228145; A > C) in the IL (interleukin)-6 receptor (IL6R) gene has been implicated in the development of AAAs. In 2 mouse models of AAA, selective blockage of the IL-6 trans-signaling pathway, but not combined blockage of both, the classical and trans-signaling pathways, was associated with improved survival ($P < .05$) [13]. Low-molecular mass protein 7 (LMP7) is a proteolytic subunit of the immunoproteasome that is involved in regulating inflammatory responses. Li et al. demonstrated that ablation or pharmacological inhibition of LMP7 attenuates Ang II-induced AAA formation, and LMP7 might be a novel therapeutic target for treating AAA in humans [51]. Ginkgo biloba extracts (GBEs), a natural herb extract widely used as food supplements, drugs, and cosmetics, has been reported to suppress development of calcium chloride-induced AAAs in mice [52]. Calcium chloride-induced AAAs do not rupture, while angiotensin II (AngII)-induced AAAs in mice have high rate of aortic rupture, implicating potentially different mechanisms from calcium chloride-induced AAAs. GBE prevented in mice the aortic rupture in AngII-infused hypercholesterolemic mice, but only in the early phase of the disease development. Cycloastragenol (CAG), derived from Astragali Radix, has various pharmacological effects. Compared to a control AAA model group in mice, CAG reduced the incidence of AAA, the dilatation of aorta and elastin degradation in media in both mouse models of AAA through down-regulation of the MAPK signalling pathways and thus attenuates inflammation, oxidation, vascular smooth muscle cell (VSMC) phenotype switch and apoptosis and the expression of MMPs as well as increasing elastin biosynthesis [53]. Curcumin is an important bioactive component of turmeric that has been widely applied as traditional medicine to prevent and treat various diseases. Recent studies have demonstrated its potent activities in modulating multiple signaling pathways associated with cellular growth, proliferation, survival, inflammation and oxidative stress. The cardiovascular protective properties of curcumin in cardiovascular diseases (CVDs) have been illustrated in numerous studies. In the review by Li et al., the medicinal history of curcumin is introduced, the preclinical studies of curcumin in CVDs such as cardiac hypertrophy, heart failure, drug-induced cardiotoxicity, myocardial infarction, atherosclerosis, AAA, stroke and diabetic cardiovascular complications are analysed and potential molecular targets of curcumin summarised [54]. Also, clinical trials of curcumin in CVDs are overviewed and the therapeutic utility of derivatives of curcumin discussed.

Little is known about preventive methods using functional food factors for nicotine-induced vascular destruction. Sesamin and sesamolin are functional food factors that are fat-soluble lignans found in Sesamum indicum seeds. Previous reports indicated that sesamin and sesamolin have anti-oxidative and anti-inflammatory effects. In mice sesame extract attenuated the degradation of collagen and elastin fibers caused by nicotine. In addition, sesame extract decreased the area positive for MMP-12 and oxidative stress in the vascular walls [55]. Doxycycline, a nonselective matrix metalloproteinases inhibitor, was reported to improve the contractile function and elastic

fiber structure and organisation in a Marfan mouse aorta using ex vivo small chamber myography. Cui et al. demonstrate the key role of matrix metalloproteinases during the progression of aortic aneurysm, and provide new insights into the potential therapeutic value of doxycycline in blocking Marfan syndrome-associated AA [56]. People heterozygous for an activating mutation in protein kinase G1 (PRKG1, p.Arg177Gln) develop TAAs and TADs as young adults. Mice heterozygous for the mutation had a three-fold increase in basal protein kinase G (PKG) activity, and developed age-dependent aortic dilation [57]. Prkg1R177Q/+ aortas showed increased smooth muscle cell apoptosis, elastin fiber breaks, and oxidative stress compared to aortas from wild type littermates. Transverse aortic constriction (TAC)-to increases wall stress in the ascending aorta and induces severe aortic pathology and mortality from aortic rupture in young mutant mice. The free radical-neutralizing vitamin B12-analog cobinamide completely prevented age-related aortic wall degeneration. Bergwall et al. showed in a prospective cohort study, Malmö Diet and Cancer Study, in 26,133 study participants' observed from 1991–1996 that a high intake of fruits and berries and vegetables, in particular leaf vegetables, are associated with a decreased risk of developing AAA [58]. In a study population included the Cohort of Swedish Men (45,072 men) and the Swedish Mammography Cohort (36,633 women), aged 45–83 years at baseline Kaluza et al. prospectively evaluated the association between the anti-inflammatory potential of diet and risk of AAA [59]. Adherence to diet with a high anti-inflammatory potential was associated with a reduced AAA risk, an association that was even more pronounced for AAA rupture. The anti-inflammatory potential of diet was estimated using Anti-inflammatory Diet Index (AIDI) based on 11 foods with anti-inflammatory potential and 5 with proinflammatory potential (maximum 16 points) that was validated against highsensitivity C reactive protein (hsCRP). In a mouse model of Marfan syndrome that shows highly penetrant postnatal AD, risk was strongly attenuated by preventing lactation or use of an oxytocin receptor antagonist [60]. Survival correlated inversely with the extent of extracellular signal-regulated kinase (ERK) activation in the aortic wall, and strong protection was observed upon attenuation of ERK phosphorylation using an inhibitor of ERK kinase (MEK) or the U.S. Food and Drug Administration-approved medication hydralazine, offering potential therapeutic strategies for pregnancy-associated vascular catastrophe in the setting of Marfan syndrome.

There are several medications which should be avoided because of their negative effects. Ciprofloxacin, levofloxacin, and moxifloxacin belong to the fluoroquinolone class of antibiotics and are amongst the most commonly prescribed antibiotics. Meng et al. aimed to examine those fluoroquinolone-associated aortic aneurysms or dissections through data mining of the US Food and Drug Administration Adverse Event Reporting System (FAERS), analysing reports from 1 January 2004 to 31 December 2016 [61]. Based on 3,721 adverse event reports, all three fluoroquinolones are associated with AA, and levofloxacin is associated with AD. The risk of AA is higher than the risk of AD. Oral administration of fluoroquinolones is more likely to produce these adverse events. A current meta-analysis summarised the effects four controlled observational studies about the use of fluoroquinolones [62]. Fluoroquinolone administration more than doubled the risk to develop AA or AD within 60 days following the exposure. Therefore, this medication should be use with caution in high-risk pts. This was confirmed by Noman et al. [63]. A systematic review and meta-analysis comprising 22 observational studies (12 cohort studies and 10 case-control studies) with 19,207,552 participants confirmed this risk in 3 collagen-associated diseases (AA or AD, retinal detachment, and tendon disorders) [64]. Pts at an increased risk of collagen-associated diseases should not use fluoroquinolones unless no other options are available.

Imaging of aneurysms and dissections

Ultrasound, colour-coded ultrasound (CDU) and contrast-enhanced ultrasound (CEUS) are the preferred tools in the diagnosis of peripheral artery and vein aneurysms. They are routinely used for detection and follow-up examinations of abdominal, iliac and carotid aneurysms. Diagnosis and treatment control of aneurysms in the thorax or abdomen require catheter angiography, CT and CTA, magnetic resonance imaging (MRI and MRA) and positron emission tomography (PET).

Ultrasound

Bao et al. aimed to evaluate the clinical significance of CDU in the diagnosis of spontaneous isolated superior mesenteric artery dissection [65]. In 19 pts with this aneurysm who had CDU and CTA no significant difference of cross-sectional area, diameter stenosis and flow rate was found.

Similar results were reported in pts with isolated dissection of the superior mesenteric artery [66]. The authors compared a combination of colour duplex and CEUS and CTA. A total of 42 pts undergoing 76 total imaging examinations during follow up were included. Both CTA and CDU plus CEUS demonstrated the thrombosed false lumen for 28 (36.8%) examinations and the dissecting aneurysm for 20 (26.3%) examinations. The entry points were visualised by CDU and CEUS for 20 (26.3%) examinations and by CTA for 14 (18.4%) examinations. No re-entry points were visualised by CDU and CEUS for any examinations, but re-entry points were visualised by CTA for two (2.6%) examinations. The peak systolic velocities were 128.2 ± 13.0 cm/s at diagnosis and 98.7 ± 4.9 cm/s after one month ($p < .001$). The combination of CDU and CEUS can be used in place of CTA for the surveillance of isolated superior mesenteric artery dissection.

Ghulam et al. evaluated three-dimensional ultrasound (3D-US) examination to be used for AAA surveillance with improved reproducibility over conventional two-dimensional ultrasound (2D-US) examination, regarding maximum anterior-to-posterior diameter by nonphysician ultrasound technicians in a typical vascular laboratory setting [67]. A total of 134 consecutive pts with asymptomatic infrarenal AAAs were screened. Both 3D-US and 2D-US examination demonstrated good reproducibility among two vascular ultrasound technicians with superior agreement from 3D-US examination. The present results support the broader use of 3D-US in standard AAA surveillance programs.

A total of 20 consecutive pts undergoing infra-renal endovascular aortic repair (EVAR) underwent immediate post-deployment rotational angiography, followed by CEUS and contrast-enhanced tomographic 3-D ultrasound (CEtUS) scans [68]. Outcomes were presence of endoleak, renal artery patency and endograft deformity. CEUS and CEtUS detected 12 endoleaks, 8 of which were not detected by rotational angiography. CEUS/CEtUS could not identify 12 and 13 renal arteries, respectively, detected by rotational angiography. Rotational angiography and CEtUS both identified 1 endograft limb deformity. CEUS and CEtUS are more sensitive to type II endoleak than rotational angiography. They should be used for post-EVAR endoleak detection where reduction of contrast agent is indicated.

Li et al. sumarises in a review paper the use of CEUS as a complementary tool and its usefulness in assessing both the macro- and microvascular anatomy of the aorta [69]. From a macrovascular perspective, CEUS has been used to characterise AA rupture, dissection and endoleaks post-EVAR repair. With regard to microvasculature CEUS enables imaging of adventitial vasa vasorum thereby assessing aortic inflammation processes, such as monitoring treatment response in chronic periaortitis. For endoleak surveillance CEUS has been shown to be equal or in certain cases superior in comparison to CTA. The recent advancement of CEUS software along with the ongoing development of drug-eluting contrast microbubbles has allowed improved targeted detection and real-time ultrasound guided therapy for aortic vasa vasorum inflammation and neovascularisation in animal models. They conclude that, CEUS is uniquely suited to comprehensively assess and potentially treat aortic vascular diseases in the future. Harky et al. assessed in a systematic review the sensitivity and specificity of CEUS compared to CTA for the detection of endoleaks within EVAR surveillance [70]. A comprehensive literature search was undertaken until October 2018. A total of 1,773 pts were analysed from across 18 included studies in the quantitative analysis of the parameters of interest. There was no significant difference in detection rate of endoleak type I (4.3% for both groups), type II endoleak detection rate was 22% in the CEUS group versus 23% in the CTA group, type III detection rate was 1.8% in CEUS group versus 2% in CTA group. However, the sensitivity rate for endoleak detection was higher in CEUS ($p = .001$) while no difference in specificity rate was noted ($p = .28$). There was a higher rate of missed endoleaks in CTA groups ($n = 12$ vs. $n = 20$) [70]. In a systematic review and meta-analysis Kapetanios et al. investigated the diagnostic accuracy of CEUS for detection of endoleak after EVAR [71]. In 26 studies reporting a total of 2,638 paired scans in 2,217 pts the pooled sensitivity and specificity of CEUS for all endoleaks were .94 and .93, respectively. The area under the curve (AUC) was .98. The summary estimate of sensitivity and specificity for type I and type III endoleaks was .97 and 1.00, respectively. The AUC was 1.00. Authors concluded that CEUS has a high sensitivity and specificity in the detection of endoleaks after EVAR and CEUS is a useful tool in EVAR surveillance.

Tran et al. investigated the use of duplex ultrasound (DUS) examinations for surveillance after fenestrated endovascular aneurysm repair (FEVAR), particularly in renal branch grafts after FEVAR [72]. They retrospectively reviewed a total of 116 pts were treated with FEVAR, of which 60 (51.7%) had concurrent CT and renal DUS images available for review. They concluded that DUS imaging is a clinically useful modality for surveillance of renal branch grafts after FEVAR. Patterns of segmental velocity elevation (proximal peak systolic velocity (PSV), > 215 cm/s) and dampening in the distal renal indicate potential hemodynamic compromise and should prompt more aggressive workup or imaging and likely be considered for secondary intervention.

A novel ultrasound system consisting of a modified console and data analysis algorithm was developed. The exploratory study included 100 pts hospitalised for elective cardiovascular surgery [73]. After admission, the arterial pulse waveform at the left carotid artery was acquired using the novel system. Based on these data, we inferred the presence of TAA based on arterial viscoelasticity and instability, which are reflected into the time-averaged trajectory of deformation of the blood vessel wall caused by disturbance of blood flow. Meanwhile, all pts underwent computed tomography as preoperative screening to confirm the presence of TAA. The sensitivity and specificity of TAA detection using the novel ultrasound system were calculated. The datasets from 37 pts were not suitable for analysis and were thus discarded. Based on CT findings, 40 pts were categorised into the aneurysm group while 23 were judged not to have an AA. On the other hand, 44 pts were diagnosed as having TAA based on ultrasound findings obtained using the novel system. The overall sensitivity and specificity of the ultrasound system were .83 and .52, respectively. Although improvements to the probe and diagnostic algorithm are warranted, this device has potential utility for mass screening to detect asymptomatic TAA as part of community-level healthcare programs.

Angiography, computed tomography and computed tomography angiography

Contrast-induced nephropathy (CIN) is one of the leading causes of hospital-acquired acute kidney injury (AKI) due

to the use of iodinated contrast media in various interventional procedures like EVAR. This study investigates the possible protective role of direct intra-arterial administration of mannitol and acetylcysteine and per os administration of simvastatin in a histopathological level. Iopromide was directly administered in the infrarenal aorta of 24 New Zealand white rabbits [74]. Animals were divided in four groups of six: G1 received iopromide with no protection, G2 iopromide with mannitol, G3 iopromide with acetylcysteine, and G4 iopromide with simvastatin. Renal function blood parameters were assessed prior to the administration, and in 48 h; histopathological evaluation of the kidneys was performed. CIN was evident only in the no protection group G1. Moreover, G1 demonstrated significantly more severe lesions than groups G2, G3, and G4 regarding histopathological findings in glomeruli, vacuolization of tubular epithelial cells, tubular proteinaceous casts, and tubular necrosis. Intra-arterial administration of mannitol seems to be effective in protection against tubular necrosis.

The reliability of assessment of the artery of Adamkiewicz before the aortic repair is highly dependent on the display of the continuity of this artery with the aorta, mainly around the vertebral pedicle, by CTA. Nishi et al. demonstrated that the sharp filter kernel significantly improved the image quality in low-tube-voltage CTA for the assessment of the artery of Adamkiewicz [75]. Thus, CTA with the sharp filter kernel can generate a high-confidence level in the evaluation of the artery of Adamkiewicz.

Pts referred for fenestrated/branched endovascular aortic repair (F/BEVAR) often present with a previous CTA, but it was unknown how recent the CTA must be to ensure accurate F/BEVAR planning. Nguyen at al investigated whether anatomic planning parameters change significantly between a CTA used for F/BEVAR planning and a CTA obtained 6 to 12 months prior and came to the conclusion, that in pts who underwent successful F/BEVAR, measurement comparisons between CTAs obtained up to 1 year prior were minor and unlikely to yield clinically significant changes to F/BEVAR design [76].

Several studies have analysed risk factors that may influence the incidence of type II endoleak with sac expansion after EVAR. The study of Fujii et al. examined the correlation between preoperative intraluminal thrombus and the incidence of type II endoleak and late sac expansion by measuring the thrombus volume. Of the 280 pts who underwent EVAR, 46.7% (131 pts) had persistent type II endoleak and 19.6% (55 pts) had persistent type II endoleak with significant sac expansion ($\geq$ 5 mm) [77]. The mean follow-up duration was 60 months (interquartile range, 24–72 months). Cox regression analysis showed that older age (p = .001), intraluminal thrombus volume ratio (thrombus volume [T vol]/AA volume [A vol]) (p = .042) and inferior mesenteric artery (IMA) diameter (p = .004) were significant predictors of the incidence of sac expansion with persistent or new type II endoleak. The receiver operating characteristic curve analysis revealed a cutoff of 51% T vol/A vol (AUC: .59) and 2.9 mm (AUC: .60). The rate of freedom from sac expansion ($\geq$ 5 mm) during follow-up was significantly higher in pts with $\geq$ 51% T vol/A vol than in those with a lower T vol/A vol (p = .010). Authors concluded that preoperative sac thrombus volume, IMA diameter and older age predict the incidence of aneurysm expansion with type II endoleak after EVAR.

Follow-up with CTA is recommended after EVAR, exposing pts to significant levels of radiation and iodine contrast medium. Dual-energy CT allows virtual noncontrast (VNC) images to be reconstructed from contrast-enhanced images using a software algorithm. If the VNC images are a good-enough approximation of true noncontrast (TNC) images, a reduction in radiation dose can be ensured through omitting a TNC scan. Sixty-three consecutive pts were examined using a dual-energy CT as elective follow-up after EVAR [78]. The examination protocol included 1 unenhanced and 2 contrast-enhanced scans (80 kV/Sn140 kV) of the aorta. Virtual noncontrast data sets were reconstructed from the arterial (A-VNC) and venous (V-VNC) phase scans, respectively. Mean attenuation and image noise were measured for TNC, A-VNC, and V-VNC images within regions of interest at 2 levels in the aorta, the liver, retroperitoneal fat, and psoas muscle. Subjective image quality was assessed on a 4-point scale by 2 blinded readers. The differences between A-VNC and TNC, and between A-VNC and V-VNC, were substantial aorta at the level of diaphragm and aorta at the level of renal arteries. The difference between V-VNC and TNC was very small and not statistically significant for the renal artery aorta. For liver, fat, and muscle tissue, there were significant differences between both A-VNC and V-VNC compared with TNC, but findings were similar between A-VNC and V-VNC. Virtual non-contrast images based on venous-phase scans appear to be a more accurate representation of TNC scans than VNC images based on arterial-phase scans.

From January 2016 to May 2018, 45 of 361 pts with Behçet's disease (BD) were diagnosed with vascular involvement. The following characteristics of vascular aneurysms were analyzed: Maximum diameter, length, wall thickness, borders, luminal changes, mural thrombus, cystic change of the vessel walls, asymmetric bulging of the right part of the aortic wall (RP type) and calcific plaques. The 45 BD pts analyzed included 37 males and 8 females with a median age of 40 years (30–49 years) [79]. Significant differences were observed among genders regarding age, ocular disorders and digestive-tract ulceration. A total of 42 aneurysms were identified with a mean diameter of 43 mm. Most aneurysmal walls (88%) were homogeneously enhanced on contrast-enhanced CT. Comparison of groups classified by aortic and larger arterial aneurysms indicated that aneurysms occurring in the aorta were more likely to form a mural thrombus, have a thicker wall (P < .001) and unclear borders (P = .036), to be of the RP type (P = .003) and have a longer extension (P = .001) compared with those in larger arteries. Unclear border of

the aneurysmal wall was the only radiologic predictor correlated with an elevated erythrocyte sedimentation rate ($P < .001$). In summary characteristic CT imaging features of aneurysms can add information in the diagnosis of BD when typical symptoms are missing.

The purpose study of Patino et al. was to assess the feasibility of performing aortoiliac CTA with 16.0 g of iodine contrast medium acquired with low-energy (40 and 50 keV) virtual monochromatic (VMC) images with rapid-kilovoltage-switching dual-energy CT. A total of 52 adults with abdominal aortoiliac aneurysm and prior 120-kVp single-energy CTA (SECTA) with 33 g iodine (standard dose) underwent follow-up dual-energy CTA (DECTA) with a 52% reduced iodine dose [80]. Two readers independently assessed the datasets for image quality using a 5-point scale. Aortoiliac intravascular attenuation was measured. In a subset of pts with DECTA after endovascular aortic repair, endoleak detection was evaluated on VMC images. Volume CT dose index, dose-length product, and size-specific dose estimate were compared between DECTA and SECTA. All DECTA examinations ($n = 52$) were rated diagnostic with image quality scores comparable to those of 120-kVp single-energy CTA (40 keV). Intravascular attenuation was uniform in all reduced-iodine DECTA examinations and was significantly higher on 40- and 50-keV images than on standard-iodine-dose SECTA images ($p < .01$). There was no difference in intravascular attenuation between the 16.2-g and the 16.0-g doses ($p = .82$). Sensitivity and specificity for endoleak detection were 78.9–94.7% and 100%. Total dose-length product was lower for DECTA (788 ± 166 mGy cm) than for SECTA (1,114 ± 468 mGy cm). The technique saves radiation dose and contrast material.

AAAs and popliteal artery aneurysms (PAAs) are characterized by degeneration of the vessel. This could be driven by inflammatory, hemodynamical and biological alterations which increases the risk aneurysm rupture. Human aortic and PAA tissues were obtained during surgical repair and studied by synchrotron radiation X-ray scanning microdiffraction and small-angle scattering, to investigate the microcalcifications present in the tissues. Data collected during the experiments were transformed into quantitative microscopy images through the combination of statistical approaches and crystallographic methods. As a result of this multi-step analysis, microcalcifications, which are markers of the pathology, were classified in terms of chemical and structural content. This analysis helped to identify the presence of nanocrystalline hydroxy-apatite and microcrystalline cholesterol, embedded in myofilament and elastin-containing tissue with low collagen content in predominantly nanocrystalline areas [81].

EVAR is the preferred first-line treatment for AAA. Current postprocedure surveillance recommendations by manufacturers are a 1-month CTA followed by a 12-month CTA in most circumstances. The objective of the study by Soult et al. was to determine the utility of the 1-month CTA following elective EVAR and determine if initial surveillance at 6-month CTA is appropriate [8]. A single-center retrospective chart review of all elective EVARs at a tertiary medical center over a 12-year period was conducted comprising 363 pts. It was found that there is limited utility to 1-month surveillance CTA in pts undergoing elective EVAR within the device instructions for use that has no evidence of type I endoleak on completion angiography. It is safe to start routine EVAR surveillance at 6 months in this pt population. This has implications when considering bundled and value-based payments in the longitudinal care of AAA pts.

Saving radiation is particularly important in aortic intervention. The aim of the study of Rehmann et al. was to determine whether performing EVAR in a dedicated vascular hybrid operating room is associated with a decreased pt radiation and contrast dose compared with mobile C-arm imaging in a conventional operating room [82]. In a retrospective study of pts undergoing standard EVAR from 2009–2016, they demonstrated that performing EVAR in a dedicated vascular hybrid operating room may be associated with a lower pt radiation dose, shorter screening time, and less contrast use than performing EVAR in a conventional operating room. The purpose of the study by Tzanis et al. was to determine the radiation exposure of primary interventionalist's different body parts during EVAR procedures and aortoiliac percutaneous transluminal angioplasty (PTA) procedures and to evaluate the efficacy of a radioprotective drape (.25 mm Pb equivalent drape (Ecolab, Saint Paul, Minnesota, USA) [83]. Median exposure dose (ED) for a typical EVAR and PTA procedure was 4.7 ± 1.4 μSv and 4.4 ± 3.6 μSv, respectively. The highest radiation doses were measured for the operator's hands in both procedures. Moreover, considerable doses were measured to the operator's head, eye lenses and thyroid. Due to the use of the drape, radiation exposure of primary operator's abdominal area, genitals, thyroid and eye lenses was reduced by an average of 59%, 60%, 65% and 59%, respectively. However, dose area product (DAP) and peak skin dose (PSD) were increased by 20% when part of the drape was placed into the X-ray field. Thus, during EVAR and PTA procedures, primary operator's organs are exposed to considerable radiation doses. Occupational radiation exposure can be reduced significantly with the proper use of a radioprotective drape.

The optimal imaging modalities in EVAR follow-up as well as the appropriate intervals between these follow-ups remain subject of controversial discussion. Objective of this study was the evaluation of the realistic radiation exposure and risk estimate postop EVAR treatment. Of the follow-ups required according to the surveillance schedule during the first year post-EVAR, only 68.3% were actually implemented [84]. Of those required from the second year onwards, an average of 70% was actually performed. During the observation period, each pt underwent a mean of 4.3 CTAs. The median effective dose calculated from all CTAs was 24.5 mSv. The minimum

and maximum cumulative effective doses for the entire observation period were 55 mSv and 310 mSv, respectively.

Magnetic resonance imaging

In this study the relationship between enhancement ratio (ER) of aneurysm walls and degrees of inflammation was examined in 25 rabbits. All underwent surgery to isolate the right common carotid artery (RCCA). Twenty rabbits underwent an aneurysm creation procedure, and 5 underwent a control procedure [85]. In the aneurysm creation procedure, there was surgical exposure of the origin of RCCA and temporary occlusion with an aneurysm clip. The distal RCCA was ligated, and the trapped segment was infused with elastase for 20 minutes, after which the clip was removed. In the control procedure, the trapped segment was infused with saline. High-resolution magnetic resonance imaging was performed at weeks 2, 3, 4, and 5 after the procedure, and wall ER was calculated. After MRI, aneurysms were harvested and stained with hematoxylin-eosin. Pearson correlation analysis and scatter plots were used to evaluate the relationship between wall ER and the degree of inflammation. The relationships between the wall ER, the number of inflammatory cells and time were analysed by linear graphs. Wall ER positively correlated with inflammatory cell count of the aneurysm wall ($r = .877$, $p < .001$). The relationships between wall ER, the number of inflammatory cells, and time increased and then decreased according linear graphs. The aneurysm wall ER was associated with the degree of inflammation on the rabbit aneurysm model.

Molecular MRI is a promising modality for the characterisation of AAAs and may improve the assessment of the risk of rupture. This study investigates the feasibility of imaging inflammatory activity and extracellular matrix degradation by concurrent dual-probe molecular magnetic resonance imaging in an AAA mouse model [86]. Osmotic minipumps with a continuous infusion of angiotensin II to induce AAAs were implanted in apolipoprotein-deficient mice (N = 58). Animals were assigned to 2 groups. In group 1 (longitudinal group, n = 13), imaging was performed once after 1 week with a clinical dose of a macrophage-specific iron oxide-based probe (ferumoxytol, 4 mgFe/kg, surrogate marker for inflammatory activity) and an elastin-specific gadolinium-based probe (.2 mmol/kg, surrogate marker for extracellular matrix degradation). Animals were then monitored with death as end point. In group 2 (week-by-week-group), imaging with both probes was performed after 1, 2, 3, and 4 weeks (n = 9 per group). The combined assessment of inflammatory activity and extracellular matrix degradation was the strongest predictor of AAA rupture (sensitivity 100%; specificity 89%). Information from each single probe alone resulted in lower predictive accuracy. In vivo measurements for the elastin- and iron oxide-probe were in good agreement with ex vivo histopathology. This study demonstrates the potential of the concurrent assessment of inflammatory activity and extracellular matrix degradation by dual-probe molecular magnetic resonance imaging in an AAA mouse model. Based on the combined information from both molecular probes, the rupture of AAAs could reliably be predicted.

The study of Tiwari et al. evaluated the aortic wall elasticity using the maximal rate of systolic distension (MRSD) and maximal rate of diastolic recoil (MRDR) and their correlation with the aortic size index (ASI) [87]. Forty-eight pts with TAA were enrolled. A standard MRI protocol was used to calculate MRSD and MRDR. Both MRSD and MRDR were expressed as percentile of maximal area/10^{-3} sec. ASI (maximal aortic diameter/body surface area) was calculated. A correlation between MRSD, MRDR, ASI, and the pt's age was performed using regression plot. A significant correlation between MRSD, MRDR, and ASI is observed. As ASI increases, aortic MRSD and MRDR decrease. Such inverse correlation between MRSD, MRDR, and ASI indicates increased stiffness of the ascending aorta. A significant correlation between the pt's age and the decrease in MRSD and MRDR is observed. These two new indexes provide a promising, accessible, and reproducible approach to evaluate the biomechanical property of the aorta.

Nuclear medicine and positron emission tomography

MMP-12 is highly upregulated in several inflammatory diseases, including AAA. The report presents four novel 99mTc-labeled radiotracers derived from a highly selective competitive MMP-12 inhibitor [88]. These tracers in their 99gTc version were assessed in vitro on a set of human metalloproteases and displayed high affinity and selectivity toward MMP-12. Their radiolabeling with 99mTc was shown to be efficient and stable in both buffer and mouse blood. The tracers showed major differences in their biodistribution and blood clearance. On the basis of its in vivo performance, [99mTc]-1 was selected for evaluation in murine AAA, where MMP-12 gene expression is upregulated. Autoradiography of aortae at 2 h postinjection revealed high uptake of [99mTc]-1 in AAA relative to adjacent aorta. Tracer uptake specificity was demonstrated through in vivo competition. This study paves the way for further evaluation of [99mTc]-1 for imaging AAA and other MMP-12-associated diseases. Large vessel vasculitis (LVV) is the most common form of primary vasculitis comprising of giant cell arteritis (GCA), Takayasu's arteritis (TAK) and idiopathic aortitis. Early diagnosis and treatment of LVV are paramount to reduce the risk of ischemic complications such as visual loss and strokes, vascular stenosis and occlusion, and aortic aneurysm formation. Use of imaging modalities [DUS, MRI, CT and PET] has steadily increased to enable assessment of cranial and extracranial arteries, as well as the aorta. These imaging modalities are less invasive, more sensitive and readily available compared to temporal artery biopsy (TAB). Modern imaging methods have changed the role of TAB in diagnosing GCA and have

replaced diagnostic angiography. Over the last two decades, several studies have evaluated the use of US, MRI, CT and PET in LVV. However, these various imaging tools are not yet uniformly used in routine clinical practice and controversy exists as to which imaging modality best provides meaningful assessments of disease activity and damage in LVV. The aim of this review is to summarize the current evidence of imaging in pts with or suspected of having LVV, and to highlight the clinical implications of the EULAR recommendations [89]. Non-invasive AAA-associated cell proliferation biomarkers are not yet established. Gandhi et al. investigated the feasibility of the cell proliferation radiotracer, fluorine-18-fluorothymidine ([18F]FLT) with positronemission tomography/computed tomography (PET/CT) in a progressive preclinical AAA mouse model (angiotensin II, AngII infusion) [90]. [18F]FLT uptake was increased during the active growth phase of the AAA model compared to saline control mice and late-stage AAA.

Extra-aortic aneurysms and dissections

The first International Consensus on the Diagnosis and Management of Fibromuscular Dysplasia was published in 2019 [91]. This is a comprehensive document on the diagnosis and management of fibromuscular dysplasia (FMD), which was commissioned by the working group "Hypertension and the Kidney" of the European Society of Hypertension (ESH) and the Society for Vascular Medicine (SVM). This document updates previous consensus documents/scientific statements on FMD published in 2014 with full harmonisation of the position of European and US experts. In addition to practical consensus-based clinical recommendations, including a consensus protocol for catheter-based angiography and percutaneous angioplasty for renal FMD, the document also includes the first analysis of the European/International FMD Registry and provides updated data from the US Registry for FMD. Finally, it provides insights on ongoing research programs and proposes future research directions for understanding this multifaceted arterial disease.

Visceral artery aneurysms and dissections

A literature review of 53 cases deals with ruptured renal artery aneurysm in pregnancy and puerperium [92]. The clinical presentation is easily confused with more common conditions and time to diagnosis is often delayed. Diagnostic delay is associated with high maternal and fetal mortality. Ruptured renal artery aneurysm should be included in the differential diagnosis for pregnant or peripartum pts presenting with acute and severe flank pain, especially if followed by a drop in blood pressure. Early diagnosis and immediate intervention are important for achieving better maternal and fetal outcomes. There are several methods of managing asymptomatic or ruptured renal artery aneurysm during pregnancy although no established guidelines exist.

Abreu et al. present their experience with robotic renal artery aneurysm (RAA) repair, concerning 9 consecutive pts who underwent intracorporeal robotic surgery for 10 RAAs [93]. This robotic operation is feasible and safe, and replicates open principles. However, it requires considerable experience and expertise.

Sousa et al. reviewed visceral arterial aneurysms (VAAs) and pseudoaneurysms, that are rare entities. Despite infrequent, these lesions are clinically important and potentially lethal, since 22% present as clinical emergencies and 8.5% result in death [8]. Visceral arterial aneurysms and pseudoaneurysms have fairly similar clinical presentations and diagnostic workups. Differences reside mainly in their etiology and indications for treatment, since immediate treatment is recommended for pseudoaneurysms regardless of their size, while true aneurysms have specific treatment cutoffs. These lesions are still frequently diagnosed only upon rupture, with significant mortality rates. Endovascular strategies represent the first line of treatment on the majority of cases, although open surgery continues to play a role in specific conditions.

Larner et al. report the use of a new pericardium covered stent [94]. This stent combines the benefits of a low-profile covered stent with those of a low immunogenic material. Authors describe the endovascular treatment of a pt with a hepatic artery pseudoaneurysm, where parent artery sacrifice was considered unacceptable. The stent was used to provide immediate and complete exclusion, with dual antiplatelet therapy for 1 week, followed by single antiplatelet use. This stent may potentially be used for a wider range of aneurysms with unfavourable morphology.

VAAs, although rare, represent a life-threatening disease with high mortality rates. The aim of the retrospective study of Martinelli et al. was to evaluate the results of open surgery or interventional endovascular strategies of VAAs in 125 open surgical or endovascular interventions with respect to technical success, therapy-associated complications, and postinterventional follow-up in the elective and emergency situation [95]. The treatment option was endovascular in 56 of 125 cases (44.8%). Technical success was 98.3%. In one case, the procedure was interrupted for the extensive dissection of the afferent vessel. Twenty-six pts were treated by coil embolisation while 29 with covered stenting. The endovascular approach was in emergency in two cases (3.6%). In the endovascular group, mortality was nil. Complications occurred in 5 cases (8.9%): 1 subacute intestinal ischemia caused by superior mesenteric artery dissection, 2 aneurysm reperfusion, 1 stent thrombosis, and 1 massive splenic hematoma. In 69 (55.2%) cases, surgical treatment was preferred, with 24 VAA resections and 45 arterial reconstructions. In 20 cases (29%), open surgery was performed in emergency conditions. In the surgical group, 8 emergency pts (40%) died intraoperatively. The mortality after elective surgical interventions

was nil. Complications after surgery were 4 graft late thrombosis (5.8%): asymptomatic in three cases and requiring splenectomy in one. Authors conclude that there is no overall consensus regarding the indications for treatment of VAA. Currently in emergent setting, the endovascular approach should be considered as the first choice because of its reduced invasiveness, faster way to access and bleeding control; this accounts for the lower morality of the interventional therapy than open surgery. Endovascular approach is effective for elective repair of VAAs, but procedure-related complications may occur in a not negligible number of pts. Given comparable mortality rates and low procedure-related complication rate, surgical approach still has space in the elective management of VAAs, especially for aneurysms unsuitable or challenging for the endovascular option in pts with low surgical risk. The size, location, and morphology of VAAs, systemic or local comorbidities, and specific anatomical situations such as previous abdominal surgery should dictate treatment choice.

Isolated superior mesenteric artery dissection (ISMAD) is rare, especially when associated with intestinal ischaemia. Medical records from 22 pts with ISMAD and intestinal ischaemia were retrospectively analysed [96]. Conservative treatment was given to all pts as first line therapy. Subsequently, 15 pts received endovascular stent placement and three pts received endovascular stent placement plus intestinal resection and anastomosis. After conservative treatment, the symptoms of three pts were remarkably relieved; however, a repeat contrast CT showed that the stenosis was aggravated. Hence, endovascular stent placement was performed in all 15 pts. Enteral nutrition was successfully restored in 12 pts. Three pts showed signs of chronic intestinal ischaemia, including peritonitis and ileus. These pts underwent intestinal resection and anastomosis. Enteral nutrition was restored at postoperative week two. No signs of intestinal ischaemia recurred during two-years of follow-up. Liu et al. recommend endovascular stent placement as a feasible, effective, and minimally invasive procedure in pts with ISMAD and symptoms of intestinal ischaemia.

Peripheral artery aneurysms and dissections

A comprehensive systematic review on the diagnosis and management of true profunda femoris artery aneurysm (TPFAA) by Kibrik et al. covered 27 cases [97]. Rupture was reported in 18.5% of the cases (n = 5); the conventional clinical presentation of unruptured TPFAA was reported in 48% of cases (n = 13), with 40.9% of unruptured aneurysms being asymptomatic (n = 9). Review of the current literature supports that CTA and DUS are the mainstay diagnostic approaches for TPFAA. Surgical repair through ligation, resection, and revascularisation remains the most common and effective therapeutic procedure. Endovascular embolisation is recommended for aneurysms when surgery is not tenable because of the pt's comorbidities and the aneurysm's anatomy.

A high prevalence of PAA among subjects with screening detected AAA and PAA was found. PAA was not correlated with the aortic diameter in this Swedish cohort, where all had dilated aortas, while correlations with peripheral and iliac artery diameters were identified [6].

A Chochrane Analysis was performed by Joshi et al. to assess the effectiveness of an endovascular stent graft versus conventional open surgery for the treatment of asymptomatic PAAs on primary and assisted patency rates, hospital stay, length of the procedure and local complications [98]. Evidence to determine the effectiveness of endovascular stent graft versus conventional open surgery for the treatment of asymptomatic PAAs was limited to data from only one small randomised clinical trial with a total of 30 PAAs which met the inclusion criteria. At four years there was no clear benefit from either endovascular stent graft or surgery to primary or assisted primary patency (moderate-certainty evidence). As both operating time and hospital stay were reduced in the endovascular group (moderate-certainty evidence), it may represent a viable alternative to open repair of PAA. A large multicenter randomised clinical trial (RCT) may provide more information in the future. However, difficulties in recruiting enough pts are likely, unless it is an international collaboration including a number of high volume vascular centres. Mansour et al. report the outcome of immediate and direct revascularisation by mechanical thrombectomy in acute limb ischemia due to thrombosed PAA [99]. The Indigo System® has proven to be safe and effective, allowing an immediate limb reperfusion, reducing the necessity for thrombolytic drug infusion. A large Medline study by Silvestri et al. focusing on carotid artery aneurysm in HIV pts included 46 cases [100]. Aneurysms were localised in the intracranial carotid (41.3%) or extracranial artery (58%). Pts were managed surgically in 58.7% of cases; surgical morbidity and mortality were of 22.2% and 7.4% respectively, higher for endovascular procedures. The overall mortality in treated and untreated cases was 26.1%. Use of a new double-layer micromeshs stent for endovascular treatment of carotid pseudoaneurysm post carotid endarterectomy is reported by Massara et al., with almost immediate thrombosis of the aneurysmal sac [101]. This allows a less invasive approach in the presence of an adequate anatomy, reducing the risk of cranial nerve injuries.

Vein aneurysms

Noppeney et al. report retrospectively on 39 cases of popliteal vein aneurysm, a condition associated with high risk of venous thromboembolism [102]. Pts were offered aneurysm resection (29 cases) or lifelong anticoagulation and compression (2 cases), when vein diameter was twice the normal vein diameter, while the other 8 pts had surveillance alone. Popliteal vein aneurysms > 20 mm, since more

prone to thrombosis, should be considered for surgical treatment or lifelong anticoagulation, depending on the pt's preference. Iliac vein aneurysm is a rare clinical entity. Following a systematic search, 50 cases of iliac venous aneurysms were identified, located in common, external or internal iliac veins were found in our systematic search. Seventeen pts were female (35.4%) and 31 pts were male (64.6%) [103]. Age ranged from 13 to 70 years. The aneurysms were located on the right side in 17 pts (34%), on the left side in 29 pts (58%) and bilateral in 4 pts (8%). The aneurysms were located in the common, external and internal iliac veins in 15 (30%), 31 (62%) and 4 (8%) pts respectively. The aneurysms were due to a previous arteriovenous fistula (AVF) in 19 pts (38%) and 16 pts (32%) had a history of AVF resulting from a previous trauma. 29 pts (59.2%) underwent open surgical 5 pts (10.2%) endovascular and 1pt (2.0%) hybrid treatment. Conservative treatment was used in 14 pts (28.6%).

Aortoiliac aneurysms and dissections

Since EVAR was first introduced in 1991, it has undergone rapid technical and quantitative developments. Hwang and Jun analyzed the characteristics and trends of EVAR research through bibliometric analysis [104]. The Journal of Vascular Surgery published approximately one quarter of the total publications between 1994 and 2017. Vascular surgeons produced most publications (n = 1,871, 78.14%), followed by radiologists (n = 377, 15.58%) and cardiologists (n = 73, 3.02%). The most studied topics on EVAR were complications and procedures. The number of publications on complex EVAR and EVAR in juxtarenal aneurysm has increased more from 2013 to 2017 (5.1% vs 9.5%) compared with from 1998 to 2002 (2.1% vs 1.8%). Two of the most important publications in this field are the European Association for Cardio-Thoracic Surgery (EACTS) & the European Society for Vascular Surgery (ESVS) Recommendations for the Treatment of Thoracic Aortic Pathologies Involving the Aortic Arch and the actual European Society for Vascular Surgery (ESVS) 2019 Clinical Practice Guidelines on the Management of Abdominal Aorto-iliac Artery Aneurysms by Wanhainen et al., most importantly raising the cut-offs for repair for the abdominal aorta in men to 5.5 cm diameter, in women to 5 cm and in common iliac aneurysms to 3.5 cm diameter [1, 105].

Predicting complications and patient selection: anatomic criteria, age, frailty, obesity and familial aortoiliac aneurysm or dissection

An expert panel made up of 9 Italian vascular surgeons from high-volume centers (>50 EVAR procedures/year), was assembled to share their opinion about the definition of hostile aortic neck anatomy for EVAR procedure. In a Delphi consensus 5 anatomic parameters were identified, namely, aortic neck length, aortic neck angulation, aortic neck diameter, conical neck, and presence of circumferential calcification [106]. Pts with wide proximal necks undergoing standard EVAR in a meta-analysis on 6,602 pts were found to have worse outcome, as indicated by a lower freedom from aneurysm-related reintervention, type Ia endoleak, sac expansion and aneurysm rupture, and a higher overall survival [107]. Particularly the use of large devices of 34–36 mm diameters is associated with a higher risk of proximal fixation failure [108]. There is also a significant increase in operative mortality in pts undergoing EVAR with severely angulated suprarenal neck. Pts who survive the operation are at increased risk of secondary interventions [109].

Likewise, the risk for late distal type I endoleak has been analysed. Common iliac artery length < 4 cm, diameter > 15 mm, and severe thrombotic apposition (>50% of circumference), at the iliac sealing zone were significant predictors of type I endoleak, on univariable analysis; oversizing of the iliac leg diameter < 10% and distal sealing > 1 cm above the hypogastric origin were independently associated with type I endoleak, on multivariable analysis [110].

The outcome of pts with acute type B aortic dissection (TBAD) is largely dictated by whether or not the case is "complicated." The following variables at admission were independently associated with increased in-hospital mortality: hypotension, ischemic complications renal dysfunction, and neutrophil percentage $\geq$ 80% [111]. On the other hand, the readmission rate following medical treatment alone was 23.6% within 90 days, with a mortality rate of 5.0% and high cost involved supporting early repair [112].

While the public preference is clearly for EVAR over open aortic aneurysm repair (OR), frailty and age may be an obvious criteria for this preference [113]. Yet, frailty is an independent risk factor for mortality in open abdominal ortic aneurysm repair, but also the only risk factor for complications following EVAR [114, 115]. Similarly, elderly pts are at higher risk for in-hospital complications after elective EVAR [116–118], however, only with ASA score 4 and PAD comorbidity [119]. Otherwise the overall early mortality may be as low as 2.1% and 2% in > 75-year-old and 80-year-old pts, respectively [120] and lower than in OR [121]. These in-hospital complications have a significant impact on both short- and long-term survival. For ruptured abdominal aortic aneurysm (rAAA) consistently an advantage of EVAR over open repair in the aged population was shown [122, 123]. Interestingly, the 30 day and one year mortality rates for rAAA repair in octogenarians are similar to the outcome at all ages [123]. Similarly, the clinical results of thoracic endovascular aortic aneurysm repair (TEVAR) in pts over 80 years of age are acceptable with early postoperative recovery, low mortality and morbidity, and midterm durability, as shown by Yamauchi T et al. in 57 pts over 80 years of age [124]. No significant difference

was seen in outcomes following debranching thoracic aortic repair [125]. Henstra et al. analysed 272 pts of whom 42 had a median age of 82 years and demonstrated that age itself is not a reason to withhold fenestrated endovascular aortic aneurysm repair (FEVAR) in the elderly, and choice of treatment should be based on the pt's comorbidities and preferences [126]. Yet, perioperative mortality is increased, whereas late mortality is not [127].

Several smaller studies and two analyses of national registries, including 7,935 pts, highlighted the advantages of EVAR over OR of AAA, especially in morbidly obese population (relative risk reduction up to 47%). On the other hand, two other studies with 1,374 pts combined, concluded that EVAR might not have an advantage over OR in obese pts (P = .52). Obesity is an established risk factor for wound infection after both EVAR and OR, which is associated with longer length of stay, subsequent major operations, and a higher rate of graft failure. Percutaneous EVAR technique could present a promising solution to reducing this complication [128]. In a single center study in 492 pts obesity was not a risk factor for negative perioperative or postoperative outcomes after EVAR with the exception of decreased sac shrinkage. Obese pts were less likely to have an endoleak, and overweight pts were protected against all-cause mortality and longer postoperative hospital stays [129].

The Vascular Quality Initiative from 2003 to 2017 comprised 1,997 familial AAA pts compared with 18,185 sporadic AAA pts undergoing open repair and EVAR. This study shows that pts with a familial form of AAA do not have increased morbidity or mortality after AAA repair. The findings suggest that EVAR and OAR are both safe and effective for familial AAA pts [130]. Familial AAA needs to be distinguished from hereditary forms of aortic aneurysms such as Marfan, Ehlers-Danlos and Loeys-Dietz syndrome.

Gender differences in aortoiliac repair

Peri-operative mortality after elective repair of an asymptomatic AAA in the Netherlands (Dutch Surgical Aneurysm Audit 2013–2018, 1,662 women, 9,637 men) is higher in women than in men. This disparity might be explained by the higher peri-operative mortality in women undergoing open surgery, because no such difference was found in pts undergoing EVAR [131]. In contrast, Locham et al. found in the Vascular Quality Initiative (2013–2018, 9,263 open surgery – 73% men and 40,950 EVAR – 81% men), that unfavorable neck anatomy occurs more frequently in women compared to men [132]. Women were also at an increased risk of developing major complications, particularly following EVAR, received more aortic extensions and more contrast volume. Careful pt selection is therefore indicated to reduce complications, with special attention in women with hostile neck. A solution might be aortic endoprostheses dedicated to such hostile necks such as the Ovation platform which proved no difference between sexes for 5-year freedom from endoleaks and overall survival despite substantially more adverse proximal neck characteristics at baseline [133]. Despite more challenging anatomy, female pts in the ENGAGE registry (1,130 males and 133 females) had long-term outcomes comparable to those of male pts. However, female pts experienced higher rates of type IA endoleaks [134]. In a systematic review and meta-analysis of all available studies reporting sex differences after EVAR for infrarenal AAA, Liu Y et al. found that compared with male sex, female sex is associated with an increased risk of 30-day mortality, in-hospital mortality, limb ischaemia, renal complications, cardiac complications, and long-term all-cause mortality after EVAR for infrarenal AAA [135].

In Sweden, of 10,724 pts fewer women with rAAA were admitted to hospital and received surgery and 30-day mortality was higher than in men [136]. Same is true for England according to the Hospital Episode Statistics from 2002–2015 in 15,717 emergency AAA of which 12,767 (62% men) died in hospital without attempting repair, the odds ratio for women vs. men was 2.8 [137]. In 3,719 open and EVAR cases (21% women) Wang et al. found that nearly half of rAAA pts have a door-to-intervention time longer than recommended in societal guidelines, however, admission-to-intervention time was 1.5 versus only 1.2 hours for men [138]. Sex differences in mortality were no longer observed in pts with intervention delays of $\leq$ 90 minutes. In pts with > 90-minute delays, a 77% increase in 30-day mortality of women over men was noted. Thus, sex differences in mortality after rAAA repair seem to be driven by in-hospital treatment delays. In Japan (7,086 pats, 32.3% women) a univariate analysis demonstrated that female pts with rAA showed worse mortality than men because of their older age, more severe clinical presentation, and low emergency operation rate. However, after adjustment for covariates, female sex itself was not associated with increased mortality [139].

Female sex in the American College of Surgeons National Surgical Quality Improvement Program (1,010 open repair – 30.7% females and 1,260 EVARs – 21.4% females) is associated with higher perioperative mortality and more major complications than for male pts after complex EVAR (juxtarenal, pararenal, or suprarenal) but not after complex open repair [140]. Also, women have a persistent elevated perioperative mortality in women (16%) undergoing endovascular thoracoabdominal aortic aneurysm (TAAA) repair compared with matched men (6%) due to differences in comorbidities, aneurysm extent, and aneurysm size [141]. Worse in-hospital and long-term survival compared to males may also relate to the impact of anatomy on outcome disparities [142].

In a meta-analysis of 7 studies from 2005–2019 for the management of intact descending aortic aneurysms, analysis of 2,758 women and 4,674 men demonstrated that 30 day mortality after TEVAR appears to be much higher in women than men with no reasons for this difference identified [143].

Aortic intervention in aortitis and graft Infection

Connective tissue disease (CTD) represents a group of genetic conditions characterized by disruptive matrix remodeling. When this process involves aortic and vascular wall, pts with CTD have a high risk of developing arterial aneurysms, dissections and ruptures. Open surgical repair is still the gold standard therapy for pts with CTD with reasonable morbidity and mortality risk. The surgical treatment of CTD often requires multiple operations. In the endovascular era, fenestrated and branched stent grafts may play a role in reducing the complications of multiple open operations. Although the long-term results of endovascular treatment in the setting of CTD are unknown, it is generally accepted that endovascular treatment is restricted to selected pts with high surgical risk. In an emergency setting, endovascular intervention can serve as a lifesaving bridge to elective OR. Aortic centers performing a large volume of complex OR and EVARs have started to combine these two techniques in a staged fashion. The goal is to reduce the morbidity and mortality associated with extensive aortic repairs in CTD pts. For this reason, recommend endovascular therapy when a "graft-to-graft" approach is possible. In this scenario, the surgeon who performs the open repair must take into consideration future interventions [144].

Surgery in pts with inflammatory abdominal aortic aneurysms is associated with a substantial amount of perioperative complications and re-interventions (9.7%). After surgery, the perianeurysmal inflammation decreases in most pts on follow-up CT. However, because the inflammatory process does not totally resolve, pts require lifelong surveillance for hydroureteronephrosis and development of aortoenteric fistulas [145]. Medical therapy for mycotic aortic aneurysms (MAA) is almost universally fatal, while surgical and endovascular repair carry high morbidity and mortality. Endovascular repair of mycotic aortic aneurysms was associated with the best long-term survival and lowest perioperative complication rate, although it is associated with greater reinfection. These tradeoffs should be considered when selecting which procedure is best for a pt [146]. A systematic review of the literature of mainly small, retrospective single centre studies concluded that EVAR appears to be associated with superior short-term survival without late disadvantages, compared with open surgery. This suggests that EVAR can be an acceptable alternative to open surgery [147]. 52 pts treated in Sweden for thoracic MAAs between 2000 and 2016 were identified in the Swedish vascular registry (2010–16) and local pt registries (2000–09). TEVAR was often used as treatment for thoraic MAAs, with acceptable short- and long-term survival when compared with open cohorts in the literature. Infection-related complications are of concern and warrant follow up and long-term antibiotic treatment [148]. Infected abdominal aortic aneurysm is rare, and information is limited whether endovascular aortic repair (EVAR) can be considered a permanent treatment or is a temporary fix preceding open surgery. In a series of 19 pts, elective EVAR for infected AAA had acceptable short- and long-term outcomes. Pts' response to initial antibiotic treatment may help facilitate management. A lack of reduction in erythrocyte sedimentation rate during the first week of antibiotic treatment may indicate risk of aneurysm rupture [149]. In a retrospective analysis of incidence, risk factors, and management of postoperative stent graft infection in 1,202 pts. After EVAR stent graft infection occurred in 15 cases during a mean follow-up of 43.9 ± 30.4 months. The median time between initial EVAR and detection of infection was 30 months (range, 14 days–86 months). Concomitant coil embolization was a risk factor for stent graft infection. For pts with aorto-enteric fistula, surgical therapy remains the first-line treatment of stent graft infection after EVAR; however, conservative therapy is a viable option for stent graft infection in pts without aorto-enteric fistula, particularly considering pts' comorbidities and limited life expectancy.

Computer-assisted aortic interventions

Different applications of the use of 3D printing and digital imaging in vascular surgery have been experimented with a different maturity level. Early experimentations show that these technologies have the potential to radically change the vascular surgery practice in the near future, in particular in treatment like EVAR, to improve the planning and therefore the success of the surgery [150]. Particularly, the numerical model of deployed fenestrated stent grafts is accurate for planning position of fenestrations – also for physician-modified grafts. It has been validated in 51 pts, for whom fenestration locations were similar to the sizing performed by physicians and the planning centre [151, 152]. During the procedures, image fusion (IF) technology using a three-dimensional (3D) IF computed tomography system/onlay fusion and cone beam computed tomography or angionavigation station in the hybrid operating room helps reduce contrast medium volume, fluoroscopy time, and procedure time in complex endovascular aortic repairs such as hybrid procedures, fenestrations and branches [153–155].

Novel strategies

Low exercise capacity preoperatively leads to increased postoperative complications, perioperative mortality, length of stay, and inpatient costs among pts going through elective AAA surgery. Kato et al. suggested that exercise training among AAA pts is generally safe, although future research should be carried out to further clarify the safety among pts with large AAAs [156]. Exercise training improved peak oxygen consumption and anaerobic threshold in AAA pts.

The majority of EVAR procedures are performed through the common femoral artery. Arterial access is gained by surgical cutdown or percutaneous approach. Whereas the

percutaneous approach demonstrated good long-term results using large bore devices such as Proglide or the lately developped MANTA large bore device with careful pt and device selection [157–160], the surgical approach has a relatively high local complication rate. The use of ProGlide for arterial repair was particularly associated with significantly lower transfusion rates, shorter index hospitalization and lower hospitalization costs compared with surgical cutdown as well as reduced pain and improved wound healing [161, 162]. Agrusa et al. used the Proglide device also for the axillary access during complex aortic interventions with high rates of safety and technical success [163]. Overall complication rates are low and occurred mainly during the early experience, indicating that there is an associated learning curve effect. Elimination of surgical cutdown incisions and arterial conduits by using percutaneous axillary access may reduce operative times and wound-related complications during complex aortic interventions requiring large-bore upper extremity access.

Avraham et al. demonstrated in 87 pts that femoral artery approach is easier to perform and has a lower complication rate compared with the common femoral artery approach [164]. During the procedure, there was particularly no dissection or damage to arterial branches, especially to the deep femoral artery.

Massiv calcifications of iliac arteries with consequent stenoses may be a contraindication for aortic endoprostheses. Rosseel et al. report the first-in-man use of intravascular iliac artery lithotripsy to enable transfemoral thoracic endovascular aortic repair [165].

Fereydooni et al. demonstrated that bifurcated unibody aortic endografts can overcome unfavorable aortoiliac anatomy for deployment of unilateral, but also even bilateral iliac branch endoprostheses [166]. Anatomic constraints are inadequate renal artery to iliac bifurcation lengths and unfavorable aortic anatomy such as distal aortic stenosis with diameters below the instructions for use (IFU) of other biiliac prostheses. Also, a transbrachial approach for the implantation of a second iliac bifurcation prostheses may not be necessary in pts with bilateral iliaca aneurysms requiring endografting.

Many efforts have been undertaken to achieve sufficient sealing for AAA. The Nellix endovascular aneurysm sealing system aimed at the complete sac filling using endobags. Choo et al. report Type I endoleak, sac enlargement, device migration, and aneurysm rupture as complications [167]. In the meantime, the device has been removed from the market. Reyes Valdivia et al. demonstrated that the suitability of EVAR of rAAA can be expanded by combining the Endurant stent-graft with the Heli-FX EndoAnchors and Galinanes et al. used such EndoAnchors to minimize endoleaks in chimney-graft endovascular repair of juxtarenal AAA [168, 169]. However, Goudeketting revealed that almost 30% of EndoAnchors had been maldeployed outside of the recommended use [170]. And if endoleaks are due to > 2-mm gaps, EndoAnchor implants alone may not provide the intended sealing, and additional devices should be considered.

Another possibility newly described is the use of an Ovation low-profile stent graft with a polymer ring sealing technology [171] which revealed an aneurysm-related 5 year-mortality of only 99.3% and freedom of endoleak type Ia at 5 years of 95.8% in 1,296 pts analysed from the ENCORE database [172]. Half of the pts had complex anatomies. It may be even implantated very near to the offspring of renal arteries combined with bare renal stents for the renal arteries (vent technique) in pts with juxtarenal aneurysm not eligible for open surgery and fenestrated endograft [173]. Also, the Treovance stent graft has been recently developed to meet the requirements of hostile neck angulation [174].

If time allows, fenestrated or branched endoprostheses are more favourable. Early and intermediate results support the safety and feasibility of the off-the-shelf Zenith p-Branch device which has become available recently [175]. However, follow-up examinations through 5 years will continue to assess the long-term results. Up to 7 branches have been described in case of variants of visceral arteries [176]. Physician-modified fenestrated stent grafts (PMSGs) are a useful option for urgent or semiurgent treatment of complex abdominal aortic aneurysms. However, Senemaud et al. report higher mortality, spinal cord ischemia (SCI) and reintervention rates for PMSGs compared with custom-made devices of the company Cook [177]. Recently, also combinations of fenestrated-branched protheses became popular. Oderich et al. observed an evolution from physician-modified to now predominantly company-manufactured fenestrated-branched endografts to treat pararenal and TAAAs [178]. Preloaded catheters and guide-wire systems facilitate catheterization during FEVAR and branched EVAR (BEVAR) [179].

Directional branches were associated with high technical success and low rates of stent occlusion, independent of stent type. However, primary patency, freedom from target artery instability and freedom from type IC or type IIIC endoleaks was lower for balloon-expandable stent grafts compared with self-expandable stent grafts [180]. Gibello et al. performed a systematic review to analyze the results of currently used balloon expandable bridging stent-grafts and to evaluate the newest developments for FEVAR in juxtarenal endovascular repair [181]. They concluded that the ideal bridging stent-graft is far to be designed. In the meantime, new bridging stentgrafts became available for such procedures. Gallitto et al. describe the first and favourable experience of Gore Viabahn balloon-expandable endoprosthesis as bridging stent in F/BEVAR, Gennai et al. and Caradu et al. describe the use of the Covera stent-graft [182–184]. Torsello et al. tested the use of BeGraft and BeGraft + in an in vitro study and reported superiority of the BeGraft + in terms of pullout, shear stress and resilience [185]. Literature review by Mazzaccaro et al. demonstrated that the use of steerable sheaths and catheters was reported as effective and safe for the cannulation of 157 target vessels

in 131 endovascular procedures, with a success rate of 95.5% and no complications [186]. It may be helpful in cases with failing attempts of cannulation e.g. a severely angulated or stenosed ostium of the vessel.

If none of endovascular techniques are suitable in complex TAAA, hybrid TAA repair using the new and improved SPIDER-graft may be an option. In a pig model, improved visceral and spinal cord perfusion was shown during the procedure, avoiding extracorporeal circulation and thoracotomy [187].

For standard TEVAR the Gore C-TAG with active control system now offers more accurate deployment both at the proximal and at the distal levels as reported by Antonello et al. [188]. The conformability, staged deployment with no need of rapid pacing, and angulation control allow good adaptation to aortic arch and precise deployment, particularly in steep aortic arches. If a low-profile device is needed in access arteries of diameters 7 mm or less, the RealyPro thoracic stent graft showed good initial performance [189]. If no iliofemoral or aortic access was possible, an antegrade approach via the ascending aorta was used in 16 selected pts with a mortality of 12.5% [190].

For pts with insuffucient proximal landing zones some off-the-shelf devices were developed. However, in one case, only 28% of pts with TBAD who required zone 2 TEVAR met all the anatomic requirements for a single branch device [191]. Tsilimparis et al. investigated the early outcomes of branched thoracic endovascular aortic repair (B-TEVAR) in various types of disease of the aortic arch [192]. All 54 pts were treated with a custom-made inner branched arch endograft with two internal branches (Cook Medical) and left-sided carotid-subclavian bypass. Treatment was reported feasible and safe with acceptable 30-day mortality of 5.5% and stroke rates (5.5%). In the emergency situation B-TEVAR with stentgrafts either already available for the pt or from another pt with similar anatomy resulted in a 30-day mortality of only 9% and major stroke rate of 9% [193].

Most of current publications, however, report the successful use of PMSG with either just one fenestration for the left subclavian artery [194, 195] or preserving more or all supra-aortic branches [196–201]. Comparison to Chimney procedures found in situ fenestrations more favourable [202].

For acute type A aortic dissections (TAAD), a new paradigm has been proposed by Matalanis to avoid the frequent secondary interventions in those pts in whom only repair of the ascending aorta was conducted: instead a total aortic repair technique for acute TAAD consisting of "branch first" total arch repair, followed by thoracoabdominal stenting and balloon rupture of the septum. Such total aortic repair technique ensures that the aortic valve, ascending aorta, and arch are surgically securely repaired, and provides complete decompression of the false lumen as well as internal support in the remainder of the aorta. This has provided excellent early results and will hopefully minimize future complications and interventions.

One such procedure following initial repair of the ascending aorta is the STABILISE technique with stent-assisted balloon-induced intimal disruption and relamination of aortic dissection (AD) to improve their long-term outcomes in terms of aortic-related events [203]. Others comprise the use of homemade Candy Plugs [204], Candy Plug II [205, 206], Coils and vascular plugs [207]. A systematic review of the literature on the intentional targeted false lumen occlusion after AD of Spanos et al. revealed that intentional false lumen occlusion seems to be a feasible less invasive approach after TAAD or TBAD treatment, which is not broadly used [208]. Four main techniques were used in 101 pts: (1) the candy-plug (19/101), (2) the knickerbocker (3/91), (3) the "cork in the bottle neck" technique (2/101), and (4) false lumen embolisation with combined use of coils, onyx, plugs, and glue (77/101). The technical success rate was 100%, with a 30-day mortality rate of 2.5% (1/40) in TAAD and 0% in TBAD pts. The false lumen remained completely thrombosed in 78% (31/40) of TAAD and 62% (38/61) of TBAD pts, whereas it was partially thrombosed in 3 and 2 pts, respectively (no report for 22 pts).

One report also demonstrated successful ascending aortic stent placement to be feasible and is associated with favorable aortic remodeling. Despite persistent perfusion to the false lumen in a subset of pts, there is minimal aortic dilation at short-term follow-up with excellent survival. (n = 13, [209]). Another report demonstrated feasibility of endovascular repair of retrograde TAAD (n = 31, [210]).

Cerebral injury and stroke from air embolism during TEVAR was adressed in a novel approach. The amount of gas released from thoracic stent-grafts during deployment can be influenced by different flushing techniques. The use of perfluorocarbon in addition to the carbon dioxide flushing technique reduces the volume of gas released during deployment of tubular thoracic stent-grafts to a few microliters [211].

Large trials, meta-analyses, databases and registries on outcomes

Several AAA screening programs have demonstrated a similar prevalence of this disease in Westerns countries, ranging from 1.2% to 2.8%. Review of the literature and national databases from 2010 until 2018 revealed a nearly eightfold variance between the countries with the highest and lowest rates of elective repair, lowest in Hungary with 2.2 and highest with 17.3 per 100,000 habitants in Germany. The yearly rate of ruptured AAA also varied enourmously between 0.5 in Hungary and 3.3 in Denmark [212]. Reasons are unknown. Interestingly, at population level, high EVAR rates had no measurable effect compared with lower EVAR rates on the outcomes in pts with intact AAA in a multicentre cohort study based on local and national registry data from an area of 815,000 inhabitants. The study involved 527 consecutive pts with an intact AAA treated with EVAR

(n = 327) or open repair (n = 200) between 2010 and 2016 [213]. However, providing aortic repair in emergency situations may save lives: England and US hospitals differ in the threshold for surgical intervention, which may be associated with increases in mortality in England for rAAA (odds ratio 1.34) and AD (odds ratio 1.67) with a larger proportion of pts not receiving surgical interventions (ruptured AAA odds ratio 4.25 and AD odds ratio 1.55) [214].

Outcomes after rAAA repair are associated with hospital volume among pts undergoing rOR but not among pts undergoing rEVAR. Thus, centralization of care may have an important impact on outcomes when OR is indicated, suggesting a benefit for preoperative interfacility transfer of care when it is feasible [215]. The reason may be the decreasing frequency of OR compared to EVAR in Europe. In contrast, an analysis of the American College of Surgeons' National Quality Improvement Program (NSQIP) database between 2008 and 2016 (43,105 AAAs, 34,177 (79.28%) EVAR, and 8,928 (20.71%) open rerair revealed a lagging use of endovascular repair of ruptured AAA in the USA [216]. There were 3,806 ruptured AAAs, 1,843 (48.42%) treated by EVAR, and 1,963 (51.58%) treated by open repair. Thus, the incidence of rEVAR lagged behind EVAR considerably. Mortality for rOR was 575 (29.29%) and 344 (18.66%) for rEVAR. No difference between the ratio of men and women in rOR versus rEVAR was noted. There was a significant increase in mortality for women versus men undergoing rEVAR (P = .0362). No difference in mortality existed between women versus men undergoing rOR (P = .0639). There was no difference in the percentage of hypotensive cases undergoing rEVAR versus rOR (P = .1873). For all rAAAs with hypotension, rOR had an increased mortality compared to rEVAR (P = .0004). There were 20 (3.11%) rEVAR and 40 (8.00%) rOR cases with lower extremity ischemia. rOR conferred a significant increase in lower extremity ischemia (P = .0002). There were 46 (7.15%) rEVAR and 60 (12.00%) rOR cases of ischemic colitis. rOR had a significant increase in ischemic colitis (P = .0052). Yet, the Cleveland Clinic Foundation database revealed that Despite the increasing anatomic and operative complexity of pts undergoing open repair of rAAAs, perioperative mortality and late aneurysm-related mortality have improved over time [217].

There is an enormous regional variability of EVAR resulting in highly variable outcomes in Germany. 31,757 procedures for intact AAA of German Federal Statistical Office from 2012 to 2014 were analysed. The mean proportion of EVAR procedures was 72.6%; however, the application of EVAR for repair of intact AAA varied widely depending on region: the lowest unadjusted regional rate of EVAR use was 48.8%, while the highest was 92.5%. Overall in-hospital mortality was 2.9% (OAR 6.2%; EVAR 1.7%) [218]. The influence of precedural volumes was also confirmed by Scali et al. (Vizient database, 3,449 pts) and the analysis of the Australasian Vascular Audit database of 14,262 aneurysm repair procedures between 2010 and 2016 [219]. There was an inverse correlation between both surgeon volume of open aortic aneurysm repair, hospital volume of thoracic EVAR and in hospital mortality. These findings suggest that in Australia TEVAR should be performed by high volume hospitals and OSR by high volume surgeons [220]. Esce et al. analysed 11,086 intact AAA repair s between 2000 and 2008 using the New York Statewide Planning and Research Cooperative System inpatient database and determined 6 cases per year as the threshold to achieve the improved mortality of a high volume center [221]. However, even a minimum annual threshold of at least two repairs per year provided a mortality benefit. Similarly, Locham et al. demonstrated using the Vascular Quality Initiative (VQI) database (2012–2018) with 2,115 pts from 118 centers a significantly lower morbidity and mortality in high volume hospitals performing complex EVAR for TAAA, despite operating on older pts with more complex TAAA types [222]. This is likely due to better rescue phenomenon in addition to more experienced operators.

Although the 30-day mortality remains similar, but postoperative complications in EVAR have decreased significantly during the recent decade, as shown in an analysis of pts who underwent EVAR for intact AAA between 2006 and 2015 were identified from the National Surgical Quality Improvement Program and divided into early (2006–2010) and late (2011–2015) periods. A total of 30,076 pts were identified, with 11,539 in the early period and 18,537 in the late period. The continuous improvement in endograft technology and surgical skills has resulted in decreased operative time, marked reduction in surgical complications, and shorter hospital length of stay after endovascular repair [223]. Zarkowsky found a similar result analysing 20,853 pts receiving EVAR between 2003 and 2017 contained within the VQI data [224].

Perioperative complications, although rare, can occur after EVAR, contributing to longer hospitalisation, higher cost, and significant comorbidity and mortality. Therefore, an exploration of 28,240 pts of the VQI database from 2003 to 2017 identified the predictors of in-hospital events (IHEs) after elective EVAR [225]. A total of 28,240 pts with full information about IHEs were included. Any IHE took place in 2365 (8.4%) pts. Pts who had an IHE were slightly older (mean age ± standard deviation, 75.6 ± 8.1 years vs. 73.3 ± 8.5 years; P < .001). A higher proportion of women had an IHE (25.6% vs. 17.9%; P < .001). Comorbid conditions were more prevalent in pts who developed an IHE (chronic kidney disease, 49.1% vs. 33.2%; coronary artery disease, 34.3% vs. 29.0%; moderate to severe cardiac heart failure, 3.9% vs. 1.4%; chronic obstructive pulmonary disease, 42.5% vs. 31.9%; hypertension, 87.0% vs. 83.1%; and diabetes, 18.0% vs. 16.1%; all P $\leq$ .015). An IHE was associated with high in-hospital (5.6% vs. 0.03%) and 30-day mortality (6.3% vs 0.3%; both P < .001) and worse 3-year survival beyond the perioperative period (81.1% vs 91.1%; P < .001). The selected predictors of IHEs were female sex, moderate or severe cardiac heart failure, chronic kidney disease, coronary artery disease, chronic obstructive pulmonary disease, hypertension, and aneurysm

diameter. Intraoperative factors were contrast material volume, operative time, and packed red blood cell transfusion. The risk of postoperative myocardial infarction is particularly increased for those who are older, who present with a ruptured AAA, who have pneumonia, who have unplanned intubation, and who have prolonged hospital stay revealed an analysis of 7,702 pts between 2011 and 2015 [226]. And the risk factor most associated with 30-day readmission after elective AAA repair was surgical site infection [227] and cardiac complications (138,014 pts, United States Nationwide Readmission Database from 2010 to 2014) [228]. Despite these events, EVAR is cost-effective with improved cost per Quality Adjusted Life Years (QALY) compared with open surgical repair [229]. And long-term overall survival rates were similar for EVAR and open repair over 10 years in a meta-analysis of 53 studies [230] which was confirmed in a retrospective, population-based cohort study used linked administrative health data from Ontario, Canada, of 17,683 elective EVARs [231]. EVAR reduces early mortality in the subgroup of pts older than 73.5 years. In pts younger than 73.5 years with a low to moderate surgical risk, EVAR offers no advantage over open repair and therefore should not be regarded as the treatment of choice [232]. Reintervention rates are high for EVARs, more than one in five Medicare pts (12,911 pts) undergo reintervention within 5 years after EVAR in the VQI; late rupture remains low at 3%. Black pts, those with large aneurysms, and those who undergo EVAR urgently and emergently have a higher likelihood of adverse outcomes [233].

Weekend repairs of ruptured aortic aneurysms are associated with significantly worse in-hospital survival compared with weekday surgery. Endovascular repair of TAA or TAAA ruptures is associated with worse in-hospital survival compared with EVAR of rAAA [234]. A Japanese nationwide observational study of 8,302 pts between 2012 and 2015 showed that in hospital outcomes for EVAR vs. open repair were more favourable for ruptured dissected TAA and comparable for rAAA. EVAR resulted in an equivalently favourable functional status at discharge and significantly shorter hospital stays [235].

Long-term survival following successful AAA repair evaluated using Australian administrative data following elective, ruptured OR and EVAR of 2,060 pts were 10.4, 8.5 and 9.7 years, respectively [236]. Long-term survival rates were similar for open repair and EVAR in age groups 65–84 years (EVAR/OR range 0.96–1.16); however, EVAR was superior to OR in persons aged > 85 years at 5 years (EVAR/OR 1.32, log-rank $P < 0.05$). Johal et al. analysed 37,139 pts of the English National Health Service between January 2006 and December 2015 identified from Hospital Episode Statistics data who underwent elective AAA repair, of which 15,523 were open and 21,615 were endovascular [237]. The 10-year mortality rate was 38.1% for pts aged under 70 years, and the survival trajectories for OR and EVAR were similar when pts had no Royal College of Surgeons-modified Charlson co-morbidity. Among older pts or those with co-morbidity, the 10-year mortality rate rose, exceeding 70 per cent for pts aged 80 years. Mean survival times over 10 years for open repair and EVAR were often similar in subgroups of older and more co-morbid pts, but their survival trajectories became increasingly dissimilar, with open repair showing greater short-term risk within 6 months but lower 10-year mortality rates. The risk of rupture over 9 years was 3.4% for EVAR and 0.9% for open repair, supporting surveillance programs post-EVAR.

Perioperative clinical outcomes in using local/regional anaesthesia (LA/RA) or general anaesthesia (GA) in pts undergoing nonemergency EVAR was evaluated in a comprehensive electronic literature search was undertaken from inception to September 2018, identifying all randomised and nonrandomised studies comparing LA/RA versus GA. A total of 12,024 pts (n = 1,664 LA/RA, n = 10,360 GA) were analysed from 12 observational studies included in this analysis. Use of LA/RA in selective EVAR procedures provides satisfactory and comparable perioperative outcomes with those of GA, with the advantage of a shorter hospital stay (3.6 ± 3.3 d vs. 4.6 ± 5 d; $p = 0.002$) [238]. This was particularly true using a fast-track EVAR protocol using a 14 French stentgraft which resulted in shorter procedure time, lower intensive care utilization, faster discharge, lower incidence of majpr adverse events, lower readmission rates, and lower perioperative costs compared to standard EVAR [239]. The UK National Vascular Registry revealed in 795 emergency EVARs treated in 56 hospitals that the use of LA for EVAR of rAAA has been adopted widely in the UK and mortality rates appear also in the emergency situation lower than in pts undergoing EVAR with GA (59 of 319 (18.5%) versus 122 of 435 (28.0%) [240]. This is consistent with the findings of the Vascular Quality Initiative database at 30 days (15.5% vs. 23.3%; P = .04) and at 1 year (22.5% vs. 32.3%; P = .02) [241].

Among 2,478 pts undergoing elective AAA repair between 2008 and 2014, approximately one in six had postoperative hyperglycemia. After AAA repair in pts with and without diabetes, postoperative hyperglycemia was associated with adverse events, including in-hospital mortality and infections. Compared with those who had open surgery, pts undergoing endovascular repair who had postoperative hyperglycemia had greater risk of infection and death. After controlling for insulin administration and postoperative hyperglycemia, a diabetes diagnosis was associated with lower odds of both infection and in-hospital mortality [242]. Epidemiological data indicate decreased risk for development and growth of AAA among pts with DM. On the other hand, DM adds to increased cardiovascular (CV) morbidity and mortality. In a nationwide observational cohort study of pts (748 with and 2,630 pts without DM) registered in the Swedish Vascular Register and the Swedish National Diabetes Register, pts with DM had higher rates of acute myocardial infarction and lower need for reintervention after elective EVAR than those without DM, whereas neither total nor CV mortality differed between groups. The putative protective effects of DM towards further AAA enlargement and late sac rupture

may help explain the lower need for reintervention and absence of excess mortality [243]. A meta-analysis of the literature even demonstrated a higher long-term mortality in diabetic pts following AAA repair [244].

The association between socioeconomic status (SES) and outcome after AAA repair is largely unknown. Thirty-day postoperative mortality and long-term mortality were documented through medical record review and the Michigan Social Security Death Index. SES was quantified in 767 pts between 1993 and 2013 using the neighborhood deprivation index, which is a standardised and reproducible index used in research that summarizes eight domains of socioeconomic deprivation. Long-term mortality was significantly associated with low SES [245].

Using the National Surgical Quality Initiative Program Database (2012–2016; 1,191 pts, open (72%) or endovascular (FEVAR: 14%, ChEVAR: 14%)), a 2- to 5-folds higher mortality and morbidity was found in pts undergoing OR versus EVAR of AAA involving the renal vessels. EVAR seems to be a safer approach, especially when managing older pts with AAA [246]. A systematic review and meta-analysis of endovascular juxtarenal aortic aneurysm repair also demonstrated lower 30-day mortality, acute renal failure, bowel ischemia, and length of stay but with increased SCI compared with OR. In this analysis the endovascular interventions included short-neck standard EVAR, parallel grafts, and F/BEVAR [247]. Among them, FEVAR should be considered as a first option 1, due to their reported safety and efficacy in the VQI among others [248–250]. In a systematic review of 30 studies including 23,385 pats of whom 2,271 pts were treated with FEVAR for pararenal/juxtarenal AAA, the pooled early mortality reached 2.55% (ranging from 0% to 6.74%), with a pooled technical success of 96.8% (ranging from 82.8% to 100%) [251]. In a multivariate analysis, early mortality was associated with procedure time (HR, 1.007 per minute; P < .001), TAAA preoperative diameter (HR, 1.053 per millimeter; P = .001), and chronic kidney disease (HR, 3.139; P = .007) [252]. For better long-term results 4 fenestrations have become the standard of care and, although, pts who needed superior mesenteric artery (SMA) or celiac trunc incorporation with stents during F/BEVAR for aortic repair had more complex procedures, as assessed by operative time, brachial access, number of vessels incorporated, and spinal drain use, the extension of the repair did not affect the outcomes, demonstrated by similar mortality and morbidity rates between groups [253]. In real-world application perioperative morbidity appears to be higher after chimney/snorkelrepair. However, when the anatomy is not favorable or when FEVAR devices are not available in an emergency setting for instance, other alternatives can be considered like parallel graft or chimney technique (ChEVAR). If chimney technique is needed, oversising of ideally 30% of the Endurant stent-graft is associated with significant lower incidence of type IA endoleaks requiring reintervention for pts treated by ChEVAR as found in the PERICLES registry [254].

Meta-analysis of fenestrated EVAR versus OR of juxtarenal AAA over the last 10 years revealed in 2,974 pts no significant difference in 30-day mortality; however, FEVAR was associated with significantly lower morbidity than OR. Long-term durability is a concern, with far higher reintervention rates after FEVAR (11.1% vs. 2.0%) [255]. Using the Zenith fenestrated endovascular graft lower perioperative mortality has been reported comparable to those of infrarenal EVAR [256]. And a systematic review of contemporary outcomes of endovascular and open TAAA repair between 2006 and 2018 revealed that endovascular repair studies included pts with more comorbidities and were associated with higher rates of SCI but similar rates of permanent paraplegia, whereas OR studies had higher rates of postoperative dialysis but similar rates of being discharged on permanent dialysis. Perioperative mortality rates were similar [257]. In contrast, data from the German Federal Statistical Office investigating 2,607 cases of ruptured and non-ruptured TAAA In hospital mortality is lower with endovascular repair and in high volume centres [258]. This demonstrates that complex endovascular repair is a highly technical procedure that requires vast experience [259].

A meta-analysis of 14,580 pts were analyzed in total of 13 articles shows that endovascular repair of TAA gives better perioperative outcomes during inhospital stay although the 1- and 5-year mortality remains the same in both groups [260]. Endovascular management of pts with TBAD results in good long-term survival compared with medical treatment even in the presence of features traditionally associated with adverse outcomes. At one and five years, overall survival was 94.0% and 74.8%, respectively, and freedom from aortic events was 75.6% and 58.7%. All pts require close lifetime surveillance as aortic events continue to occur during follow up even after endografting [261].

In a comprehensive review and meta-analysis of 39 studies Boufi et al. compared outcomes of endovascular repair versus OR in chronic TBAD treatment [262]. Endovascular repair was associated with significant early benefits, but this was not sustained at midterm. Reintervention was more frequent, but the OR is not exempt from reintervention or late rupture. Thirty-day outcomes from the Society for Vascular Surgery Vascular Quality Initiative TEVAR for TBAD project on 397 pts from 40 institutions demonstrated as expected for acute AD pts a trend toward a higher 30-day mortality and lower freedom from reintervention compared with chronic dissection pts (9.3% vs. 5.2%). Mortality at 30 days after TEVAR for uncomplicated AD was 5.8%, and there were no clear patterns in mortality or reintervention based on timing of treatment [263]. Lower mortality was confirmed by the meta-analysis of 18,193 pts by Harky et al. for acute type B thoracic AD, OR compared with endovascular repair [264]. The all-cause operative and 1-year death rate was reported as higher in the OR group (18.6% vs. 7.4%, P < .0001 and 24.3% vs. 14.3%, P < .0001, respectively). Analysis of the literature data between 2006 and 2016 demonstrated that

the PETTICOAT technique is safe and feasible but also is able to enhance the effect of the proximal TEVAR improving the re-expansion of the true lumen of the distal thoracoabdominal aorta possibly improving end-organ perfusion. However, Bertoglio et al. conclude that since there is no evidence of improved short and mid-term survival as well as positive remodeling of the false lumen in the distal aorta, when compared to a simple proximal stent-grafting, a widespread use of the PETTICOAT technique is not justified and it should be limited to cases complicated by dynamic malperfusion as a bailout adjunctive tool [265]. Canaud et al. identified in a systemic review of 7 articles and 1,415 pts excessive distal oversizing as a risk factor of distal stent graft-induced new entry in ADs [266]. It is relatively frequent and can generally be treated with additional TEVAR without a poor outcome. Short and mid-term outcomes in the study of Ding et al. comprising 159 pts demonstrated that the chimney technique is safe and feasible for preservation of the left subclavian artery (LSA) in pts with TBAD, but the durability of chimney stent needs to be evaluated carefully and immediate type Ia endoleak is a concern [267]. Tenorio et al. analysed the outcomes of F/BEVAR for treatment of postdissection and degenerative TAAAs and found nearly identical outcomes [268].

Acute AD pts with primary entry tear in the arch are currently managed by a patient-specific approach. In choosing the management type of these pts, it may be advisable to stratify them based on retrograde or only antegrade extension of the dissection. Management for both groups (arch A (n = 228) and arch B (n = 140)) in the International Registry of Acute AD were OR (77.6% vs. 18.6%; P < .001), endovascular treatment (3.5% vs. 25.0%; P < .001), and medical management (16.2% vs. 51.4%; P < .001). Overall in-hospital mortality was similar (16.7% vs. 19.3%; P = .574), but mortality tended to be lower in the arch A group after OR (15.3% vs. 30.8%; P = .090), and higher after endovascular (25.0% vs. 14.3%; P = .597) or medical treatment (24.3% vs. 13.9%; P = .191), although the differences were not significant [269]. If debranching is needed in such cases, Konstantinou et al. revealed that cervical debranching procedures showed not only excellent patency rates, but also a significant rate of local complications [270]. Carotid-subclavian bypass appeared to be safer with significantly fewer postoperative complications. Staged hybrid procedures also seemed to be safer.

Iliac branch devices (IBDs) have been increasingly reported for treating aortoiliac aneurysms. In a systematic review and meta-analysis 21 studies with a total of 1,064 pts met the inclusion criteria and were selected for analysis. The pooled technical success rate of IBD was 93%. After pts were treated with the IBD, the 30-day mortality rate was 2%, 30-day patency rate was 93%, follow-up patency was 86%, endoleak rate was 12%, buttock claudication rate was 6%, and IBD-associated reintervention rate was 11% [271]. Also the NSQIP vascular aneurysm specific Participant User Files (2012–2016) comprising 593 pts revealed that OR was associated with higher rate of major complications (65.5% vs. IBD: 8.8% and coil&cover: 13.6%, P = <.001) and higher mortality (3.6% vs. IBD: .7% and coil&cover: 0%, P = .017). IBD pts had significantly shorter total operative time and total and intensive care unit length of stay. After adjustment, OR was associated with higher major complications compared with IBD (odds ratio: 11.3, P < .001), primarily because of the use of transfusions (major complications excluding transfusions OR: 1.3, P = .52) [272]. In the wide real-world pELVIS study, long-term results of endovascular treatment of aortoiliac aneurysms with the IBD are favourable, with a low rate of late graft occlusion and aneurysm-related death. No significant differences in clinical outcomes were observed in pts receiving hypogastric balloon-expanding versus self-expanding stentgrafts or endovascular relining [273]. Coexisting hypogastric aneurysms significantly worsen the outcomes of endovascular treatment by the iliac branch devices within the pELVIS Registry. Lengthening the distal landing zone with more than one bridging stent graft into the distal healthy hypogastric artery or one of its main branches improves [274].

Isolated iliac artery aneurysm is uncommon and is frequently treated by EVAR. Treatment included various endovascular modalities in part also involving the distal aorta as well as OR. Regular surveillance is still needed due to aortic dilatation after its treatment [275]. Whereas bilateral occlusion of the hypogastric artery may lead to ischaemic colitis, inferior mesenteric artery replantation does not decrease the risk of ischemic colitis after open infrarenal AAA repair [276].

Neurological complications including spinal cord injury

In a large cohort of 17,689 elective endovascular AAA repairs, compared with standard EVAR, FEVAR is associated with significantly increased odds of neurologic injury [277]. Rates of SCI vary from 0% up to 40%. Established strategies that are utilized to minimise risk of SCI include use of cerebrospinal fluid (CSF) drainage, early limb reperfusion, staging and neuro-monitoring [278]. Spanos et al. found that the majority of SCI incidence after FEVAR or BEVAR of complex aortic aneurysms is manifested immediately postoperatively [279]. Pts with glomerular filtration rate (GFR) < 60 mL/min/1.73 m^2 and with longer aortic stent graft coverage are at higher risk of SCI. The total incidence of SCI was 17.7% [43/243; paraplegia in 4% (10/243) and paraparesis in 13.7% (33/243)]. Most of the pts with SCI presented with immediate postoperative symptoms (72% [31/43]). Neurological complications following TEVAR in the Global Registry for Endovascular Aortic Treatment (GREAT) included 833 pts with arch, descending thoracic, TBAD and other pathologies [280]. There were 13 early cerebrovascular accidents (CVA) (1.5%) and the 4 year freedom from CVA rate was 96.3%. On multivariable analysis, aortic arch aneurysm was the only independent

predictor of early CVA (odds ratio 16.7, p = .001). LSA coverage (hazard ratio 3.31, p = .005) and hypercholesterolaemia (HR 2.96, p = .024) were independent predictors of mid-term ischaemic CVAs. There were 15 (1.8%) early SCIs, and the 4 year freedom from SCI rate was 97.8%. No independent predictors of early SCI were identified, but length of coverage was an independent predictor of SCI at four years (HR 1.24; p = .044). Also Yang et al. identified length of aortic coverage to be the sole independent predictor of SCI in TEVARs (odds ratio 8.2, P = .026) [281].

A systematic review of 14 studies on 321 pts by Choong et al. of biochemical markers in the assessment of SCI in TAA repair demonstrated a dramatic rise of S100B proteins, neurone-specific enolase (NFL) and glial fibrillary acidic protein (GFAp) in CSF which may be of use [282]. In contrast, Harky et al. who also performed a systematic review found that there is a lack of high-quality studies investigating CSF biomarkers during TAA repair to detect SCI [283].

The use of preoperative spinal drainage may prevent SCI. A spinal drain preoperatively placed in F/BEVAR cases in 53% (130/243) and was associated with the prevention of SCI with spinal drainage, 12% [16/130]; SCI without spinal drainage, 24% [27/113]; P = .018) [279]. However, according to Yang et al., complications related to CSF drainage occurred in 4 pts (5.6%) with major complications occurring in 2 pts (2.8%), including 1 with an intrathecal hematoma and permanent bilateral paraparesis [281]. Therefore, they concluded that selective use of prophylactic CSF drainage in TEVAR was associated with moderate risk and questionable benefit. Although, the use of neurophysiological monitoring allowed for early detection and treatment of spinal ischemia (which may avoid the primary use of CSF drainage), its utility is limited by logistical factors and to the minority of pts with intraoperative spinal ischemic events. Such complications were confirmed by Kärkkäinen et al. for FEVARS and BEVARS. Of 187 pts, 19 pts (10%) had 22 CSF drainage-related complications after 21 aortic procedures (9%) [284]. Complications were graded as severe to moderate in 17 pts (9%). There were 12 pts (6%) with intracranial hypotension, including 3 (2%) who had intracranial hemorrhage and 9 (5%) with post dural puncture headache requiring blood patches in 6. Another 6 pts (3%) developed spinal hematomas resulting in paraplegia in two (1%) and transient paraparesis in two (1%). One pt had CSF leakage from the puncture site (no intervention required). Four pts had bleeding during attempted drain placement, which required postponement of F/BEVAR. Technical difficulties were experienced in 57 drain insertions (24%). A meta-analysis of 8 studies revealed protocols for drainage most commonly included draining to a target pressure intra- and postoperatively, between 8 and 12 mm Hg. Incidence of SCI ranged from 0% to 17% in pts with CSF drainage, and from 0% to 50% in those without CSF drainage. Rates of CSF drainage-related complications ranged from < 1% to 28% [285].

A combination of CSF drainage, epidural corticosteroid and accurate haemodynamic control resulted in 50 consecutive cases with TEVAR for TAA in the absence of SCI within 5 days post-intervention which may be more promising than CSF drain alone [286].

Bertoglio et al. found that a multistaged approach with a third limb step in case of TAAAs is safe and technically feasible, with an acceptable rate of permanent SCI., 4% had permanent and fatal spinal cord impairment [287]. Another possibility is to leave one of the branches in BEVAR unstented or, as described by Orrico et al., bridged with a "bare branch" and in the second step, realignment of the bare branch with a covered stent after total endovascular repair of TAAAs [288]. In the latter situation the SCI rate was 6.4% with 0% permanent neurologic deficit. A novel approach for paraplegia prevention in AA repair by thoracoabdominal staging is the "minimally invasive staged segmental artery coil embolisation" (MIS^{2}ACE) currently investigated in a multicenter trial [289]. Sonesson et al. suggest as an alternative to tidious selective embolization of segmental arteries a more simplified approach using a short and large stentgraft where graft-wall apposition occurs [290]. The segmental arteries were always closed at their ostia in contrast to selective coil embolisation, where there is a risk of more peripheral closure. Follow-up imaging showed thrombus lining the stent-graft-covered portion of the aneurysm and secondary proximal segmental artery occlusion.

Interestingly, also the strict control of blood glucose with an intravenous insulin infusion decreases the risk of postoperative lower extremity weakness after complex EVAR [291]. A number of promising drugs have been tested animal experiments for the attenuation of SCI: diazoxide and erythropoietin [292], astaxanthin [293], rapamycin [294], quercetin [295], and CNB-001 [296]. The clinical relevance, however, has yet to be proven.

SCI also occurs following frozen elephant trunk procedures. A meta-analysis on 3,154 pts determined that stent length of 10 cm was associated with significantly less risk of SCI [297]. Using a stent 15 cm or greater or coverage extending to T8 or further should be avoided. And paraplegia is also a major problem in OR of TAA. Open two stage repair was recommended in a retrospective analysis of 94 pts by Gombert et al. as a treatment option for type II TAAAs if anatomically feasible, as it has a lower mortality and similar complication rates to one stage repair [298]. In hospital mortality after open one stage repair versus open two stage type II repair was 22.4% versus 0%, p = .19. The 1 year survival rate after one stage repair versus open two stage repair was 74.7% versus 90.9%, p = .225. The 5 year survival rate after one stage repair versus open two stage repair was 53.0% versus 90.9%, p = .141. The HR for survival after one stage repair and after open two stage repair was 4.563, p = .137. Paraplegia was observed after open one stage repair versus open two stage in 10.5% vs. 8% (p = 1). Myocardial infarction was seen for after open

one stage repair and open two stage in 5.3% vs. 0% (p = 1), respectively.

Renal failure as a complication

In a large cohort of 17,689 elective endovascular AAA repairs, compared with standard EVAR, FEVAR is associated with significantly increased odds of renal complications ([277] and Cost et al.). In F/BEVAR, acute kidney injury (AKI) was the most common postoperative complication observed in nearly 20% of pts. AKI after F/BEVAR was found to be associated with decreased short- and long-term survival [299], although, it rarely results in permanent renal dysfunction as both sCr concentration and GFR returned to baseline by 6 months after the procedure as described by Wang et al. [300]. Charles et al. confirm higher mortality with eGFR loss at long term over a median of 9 years following EVAR, and observed long-term decrease of renal functions in some of the pts [301]. Gombert et al. Investigated open repair for type II TAAAs if anatomically feasible [298]. AKI requiring permanent dialysis was seen for after open one stage repair and open two stage in TAA in 3.9% vs. 0% (p = 1), respectively. Age, renal function, and cardiovascular disease are the main risk factors [302]. Other factors associated with such complications are controversial like suprarenal as opposed to infrarenal fixations in EVARs, with or without partial coverage of renal arteries [303, 304].

Consistently, coverage of accessory renal arteries did not or only transiently lead to either temporary AKI after EVAR or to chronic kidney disease in EVARs [305, 306], however, may impact long-term renal function in FEVARs [307]. Here it may be also a consequence of repetitive contrast CT angiographies in FEVARS as opposed to widely used contrast-induced ultrasound for the follow-up of EVARs. Gombert et al. report that urine neutrophil gelatinase-associated lipocalin and, to a lesser extent, serum neutrophil gelatinase-associated lipocalinand could be considered biomarkers for early detection of perioperative AKI after open and endovascular TAAA surgery [308].

Screening and follow-up of arterial aneurysm

Screening for abdominal aortic aneurysms

A meta-analysis of population-based randomised clinical trials, comissioned by the US Preventive Services Task Force (USPSTF) estimated that screening for AAA by ultrasound in men 65 years or older was associated with long-term reduction of AAA-related mortality, AAA-related ruptures and emergency surgical procedures [309]. In contrast, no all-cause mortality benefit or quality of life improvement was noted at 12- to 15-year follow-up [309]. There was a higher rate of elective surgerical procedures among screened subjects, and women had a higher rate of surgical complications and postoperative mortality compared to men [309].

Based on the above-mentioned findings, the USPSTF recommends [310]:

- 1-time ultrasonography screening for AAA in men aged 65 to 75 years who have ever smoked,
- selectively offering ultrasonography screening for AAA to men aged 65 to 75 years who have never smoked, rather than routinely screening all men in this group,
- recommends against routine ultrasonography screening for AAA in women who have never smoked and have no family history of AAA.

Screening for thoracic aortic aneurysms

Screening for ascending TAA is not recommended by current guidelines, since the yield and benefit are not known. Among adult pts receiving CT scans of the chest, ascending TAA with a diameter of $\geq$ 4 cm were identified in 2.1% (3.2% of males and .9% of females), with older age being an important risk factor [311].

Among pts with AAA, 18% had an associated TAA [312]. The authors suggest obtaining a screening chest CT scan in all pts diagnosed with AAA.

Follow-up of small abdominal aortic aneurysm

The risk of rupture of small AAA (with a diameter of < 5.5 cm) in men under regular ultrasonographic surveillance is < 0.5% per year [313]. Rupture of AAA occurs more frequently in autumn and winter compared to spring and summer, but recommendations on seasonal follow-up cannot be given since potential co-founding or additional factors, such as blood pressure, were not controlled for [314]. A meta-analysis found that the volume of intraluminal thrombus was larger in ruptured than in asymptomatic AAAs, but this was most likely the consequence of larger overall volumes of ruptured AAAs [315]. A retrospective cohort study of elderly pts, aged $\geq$ 85 years, with AAA 3.0–5.4 cm in diameter at baseline, showed that discontinuation of follow-up might be safe in aneurysms measuring < 4 cm in diameter at baseline [316]. For elderly pts with aneurysms measuring 4–5.4 cm in diameter, assessment of fitness for surgery may prevent unnecessary surveillance [316].

Follow-up of thoracic aortic aneurysms

In ascending TAAs, evidence is accumulating that surgery may be preferable already at diameters below the currently recommended threshold of 5.5 cm [317]. The main reasons are that novel, more precise data show a hinge point at ascending aortic diameter of 5.25 cm, that pre-dissection aortic diameters are at least 0.7 cm smaller than after dissection, that more and more pts with ascending AA are diagnosed with genetic mutations responsible for AD or

rupture at smaller aortic sizes, and that aortic arch surgery is becoming increasingly safe [317]. In contrast to ascending TAA, decisions for surgery in pts with descending TAAs and TAAAs often remain difficult. In pts with degenerative or dissection-related descending TAAc or TAAAs with diameters $\geq$ 6 cm, who were treated conservatively, the aortic-related mortality reached 60% at 1 year [318]. Women with TAAs have higher risk of acute aortic syndromes and death because their aneurysms grow twice as fast as in men and because in women aneurysm growth is related to aortic stiffness [12].

Post-EVAR follow-up

The European Society for Vascular Sugery proposed a rationalised protocol for post-EVAR follow-up. On the first, 1-month-post-EVAR CTA the following parameters with prognostic significance should be evaluated: the presence of endoleak, the aneurysmal sac size and the extent of stent-graft seal against the arterial wall [1]. If there is no endoleak and the stent-graft seal is at least 1 cm in length proximally and distally, the pts may be considered for limited follow-up with the next CTA after 5 years [1]. If there is adequate seal of the stent-graft, but an endoleak type II, the pts need annual ultrasound surveillance of the aneurysmal sac size. If the sac shrinks by $\geq$ 1 cm, the pts may be reclassified as low-risk with a CT angiography after 5 years. On the other hand, if the sac expands by at $\geq$ 1 cm after EVAR in the presece of an endoleak type II, the pt should be reassessed for intervention. The need for re-intervention should also be assessed promptly in pts who on the first post-EVAR CTA show an endoleak type I or III or who have a stent-graft seal length of < 1 cm [1]. Pts with higher preprocedural levels of fibrinogen were more likely to show regression of aneurysmal sac after EVAR [319].

CEUS is becoming an increasingly useful tool for detection of endoleaks type II [69]. Second-generation contrast microbules provide superior sensitivity for detection of small and slow flow in comparison to gadoinium-enhanced MRA, enable detection of endoelaks in real-time and – in contrast to CTA – do not cause radiation exposure [69]. When the endoleak type II nidus can be identified by DUS, flow velocities > 100 cm/s identify persistent and often treatment-resistant endoleaks [320].

Type II endoleaks are common after EVAR and even more so after fenestrated-branched EVAR [321]. The inferior mesenteric artery plays an important role in endoleaks type II, since pts with an occluded inferior mesenteric artery prior to EVAR and thus without possibility for retrogarde flow after EVAR, showed less sac enlargement and required significantly fewer interventions for endoleak type II [322–324].

Treating type II endoleaks after EVAR with fusion-image-guided translumbar puncture using intraoperative cone beam CT "fused" with preprocedure CTA in hybrid operating rooms is a promissing approach [325]. A meta-analysis comparing the outcomes of transarterial and translumbar approaches for persistent type II endoleak treatment after EVAR favored the tanslumbar approach, i.e., direct aneurysm sac puncture, but the difference in the odds ratio for absence of endoleak on the last follow-up barely missed statistical significance (Odds ratio 2.29, 95% CI 1.00–5.25, p = .05) [326].

Post TEVAR follow-up

Complications after TEVAR are not rare. The reported incidence of type Ib endoleak 1 year after TEVAR is between 1.0% and 15.0%, with a tortuous aorta being a predictor of endoleak [327] and therefore require surveillance.

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