Aortic Stent Graft Surveillance

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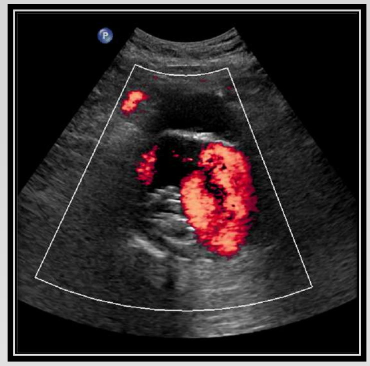
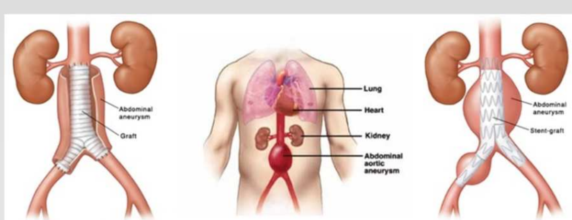


Aortic Aneurysms

- Approximately 1.5-2 million Aneurysms in US
  - ~200,000 diagnosed per year
  - ~25,000 surgical procedures on Aorta/yr
  - ~15,000 annual deaths attributed to AAA
  - ~20% of surgical procedures done emergently with a 30 day mortality as high as 60%



Endovascular AAA Repair (EVAR)

- Small or no incisions (percutaneous)
- No aortic cross clamp
- Lower morbidity and mortality compared with open surgery
- Shorter hospital stay

- Vast majority of AAA repair now endovascular

Table. Depicted are the number of open aneurysm repair (*OAR*) cases predicted nationally and for trainees until 2020

	National cases				Teaching cases			
Year	OAR	EVAR	FEVAR/BrEVAR	Total	OAR	EVAR	FEVAR/BrEVAR	Total
1998	42,213	N/A	N/A	42,213	22,015	N/A	N/A	22,015
1999	42,415	N/A	N/A	42,415	23,981	N/A	N/A	23,981
2000	42,872	2358	N/A	45,230	23,933	1751	N/A	25,685
2001	33,499	13,845	N/A	47,344	17,251	9059	N/A	26,309
2002	28,842	13,821	N/A	42,663	14,467	8924	N/A	23,390
2003	27,404	17,119	N/A	44,523	14,292	10,439	N/A	24,731
2004	24,881	19,414	N/A	44,295	13,759	13,040	N/A	26,799
2005	21,485	21,332	N/A	42,817	10,369	11,789	N/A	22,158
2006	19,126	27,845	N/A	46,971	10,325	15,943	N/A	26,268
2007	15,895	29,769	N/A	45,664	8408	17,852	N/A	26,260
2008	16,253	34,888	N/A	51,141	8840	18,947	N/A	27,788
2009	14,389	32,403	N/A	46,792	8344	18,711	N/A	27,055
2010	11,428	32,521	N/A	43,949	7128	17,776	N/A	24,904
2011	10,039	35,028	722	45,788	6055	19,876	469	26,400
2012	8948	32,577	3278	44,803	5458	18,242	2131	25,831
2013	6195				3476			
2014	3958				2185			
2015	3117				1682			
2016	3176				1655			
2017	3109				1632			
2018	2963				1529			
2019	2958				1500			
2020	2889				1339			

BrEVAR, Branched endovascular aneurysm repair; *EVAR*, endovascular aneurysm repair; *FEVAR*, fenestrated endovascular aneurysm repair; *N/A*, not available.

Dua et al. J Vasc Surg 2017; 65:257-61

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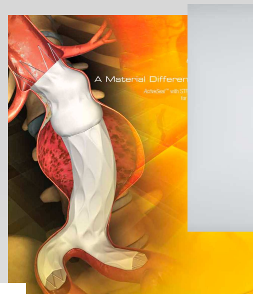
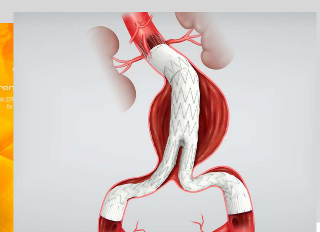
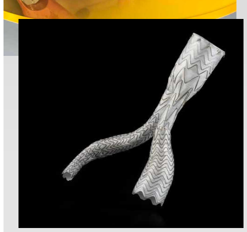
Current FDA approved EVAR Devices

- Cook: Zenith and Zenith Fenestrated
- Gore: Excluder C3
- Medtronic: Endurant II
- Endologix: AFX, Ovation, Alto
- Terumo: Treo







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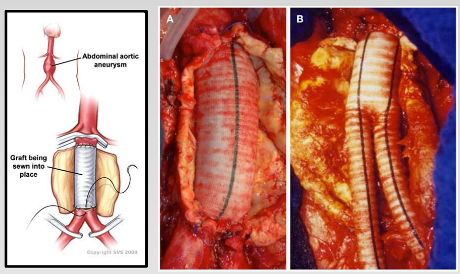
Principles of EVAR

- Unlike open AAA repair, aneurysm sac is not resected
- Relies on exclusion of sac from flow



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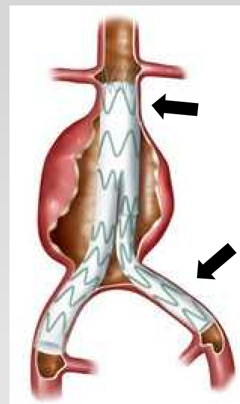
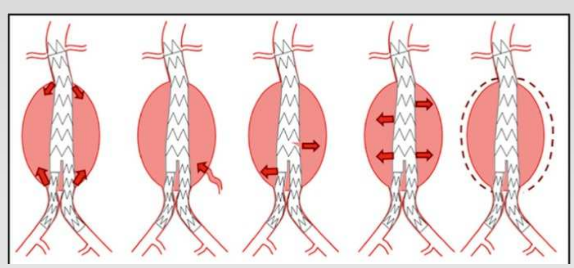


EVAR: Endoleaks

- Goal with Endografts is to exclude aneurysms from flow.
- Requires a **seal** within normal segment of aorta
- Without adequate seal, patients can have an endoleak
- **Endoleak** = flow within sac, outside of the graft

Type I – Proximal (Ia) or distal (Ib) seal zones
Type II – Retrograde flow through branches
Type III – Between components
Type IV – Graft porosity
Type V – "Endotension"



Endoleaks: Natural History

- All endoleaks are not created equal

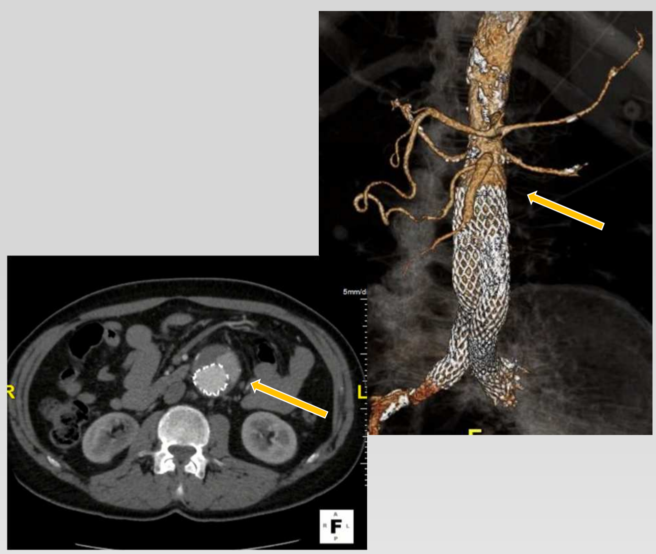
- Type I, III are pressurizing → can lead to sac expansion and rupture
- Type II generally benign
- Type IV rarely seen, more common with prior generation stent grafts
- Type V debatable

- Because there is ongoing risk of endoleak development over time, EVAR patients require life-long surveillance
- Just because it's sealed now, does not mean it will stay that way…

Endoleaks: Type Ia

- Most dangerous type
- Loss of proximal seal
  - Degeneration of native aorta
  - Graft slippage

- Frequent cause of late rupture



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Outcomes of patients with type I endoleak at completion of endovascular abdominal aneurysm repair

Tze-Woei Tan, MD,[a] Mohammed Eslami, MD,[b] Denis Rybin, PhD,[c] Gheorghe Doros, PhD,[c] Wayne W. Zhang, MD,[a] and Alik Farber, MD,[b] *Shreveport, La; and Boston, Mass*

J Vasc Surg 2016; 63:1420-7.

- 2402 EVARs for non-ruptured AAA in VSGNE
- Type 1a endoleak (3%)
- Associated with in-hospital mortality

Early and delayed rupture after endovascular abdominal aortic aneurysm repair in a 10-year multicenter registry

Leah Candell, MD,[a] Lue-Yen Tucker, BA,[b] Philip Goodney, MD,[c] Joy Walker, MD,[d] Steven Okuhn, MD,[e] Bradley Hill, MD,[f] and Robert Chang, MD,[g] *Oakland, San Francisco, Santa Clara, and South San Francisco, Calif; and Lebanon, NH*

J Vasc Surg 2014; 60:1146-53.

- Late outcomes also compromised
- Persistent aneurysm expansion
- Late ruptures

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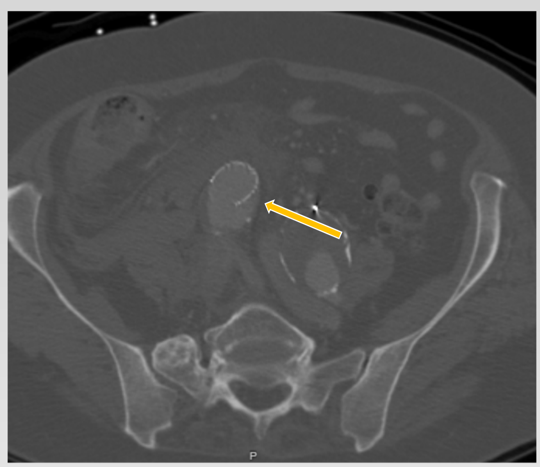
Endoleaks: Type Ib

- Also dangerous
- Strong retrograde flow into sac
- Loss of distal seal
  - Aneurysmal degeneration of native iliac
  - Graft slippage
- Can lead to late rupture



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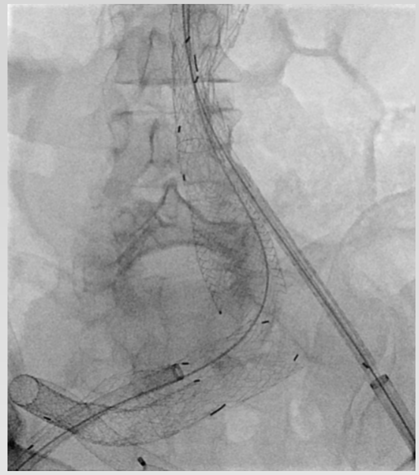
Endoleaks: Type III

- Separation of components
- Inadequate overlap
- High pressure flow
- Can lead to late rupture



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Endoleaks: Type II

- Most common (10% or more)
- Reversal of flow in branch vessels
  - IMA
  - Lumbar arteries
- Generally low pressure
- Can lead to sac expansion in minority

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Persistent type 2 endoleak after endovascular repair of abdominal aortic aneurysm is associated with adverse late outcomes

John E. Jones, MD, Marvin D. Atkins, MD, David C. Brewster, MD, Thomas K. Chung, MA, Christopher J. Kwolek, MD, Glenn M. LaMuraglia, MD, Thomas M. Hodgman, BA, and Richard P. Cambria, MD, *Boston, Mass*

J Vasc Surg 2007;46:1-8.

- Single institution review of 164 EVAR patients
- Type II leak associated with worse clinical outcomes, particularly when they persist past 6 months
- Associated with sac expansion, long-term risk of rupture, conversion to open/explant
- Sac expansion is an indication for intervention

EVAR Surveillance

- EVAR requires lifelong surveillance
- Identification of endoleaks, sac measurements to assess for stability, regression or growth

- Patients generally imaged at 30d, 3 mo, 6 mo, 1 yr, then annually if stable
- Presence of abnormalities may lead to more frequent assessment

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EVAR Surveillance: Modalities

- **CT Angiogram** – Gold standard
  - Arterial and Venous (Delayed) phase

- **Duplex Ultrasound**
  - Non-invasive
  - Can accurately assess and characterize endoleaks, flow direction
  - Can also assess for flow disturbance in limbs (kink/stenosis)
  - No contrast or radiation
  - Technician-dependent
  - Limited by habitus, bowel gas

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The Role of Duplex in EVAR Surveillance

- CT angiography is gold standard
  - Anatomic information, sizing/planning for re-intervention

- Many potential disadvantages:
  - Nephrotoxic contrast agents
  - Ionizing radiation
  - Cost

- Technical limitations
  - Timing of contrast bolus (especially for type II leaks)
  - Slice thickness
  - Scatter artifact (stent, prior embolization material, metal implants)

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Advantages of Duplex Surveillance

- Duplex Ultrasound plays key role in follow-up imaging, preferred by many
- Non-invasive, no contrast or radiation
- Cost significantly reduced
  - An estimated 33-65% of post-EVAR cost is related to CT imaging[1,2]
  - CT $2500, Duplex $500[3]

- Detect and characterize endoleaks
- Measure diameter of residual sac
- Evaluate flow through graft and stenosis/occlusion
- Patency/flow disturbance in branch vessels
- Evaluate CFA access site

[1] Noll et al. J Vasc Surg 2007;46:9-15.
[2] Prinssen et al. Ann Vasc Surg 2004;18:421-7.
[3] Bendick et al. Vasc Endovasc Surg 2003;37:165-70.

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Accuracy of Duplex Ultrasound

- Measurement of Sac Diameter
  - Correlates to within 5mm of CT measurement in >70% of cases[1,2]
  - Particularly accurate when performed by same technician

- Identification of Endoleaks
  - Arko et al[3] compared 201 patients with CT and duplex in finding endoleaks
  - Sensitivity 81%, specificity 95%
  - PPV 94%, NPV 90%

[1] Badri et al. Angiology 2010;61:131-6.
[2] Raman et al. J Vasc Surg 2003;38:645-51.
[3] Arko et al. Semin Vasc Surg 2004;17:161-5.

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Disadvantages of Duplex Surveillance

- Technician dependent
- Limited by body habitus, bowel gas, ascites
- Limited imaging above diaphragm for more extensive aneurysms
- No 3D anatomic information, limited use in planning for reintervention

- Duplex should be preferentially used for: stable repairs without endoleak or those with easily identified type II leaks that are being surveilled, patients with renal dysfunction
- Identification of issues or inability to characterize should prompt CTA

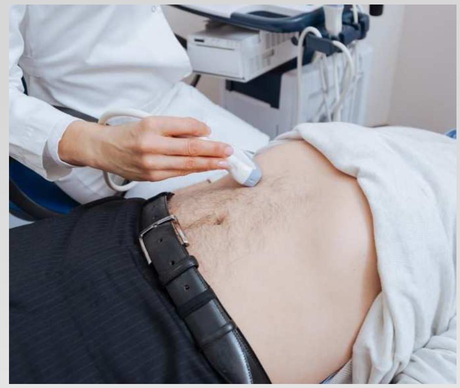
Duplex Ultrasound: Instrumentation

- One of the more technically challenging exams to perform
- High quality ultrasound with advanced functionality
  - B-mode, color flow, spectral Doppler with adjustable sensitivity/gain

- Low frequency linear/curvilinear probe (2-5 mHz) for deeper structures
- Small, low frequency phased-array transducer for intercostal views, if desired

Duplex Ultrasound: Prep and Positioning

- Patient should be NPO
- Gown or loose clothing to allow exposure of abdomen from costal margin to groins, back, flanks
- Ability to transition between supine and lateral decubitus positions
- Technologist stands at patient's side, step stool may be helpful
- Warn patient that deep pressure may be needed during some portions of exam, which may lead to tenderness



Duplex Ultrasound: Exam Protocol

- Exam begins with B-mode imaging in supine position
- Aorta imaged in transverse from anterior abdomen, which should demonstrate endograft within the larger aortic lumen
- Measure diameter, assess thrombus in residual sac
- Measurements performed at various levels, noting **maximal** diameter
  - Proximal attachment site (infrarenal), residual sac, distal attachment sites (iliacs)
- Note any graft malposition, non-apposition, kinks, thrombus
- Longitudinal view used selectively

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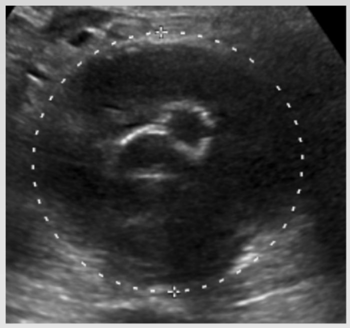
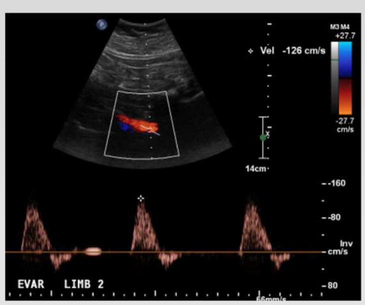
Duplex Ultrasound: Exam Protocol

- B-mode assessment of residual sac itself
- Thrombus should be uniform and produce echoes, while anechoic areas may represent sites of active flow/endoleak



Duplex Ultrasound: Exam Protocol

- Once B-mode imaging completed, move to Doppler interrogation
- Assess flow pattern/waveforms in aorta, branch vessels, iliac vessels
- Doppler should be performed at 60^{o} angle to flow to maximize shift
- Areas of velocity elevation noted and measured pre/post



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Duplex Ultrasound: Exam Protocol

- Next, attention moves to identification of endoleaks
- ***Most critical*** portion of the exam – unidentified endoleak can potentially leave patient at risk of rupture
- Patience required to systematically evaluate residual sac using combination of Doppler and Color Flow
- May require multiple positions and views, probes

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Identifying and Characterizing Endoleaks

- Color Flow sensitivity/gain must be optimized
  - Too low → Missed endoleak
  - Too high → artifact, false positive
- Helpful to reduce color PRF, increase color gain and persistence
- Positioning color box over sac but <u>not</u> including graft/limbs
- Any areas of color flow should be interrogated with Doppler
  - Strong waveforms with high velocity → possible type I/III
  - To-and-fro waveforms, low velocity → possible type II

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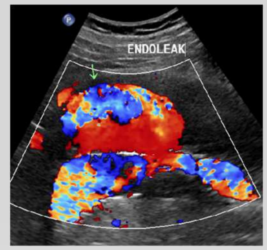
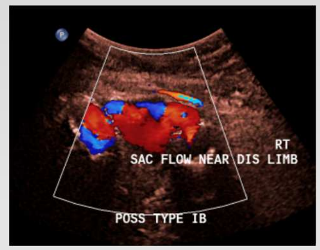
Assessing Type I Endoleaks

- Particular attention should be paid to the proximal and distal attachment zones
- Remember, type I endoleaks are dangerous!
- B-mode to evaluate apposition of the graft and the wall
- Graft motion at this site may also indicate loss of seal
- Longitudinal view may help identify graft migration
- Carefully inspect for flow signals in areas near apposition sites with both color flow and Doppler





Assessing Type II Endoleaks

- Most endoleaks will be type II leaks
- Slow, to-and-fro flow similar to that seen in pseudoaneurysm
- Location on aneurysm sac key to determining culprit vessel
  - Anterior wall → inferior mesenteric artery
  - Posterior wall → lumbar vessels
- May also be helpful to determine inflow vs. outflow vessel

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Assessing Type III Endoleaks

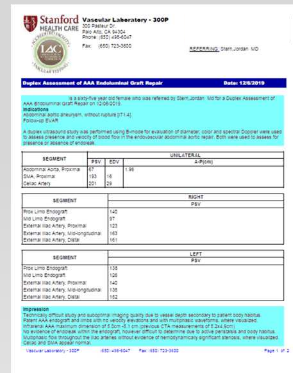
- Uncommon relative to type I/II
- Also cause sac pressurization, so identification is crucial
- B-mode assessment at interface between graft components may identify gaps, inadequate seal or even frank component separation
- Flow directly adjacent to these areas may well represent type III leaks

Contrast-Enhanced Ultrasound

- Rarely used
- Approved for use in echocardiography
- Microbubbles with sugar/lipid/polymer shell
- Can increase signal intensity of Doppler, may allow detection of subtle flow and smaller leaks
- Lower acoustic impedance than surrounding blood cells
- Requires intravenous injection, either bolus or continuous infusion; limited window to scan after administering
- No nephrotoxicity, generally inert
- Clinical applicability still largely unknown, for now limited to centers with experience and in patients with otherwise equivocal findings

Completing a Preliminary Report

- After exam is completed, report generated
- Key components include:
  - Sac and vessel diameters
  - Patency of graft and limbs
  - Doppler waveforms and evidence of flow disturbances
  - Presence of endoleak and presumptive type/site/vessel



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Vascular Laboratory - 300P
300 Pasteur Dr.
Palo Alto, CA 94304
Phone: (650) 498-6047
Fax: (650) 723-3600

REFERRING: Stern,Jordan MD

Duplex Assessment of AAA Endoluminal Graft Repair **Date: 12/6/2019**

is a sixty-five year old female who was referred by Stern,Jordan MD for a Duplex Assessment of AAA Endoluminal Graft Repair on 12/06/2019.
Indications
Abdominal aortic aneurysm, without rupture [I71.4]
Follow-up EVAR

A duplex ultrasound study was performed using B-mode for evaluation of diameter; color and spectral Doppler were used to assess presence and velocity of blood flow in the endovascular abdominal aortic repair. Both were used to assess for presence or absence of endoleak.

SEGMENT	UNILATERAL		
	PSV	EDV	A-P(cm)
Abdominal Aorta, Proximal	67		1.96
SMA, Proximal	193	16	
Celiac Artery	201	29	

SEGMENT	RIGHT
	PSV
Prox Limb Endograft	140
Mid Limb Endograft	97
External Iliac Artery, Proximal	123
External Iliac Artery, Mid-longitudinal	163
External Iliac Artery, Distal	161

SEGMENT	LEFT
	PSV
Prox Limb Endograft	138
Mid Limb Endograft	126
External Iliac Artery, Proximal	140
External Iliac Artery, Mid-longitudinal	138
External Iliac Artery, Distal	152

Impression
Technically difficult study and suboptimal imaging quality due to vessel depth secondary to patient body habitus.
Patent AAA endograft and limbs with no velocity elevations and with multiphasic waveforms, where visualized.
Infrarenal AAA maximum dimension of 5.0cm -5.1 cm (previous CTA measurements of 5.2x4.9cm)
No evidence of endoleak within the endograft, however difficult to determine due to active peristalsis and body habitus.
Multiphasic flow throughout the iliac arteries without evidence of hemodynamically significant stenosis, where visualized.
Celiac and SMA appear normal.

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Presence of Type I/III endoleak, sac enlargement, or critical flow disturbance/occlusion should prompt call to surgeon and likely CTA

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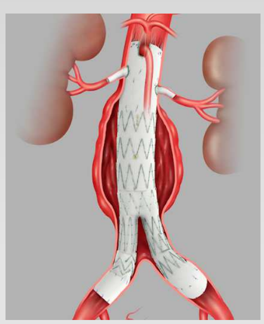
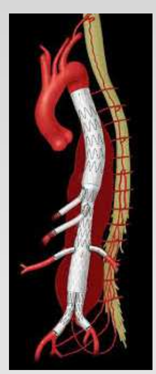
Special Considerations: F/BEVAR

- Fenestrated or branched repair of more complex aneurysms
- Involves bridging stents into the visceral branch arteries (CA, SMA, RA)
- Can still be surveilled with duplex





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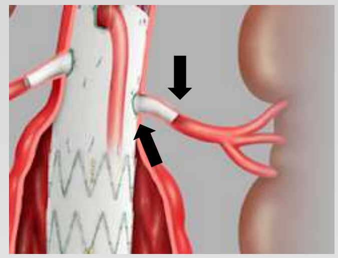
Special Considerations: F/BEVAR

- Evaluation of flow and endoleak largely the same
- Proximal edge higher (above renals), type 1a endoleak harder to assess
- Flow within each branch stent is important
  - Velocity elevations
  - Kinking
  - Thrombosis/occlusion



- Type 1c endoleak – at distal end of branch stent
- Type IIIc endoleak – at interface between graft and branch

Special Considerations: F/BEVAR

- Flow within each branch should look like its corresponding native vessel
  - (e.g.) flow within SMA high/low resistance based on fasting
  - Velocity thresholds largely unknown for stented vessels

Duplex ultrasound surveillance of renal branch grafts after fenestrated endovascular aneurysm repair

Kenneth Tran, MD, Graeme Mcfarland, MD, Michael Sgroi, MD, *and* Jason T. Lee, MD, *Stanford, Calif*

J Vasc Surg 2019;70:1048-55.

- Correlated CT findings to duplex in renal branches in FEVAR
- Proximal PSV > 215 cm/s, distal < 25 cm/s associated with need for reintervention and future occlusion

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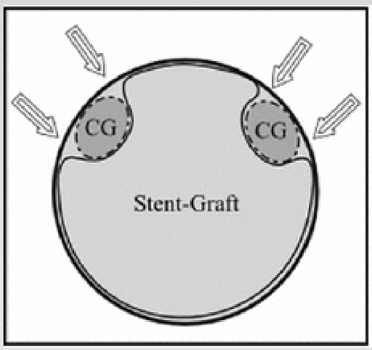
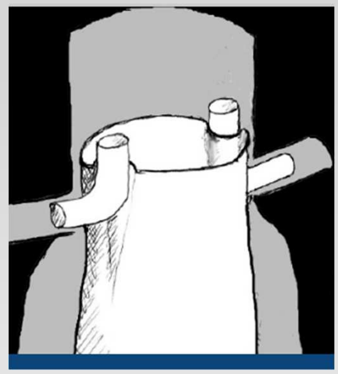
Special Considerations: ChEVAR

- Parallel grafts may be used instead of fenestrations
- Unique "gutter" endoleaks
- Should appear similar to type Ia





Case Example #1

- 86M s/p EVAR 7 years prior, original size 8.2 cm
- Sac now expanded to 9.5 cm maximal dimension

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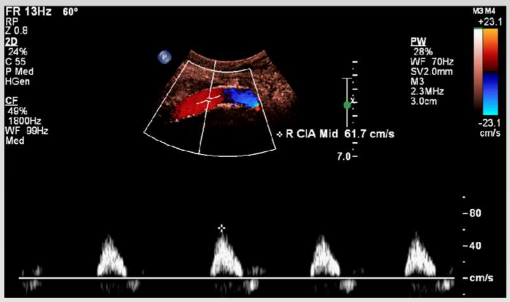
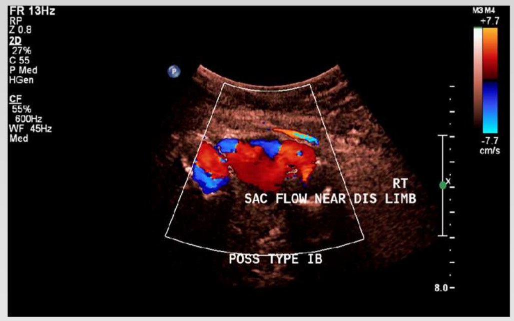
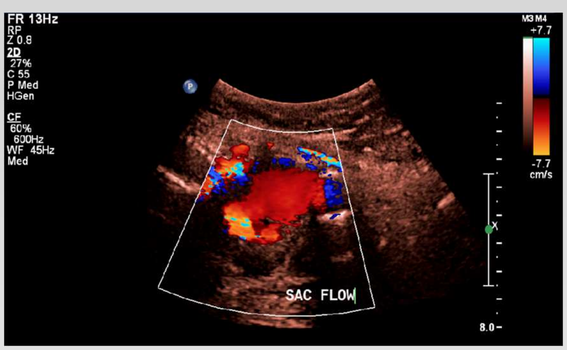
Case Example #1

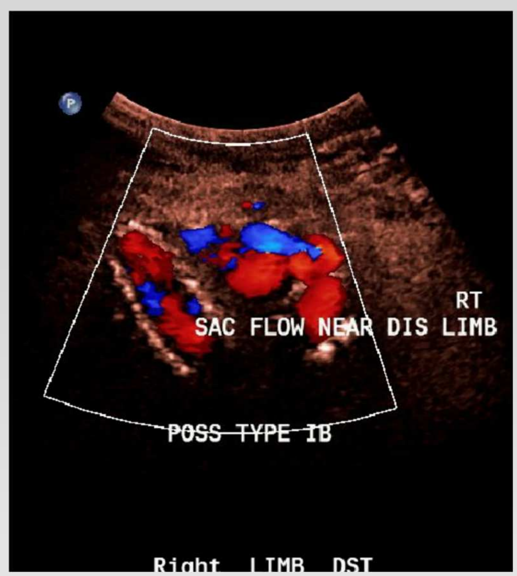
- Possible type 1b endoleak noted – flow near iliac limb





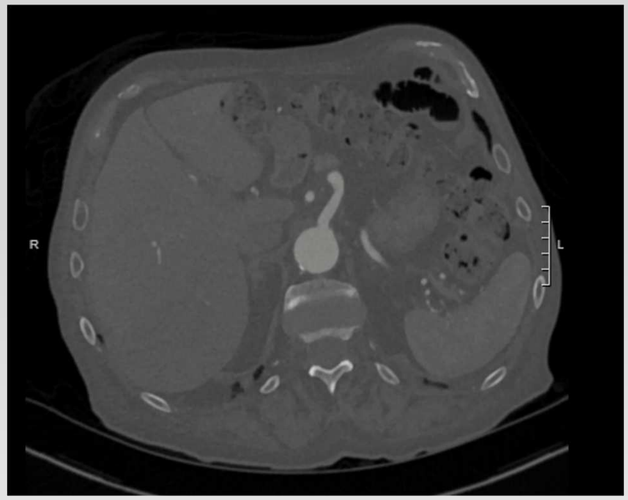
Case Example #1





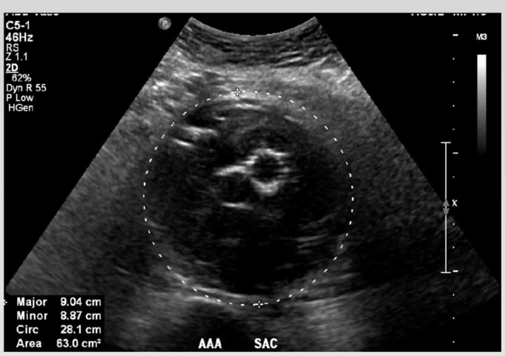
Case Example #1

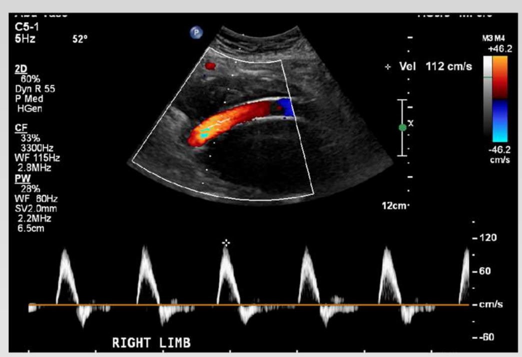
- CTA confirmed type Ib endoleak from right limb
- Aneurysmal degeneration and loss of seal
- Treated with coil/extend into EIA



Case Example #2

- 71M s/p EVAR 3 years prior
- Undergoing yearly surveillance, sac now growing





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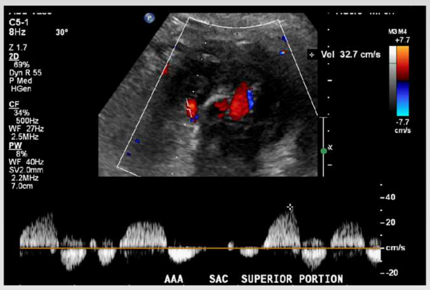
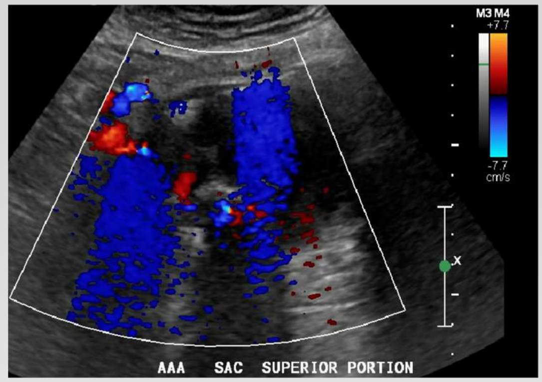
Case Example #2

- Endoleak noted in proximal aorta, near graft flow divider
- Type Ia? Type II?





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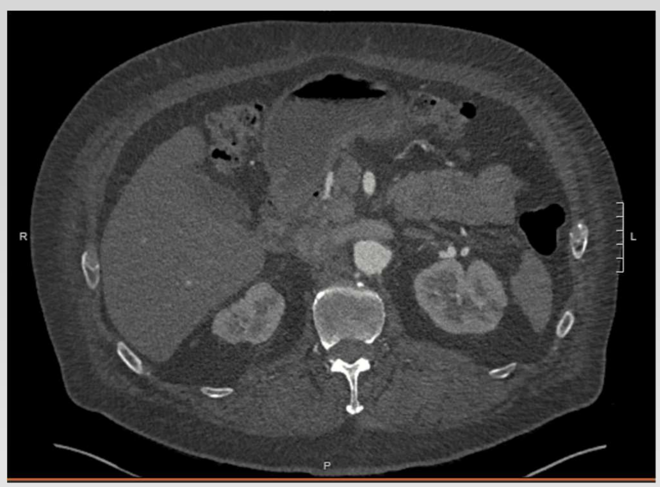
Case Example #2

- Type II leak from paired lumbars
- Brighter on delayed sequence



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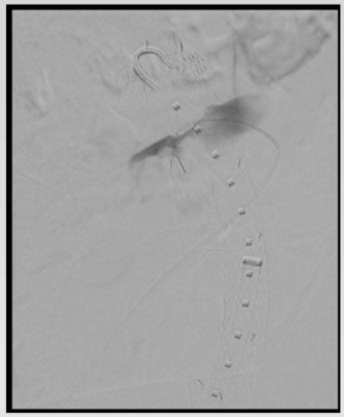
Case Example #2

- Treated with transcaval embolization and resolved



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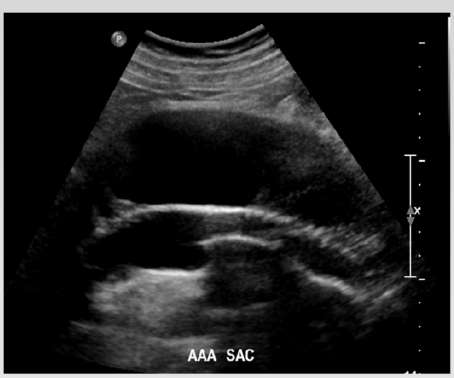
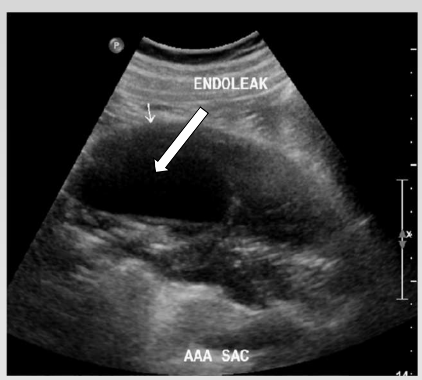
Case Example #3

- 76M s/p EVAR
- Large endoleak near top of graft





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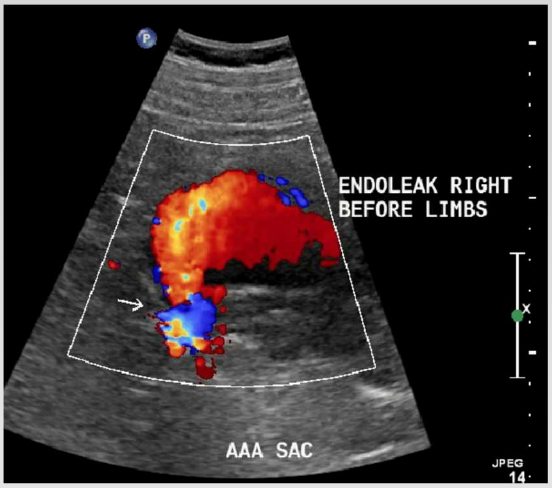
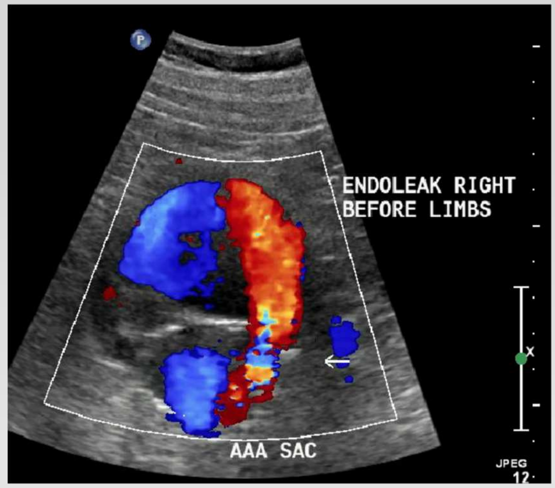
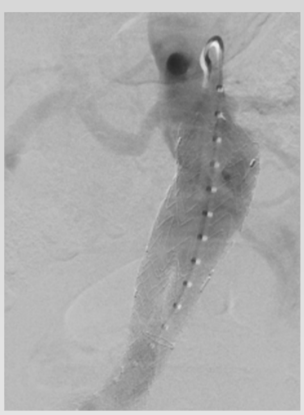
Case Example #3

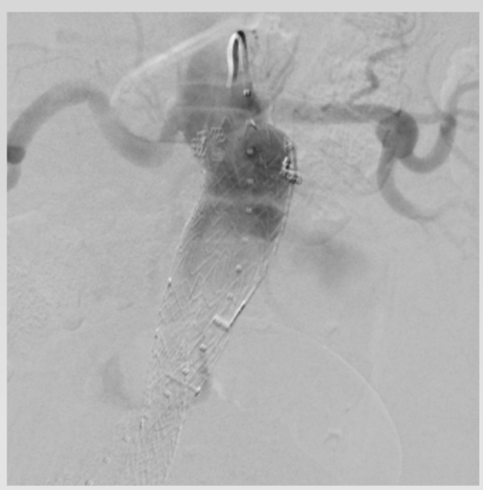




Case Example #3

- Taken for angiogram/repair

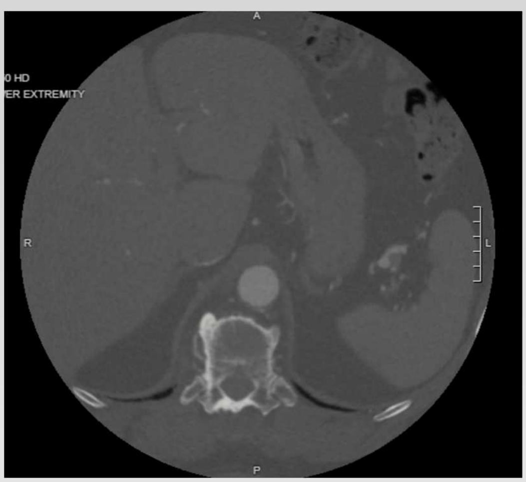




Case Example #3

- Taken for angiogram/repair

Case Example #3



- Bilateral renal chimney grafts, cuff
- Endoleak resolved on post-op CTA

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