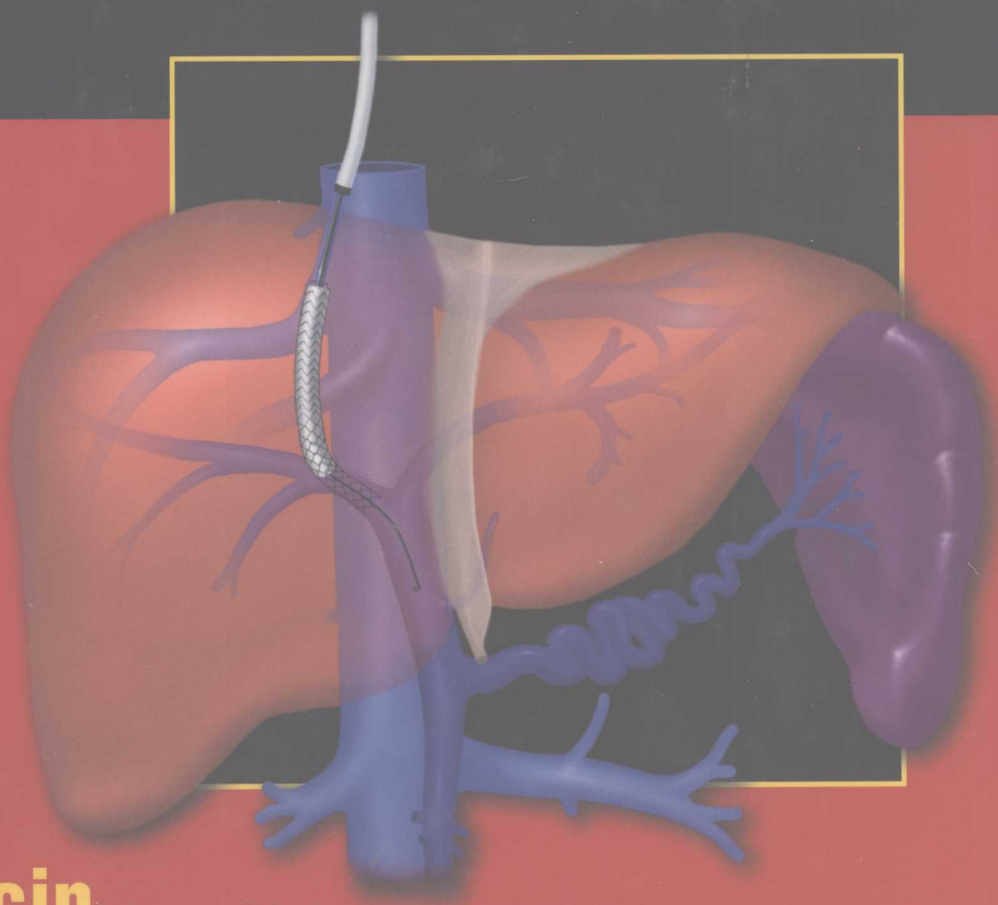
DIAGNOSTIC IMAGING

INTERVENTIONAL PROCEDURES



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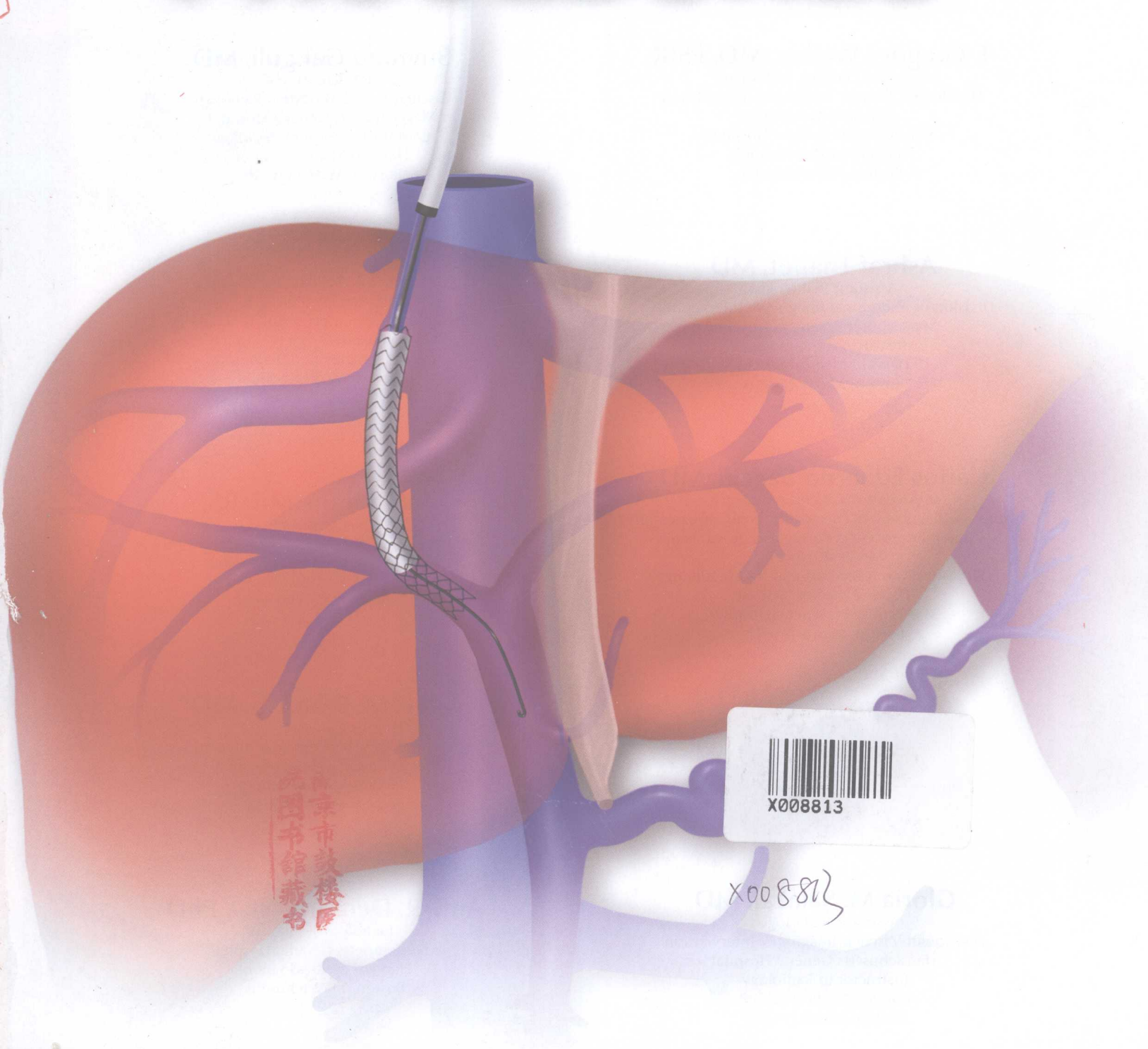

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First Edition

Printed in Canada by Friesens, Altona, Manitoba, Canada

ISBN: 978-1-931884-86-0

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Library of Congress Cataloging-in-Publication Data

Diagnostic imaging : Interventional procedures / [edited by] T. Gregory Walker. -- 1st ed.
p. ; cm.
Interventional procedures
Includes bibliographical references and index.
ISBN 978-1-931884-86-0 (hardback)
I. Walker, T. Gregory (Thomas Gregory), 1953- II. Title: Interventional procedures.
[DNLM: 1. Diagnostic Imaging--methods--Atlases. 2. Diagnostic Imaging--methods--Handbooks. 3. Surgical Procedures, Minimally Invasive--methods--Atlases. 4. Surgical Procedures, Minimally Invasive--methods--Handbooks. WN 39]
LC classification not assigned
616.07'54--dc23

2011028960

DIAGNOSTIC IMAGING
INTERVENTIONAL PROCEDURES

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to the extraordinary interventional radiologists and mentors
of the Massachusetts General Hospital:

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PREFACE

As a member of the faculty of the Division of Vascular Imaging and Intervention in the Department of Imaging at the Massachusetts General Hospital, over the course of many years I have had the privilege of participating in the education of our residents and fellows. I have recognized that almost all trainees initially view the clinical and technical skills that are required of interventional radiologists with a bit of apprehension but simultaneously wish to master these and excel in this arena. An experienced mentor serves as an invaluable resource for encouraging and guiding these physicians-in-training, yet most trainees also seek a medical reference for background, clarification, and additional guidance as they immerse themselves in interventional procedures and clinical patient management. Thus a comprehensive yet practical textbook addressing the breadth and scope of image-guided interventions can provide a valuable resource for these trainees. *Diagnostic Imaging: Interventional Procedures* was conceived of as a practical reference that could also serve as a "how-to" guide for performing image-guided interventions in the appropriate clinical scenarios. The aim was to produce a textbook that would be valuable not only to trainees but also to seasoned interventionalists.

The text is divided into seven sections that address a wide range of vascular and nonvascular interventional procedures. Most sections are further subdivided into groupings of chapters that deal with specific types of interventions such as arterial revascularization or arterial exclusion procedures.

Each chapter addresses topics such as the procedural indications and contraindications, optimal preprocedural clinical and imaging evaluation, and the medications and equipment that may be needed for the particular intervention. The procedure steps are then described and richly illustrated. If there are multiple approaches that may be considered or used for treating a particular lesion or disease state, these are also outlined in a stepwise fashion. The lengths of the individual chapters and the contents of the image galleries vary in accordance with the complexity of the subject matter. In all instances, the intention has been to provide a concise yet comprehensive review of a specific intervention or a group of interventions along with their various indications and the anatomic territories in which they are utilized. There are several types of general procedures, such as angioplasty, embolization, and stenting, which may be widely applied in various vascular or nonvascular territories. In these cases, a chapter is devoted to the general principles of the particular procedure and additional chapters address the application of the procedure to a specific anatomic territory or clinical scenario. This organizational approach allows the comparison of various procedural techniques that may have complimentary or alternative roles in managing specific disease states. For example, angioplasty, atherectomy, stenting, or some combination of these interventions may be used to treat an infrainguinal atherosclerotic stenosis. Thus the text has chapters detailing each of these individual interventional procedures, with subsequent chapters that examine their use in specific circumstances.

One of the remarkable aspects of working at the Massachusetts General Hospital is the tremendous volume and diversity of clinical material to which we are exposed. This has provided an invaluable repository for assembling a work such as this. Additionally, as the lead author, I have been fortunate to have colleagues in our hospital who are interested in materially contributing to a procedural textbook. The vast majority of contributors are current or former MGH physicians (residents, fellows, and attendings). The other contributors have produced substantial work for Amirsys and are seasoned authors. Together we have all worked to create a comprehensive reference manual on image-guided interventional procedures that will serve a broad audience and will be a valued addition to the Diagnostic Imaging medical textbook series. Hopefully we have succeeded on all counts.

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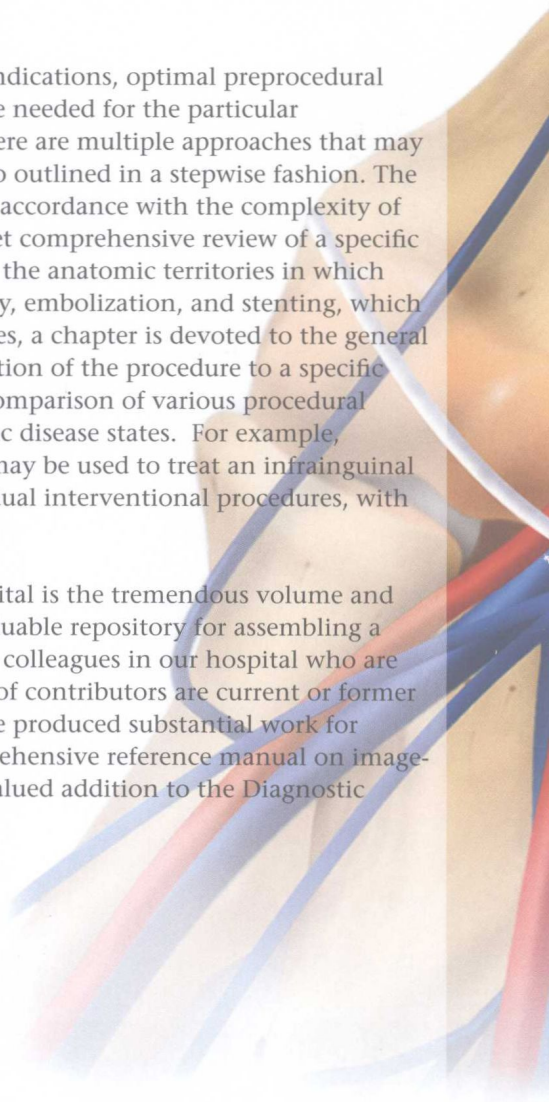

ACKNOWLEDGEMENTS

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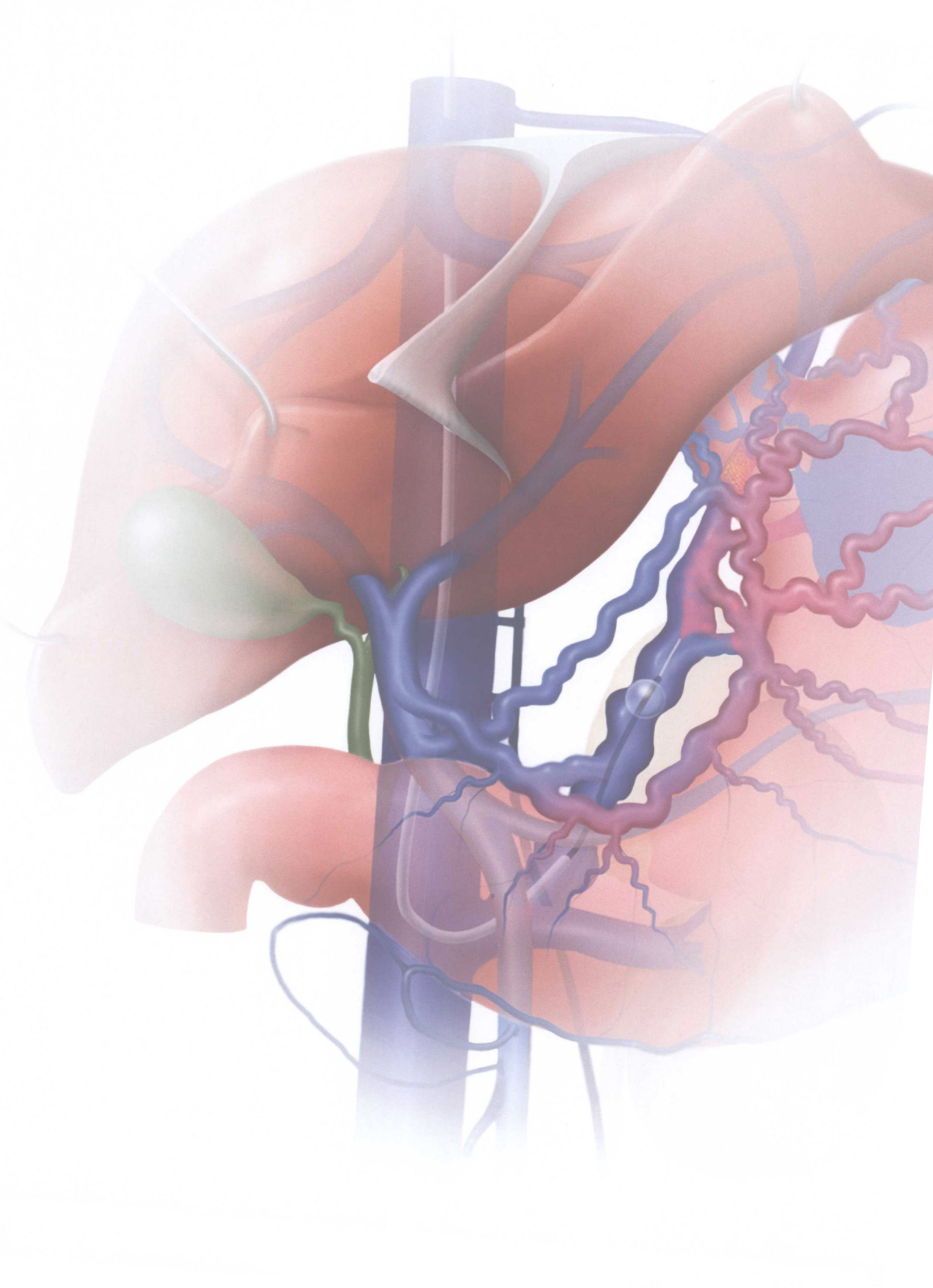

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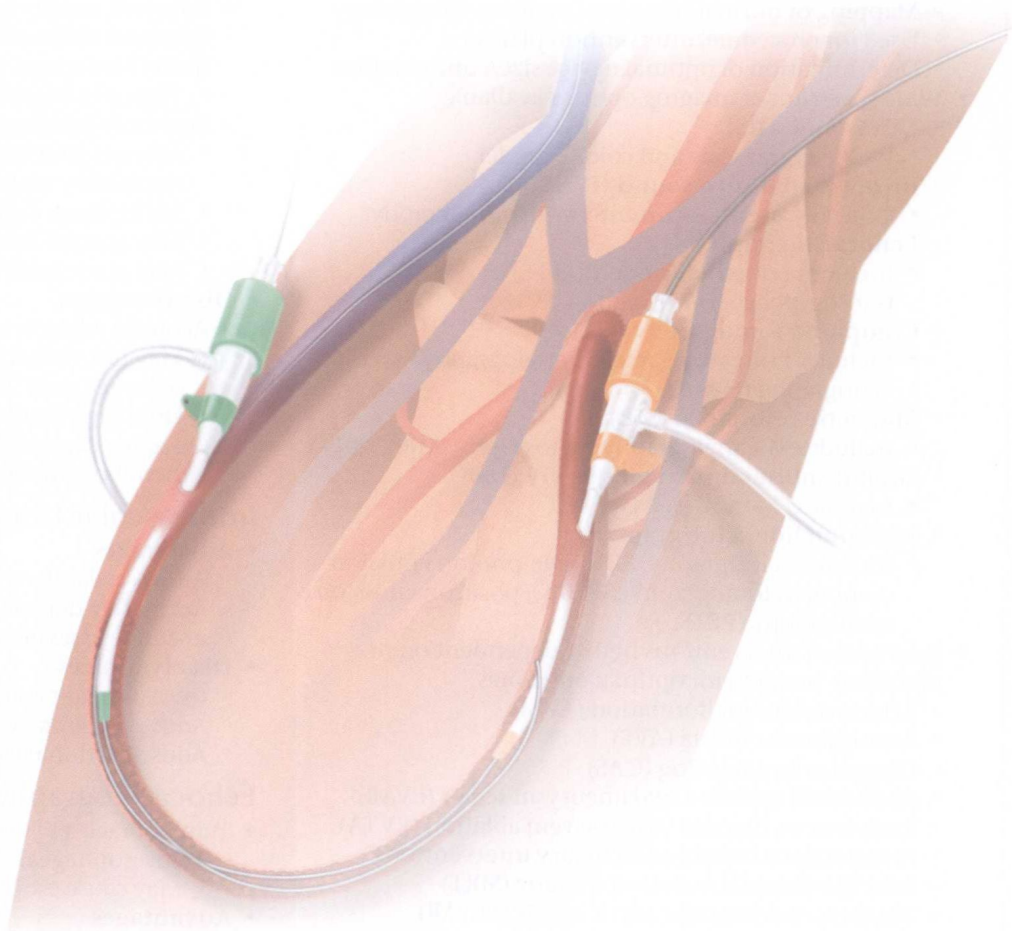
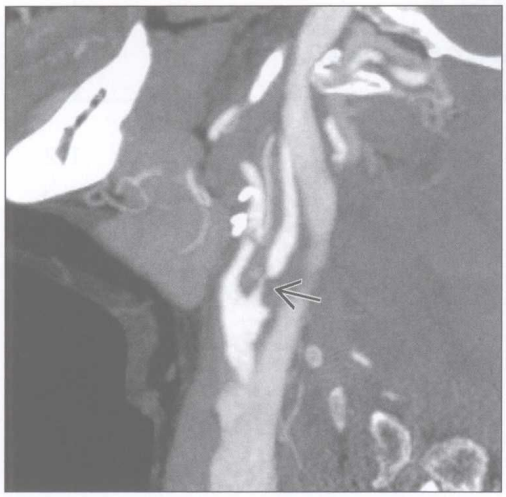
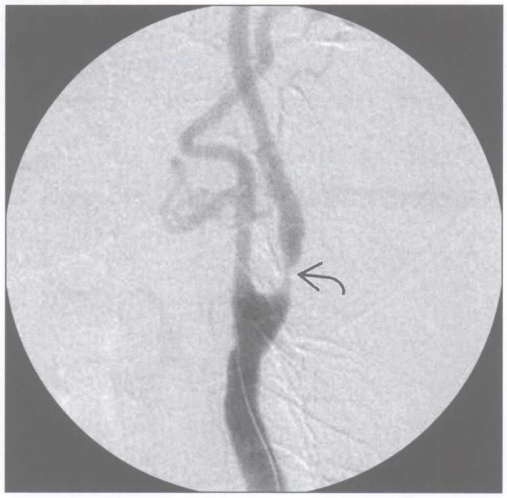
General Considerations



PRE-PROCEDURE IMAGING



CTA in a patient being evaluated for possible carotid artery stenting because of a history of prior carotid endarterectomy and new onset of slurred speech shows a severe left internal carotid artery stenosis.



The preprocedural CTA results indicated that the patient was anatomically suitable for carotid stenting with embolic protection. Intraoperative DSA confirms the severe internal carotid artery stenosis.

INTRODUCTION

Pre-Procedure Imaging Options

- Pre-procedure imaging should be obtained prior to certain vascular or nonvascular interventions
  - Mapping of normal/abnormal anatomy/physiology
  - Used for procedure/intervention planning
  - Determination of optimal device size/configuration
- Wide spectrum of imaging options available
  - **Ultrasound (US)**
    - Includes grayscale and color Doppler
  - **Intravascular ultrasound (IVUS)**
    - Typically used concurrently with angiography
  - **Echocardiography**
    - Includes transthoracic echo (TTE) or transesophageal (TEE) echo
  - **Computed tomography (CT)**
    - Includes nongated/gated CT angiography/venography (CTA/CTV)
  - **Magnetic resonance (MR)**
    - Includes MR angiography/venography (MRA/MRV)
  - **Digital subtraction angiography (DSA)**
    - Includes C-arm-based DynaCT
  - **Radionuclide scintigraphy**
    - Includes scintigraphy, 3D single-photon emission computed tomography (SPECT), positron emission tomography (PET)
- Examples of interventions highly dependent on pre-procedure imaging for optimal outcomes
  - Arteriovenous malformation (AVM)
  - Arteriovenous fistula (AVF)
  - Carotid artery stenting (CAS)
  - Abdominal endovascular aneurysm repair (EVAR)
  - Endovenous thermal varicose vein ablation (EVTA)
  - Percutaneous transhepatic biliary interventions
  - Selective internal radiation therapy (SIRT)
  - Thoracic endovascular aortic repair (TEVAR)
  - Transcatheter arterial chemoembolization (TACE)
  - Transjugular intrahepatic portosystemic shunt (TIPS)
  - Uterine artery embolization (UAE)

IMAGING MODALITIES

Ultrasonography (US)

- **Advantages**
  - No radiation exposure
  - Low cost, readily available
  - Excellent delineation of interfaces between solid & fluid-filled spaces
    - Typically images soft tissues very well
  - Real-time imaging
    - Assesses structural/physiologic changes with respiratory maneuvers, positional changes, etc.
    - Multiplanar capability
    - May acquire limited 3D datasets
    - May guide interventions in real time
- **Disadvantages**
  - Acoustic window restrictions
    - May not visualize tissue deep to air (in bowel/lungs) or bone (need "window" between ribs)
    - Dressings/bandages/casts limit viewing window
  - Operator dependent
  - Patient body habitus dependent

Intravascular Ultrasound (IVUS)

- **Advantages**
  - Allows accurate visualization of vascular lumen
  - Accurately depicts intraluminal/mural abnormalities
  - Accurate assessment of intravascular device position
- **Disadvantages**
  - Invasive compared to conventional US
  - Adds procedural expense
  - Adds additional examination time

Echocardiography

- Transthoracic (TTE) or transesophageal (TEE) options
  - Transesophageal requires sedation; is invasive
    - May cause esophageal rupture
- **Advantages**
  - Allows flow velocity quantification/gradient calculations
  - No radiation or contrast agents needed

PRE-PROCEDURE IMAGING

Key Facts

Utility of Pre-Procedure Imaging
- Mapping of normal/abnormal anatomy
- Physiologic information
- Used for procedure/intervention planning
- Determination of appropriate device type and size

Pre-Procedure Imaging Options
- **Ultrasound**: Includes grayscale, color Doppler, intravascular ultrasound (IVUS)
  - Advantages: Noninvasive/excellent tissue contrast
  - Disadvantages: Window limits/operator dependent
- **Intravascular ultrasound**: Used with angiography
  - Advantages: Depicts intraluminal characteristics
  - Disadvantages: Invasive/added expense
- **Echocardiography**: Includes transthoracic echo and transesophageal echo
  - Advantages: No radiation/contrast agents needed
  - Disadvantages: Limited 3D capability
- **Computed tomography**: Includes CTA/CTV
  - Advantages: Excellent 3D spatial resolution
  - Disadvantages: Ionizing radiation/requires contrast
- **Magnetic resonance**: Includes MRA/MRV
  - Advantages: Best tool for tissue characterization
  - Disadvantages: Inferior spatial resolution/expensive
- **Digital subtraction angiography**: Includes DynaCT
  - Advantages: Guidance for vascular interventions
  - Disadvantages: Invasive/requires contrast
- **Radionuclide scintigraphy**: Includes scintigraphy, 3D single-photon emission computed tomography (SPECT), positron emission tomography (PET)
  - Advantages: Physiologic information
  - Disadvantages: Radioisotope exposure

- **Disadvantages**
  - Acoustic window restrictions
    - Various available acoustic windows: Intercostal spaces, liver, epigastrium, or suprasternal notch
    - Cannot see through lung (due to air)
    - Cannot evaluate entire aortic arch/great vessels
    - Limited 3D capability compared to MR/CT

Computed Tomography (CT)
- **Advantages**
  - Accurately demonstrates vascular anatomy
  - Has excellent 3D spatial resolution
  - Allows post hoc image reconstructions in any plane
  - Best test for imaging of calcium
- **Disadvantages**
  - Requires iodinated contrast to evaluate vasculature
  - Uses ionizing radiation
    - Addition of multiphasic acquisitions, noncontrast or delayed scans increases radiation dose
  - Ascending aorta pulsation artifacts/pseudoflaps
    - Occurs with nongated study
- **Contraindications**
  - Severe allergy to iodinated contrast
    - Relative contraindication; use premedication regimen unless prior anaphylaxis
  - Renal dysfunction
    - Estimated glomerular filtration rate (eGFR) > 60: No contraindication to contrast administration
    - eGFR > 30 and < 60: Relative contraindication
    - May obtain CTA with precautions/hydration
    - Consider whether noncontrast CT is adequate

Magnetic Resonance (MR)
- **Advantages**
  - Phase contrast imaging allows flow quantification
  - Allows cardiovascular evaluation without IV contrast
  - Best tool for tissue characterization
    - Soft tissue contrast resolution superior to CT
  - May use despite iodinated contrast allergy
- **Disadvantages**
  - Long procedure; often requires several breath holds
  - High cost; not readily available
  - Inferior spatial resolution
  - Artifacts may mimic disease
  - Does not directly visualize calcium
  - Poor access to patient during examination
    - Difficult life support/monitoring in severely ill
  - Motion sensitive due to long acquisition times
    - May require sedation
- **Contraindications**
  - Severe claustrophobia
  - Medical implants
    - e.g., pacemakers, programmable ventricular shunts, medication pumps, brain aneurysm clips
  - Cannot use gadolinium contrast if renal failure
    - Risk of nephrogenic systemic fibrosis (NSF)

Digital Subtraction Angiography (DSA)
- **Advantages**
  - Guidance for performing vascular interventions
  - Real-time information regarding hemodynamics
- **Disadvantages**
  - Invasive
    - If sole planning modality, may require staged procedure due to contrast volume limitations
  - Requires exposure to ionizing radiation
    - Both patient and procedural personnel
  - Requires administration of intravascular contrast
    - Iodinated contrast typically used
    - May also use CO_2 contrast
    - Potential for contrast allergy/anaphylaxis
    - Potential for contrast-induced nephropathy
  - Underestimates vascular calcifications/thrombus
    - Predominantly displays intravascular contrast
  - Can have significant image quality issues due to misregistration artifacts
    - Bowel/patient/respiratory motion

Radionuclide Scintigraphy
- **Advantages**
  - Provides physiologic information
    - PET images uptake of labeled fluorodeoxyglucose (FDG), a glucose analogue; neoplasms are highly metabolic/rapidly synthesize FDG
    - Technetium (Tc-99m) labeled red blood cell (RBC) scan detects active gastrointestinal (GI) bleeding
- **Disadvantages**
  - Radioisotope exposure

- Highly sensitive but may be nonspecific
  - e.g., Tc-99m labeled RBC scan may detect active bleeding but localize only to right lower quadrant

PLANNING FOR SPECIFIC PROCEDURES

Arteriovenous Malformation/Fistula

- Ultrasound or cross-sectional (CTA/MRA) mapping of vascular anatomy
  - Delineation of inflow artery(ies)/outflow vein(s)
    - Demonstration of nidus/communication point
  - Determination of hemodynamic characteristics
    - "High flow" vs. "low flow"

Carotid Artery Stenting

- Stenosis severity determined with various modalities
  - Color Doppler ultrasound with spectral analysis
  - CT/MR angiography
    - Includes CTA reformations/maximum intensity projections (MIP)/stenosis severity calculations
  - Digital subtraction angiography
    - Typically combined with CAS procedure
- Stent choice based on CTA/MRA measurements and arterial anatomy
  - Various stent designs/configurations/lengths
    - Open vs. closed cell stent design
    - Straight vs. tapered configurations
  - Vessel diameters important for sizing stent appropriately for target vessel
- Embolic protection device (EPD) choice based on CTA/MRA measurements and arterial anatomy
  - Various types of embolic protection devices
    - Filter: Guidewire-mounted porous filtering device; deployed distal to target lesion
    - Proximal flow blockage: Proximal occlusion of target artery using catheter-compatible sheath, with occlusion balloon at distal end
  - Vessel diameters/lengths important for sizing EPD appropriately for target vessel
    - Need sufficient distance between target lesion and landing zone for EPD deployment
    - Need adequate vessel diameter distal to lesion for EPD deployment if using filter-type EPD

Abdominal Endovascular Aneurysm Repair

- Endograft choice based on CTA/MRA measurements
  - Endograft diameter based on true aortic short axis
    - Measured immediately below lowest renal artery
    - Graft proximal attachment measurement should include 10-15 mm distal to lowest renal artery
    - 10-20% oversizing to assure good graft apposition
- Proximal landing zone requires ≥ 10 mm long segment of normal aortic diameter
- External iliac artery diameter ≥ 7 mm for access
  - Most device delivery systems ≥ 21 French
  - Circumferential/excessive calcification limits access
- Excessive iliac artery tortuosity may complicate access
- Aneurysm neck morphology/angulation/length are determinants of proximal seal zone suitability
  - Neck angulation > 60° is contraindication
    - 30-60°angle can be challenging/problematic
  - Nontapered necks most favorable anatomy
  - Reverse tapered (conical) neck problematic
  - Mural thrombus/excessive calcifications problematic
- Bifurcated endografts require minimal distal aortic diameter (also known as distal neck)
  - Small distal neck may limit iliac limb perfusion
    - Risk for iliac limb thrombosis
  - Can place aorto-uni-iliac graft in small caliber distal aorta, combined with cross-femoral graft
- Determination of branch vessel patency/location
  - Relationship of renal arteries to neck is critical
  - Large lumbar arteries/patent inferior mesenteric artery may predispose to type II endoleak
- Abdominal aortic aneurysm (AAA) measurements generally include (but not limited to)
  - **Diameters**: Proximal and distal neck; aortic bifurcation; maximal aneurysm diameter; common/external iliac and common femoral arteries
  - **Length**: Lowest renal artery to aneurysm (neck length); lowest renal artery to aortic bifurcation; lowest renal artery to iliac bifurcation
  - **Angles**: Proximal and distal neck angulation; excessive iliac artery angulation

Endovenous Thermal Varicose Vein Ablation

- Pre-procedure duplex US imaging
  - Mapping of venous anatomy
    - Important to demonstrate great/small saphenous vein (GSV/SSV) distribution/course/size
    - Evaluation of nonsaphenous causes of venous insufficiency (e.g., Giacomini vein)
    - Used for planning EVTA vs. sclerotherapy as treatment for varicose veins
  - Assessment of valve closure times/venous reflux
    - Measure of severity of reflux/venous insufficiency
  - Evaluation for incompetent perforators
  - Evidence of post-thrombotic obstruction
  - Evaluation for deep/superficial venous thrombosis
- Cross-sectional imaging: CT/MR venography
  - Suspected pelvic/abdominal venous outflow disease
    - Evaluation for iliocaval thrombosis
    - Evaluation for compressive pathology (e.g., May-Thurner anatomy/syndrome)
    - Evaluation for pelvic venous incompetency/pelvic venous congestion
  - EVTA ineffective if venous outflow compromise

Transhepatic Biliary Interventions

- Pre-procedure duplex US imaging
  - Demonstrates biliary ductal anatomy
  - Confirms ductal dilatation
- Cross-sectional CT/MR imaging
  - Demonstrates etiology of biliary obstruction
  - MR cholangiopancreatography (MRCP) useful for pre-procedure biliary anatomy
- Hepatobiliary scintigraphy
  - Confirms/excludes biliary leak

Selective Internal Radiation Treatment

- Targeted treatment alternative for nonoperable primary/secondary hepatic malignancies
  - Pre-procedure CECT or contrast-enhanced MR evaluation of tumor burden
    - Used to calculate final amount of radioactivity to be delivered during SIRT
    - Need liver parenchyma involvement of < 50%
  - CTA/MRA evaluation of vascular anatomy
    - Evaluate for variant anatomy

- Hepaticoenteric communications
- Evaluation of portal vein patency
- Prophylactic embolization of hepaticoenteric arterial communications pre-SIRT; DSA guidance required
  - Elimination of potential pathways for nontarget embolization of injected radioactive particles
- Injection of Tc-99m-MAA (macroaggregated albumin) via catheter placed in intended position for SIRT
  - Followed by radionuclide lung perfusion scan; evaluates for any shunting to lungs

Thoracic Endovascular Aortic Repair

- Used for treatment of aneurysm, transection, type B dissection, intramural hematoma, penetrating ulcer
  - Requires satisfactory proximal landing zone
    - Need 20 mm proximal seal zone
    - Need close apposition of endograft to inner curve of aortic arch
  - May require endograft coverage of left subclavian artery to achieve adequate proximal seal zone
    - Requires vertebral/carotid duplex US; assess if left common carotid to left subclavian artery bypass or left subclavian transposition needed
  - May require debranching of aortic arch to achieve adequate proximal seal zone
    - Allows more proximal positioning of endograft
  - Requires satisfactory distal landing zone
    - Need 20 mm distal seal zone
    - Preferable not to cover celiac axis if possible
- Endograft choice based on CTA/MRA measurements
  - Endograft diameter based on true aortic short axis
    - Determination of aortic diameter at proximal and distal seal zones of endograft
  - Determination of length of coverage required
  - Assessment of aortic angulation/tortuosity
  - Mural/luminal characteristics of aorta
    - e.g., thrombus burden, calcifications
  - Characterization of access vessels
    - Common femoral/iliac artery diameters/tortuosity/calcifications

Transcatheter Arterial Chemoembolization

- Targeted treatment for inoperable primary/secondary hepatic malignancies
  - Pre-procedure CECT or contrast-enhanced MR evaluation of tumor burden
    - Need liver parenchyma involvement of < 50%
    - Assess tumor enhancement
    - Vascular tumors have better response
  - CTA/MRA evaluation of vascular anatomy
    - Determine arterial supply to tumor(s)
    - Evaluate for variant anatomy
    - Evaluation of portal vein patency

TIPS Creation

- Percutaneously created connection within liver between portal and systemic circulations
  - Pre-procedure ultrasound
    - Ultrasound confirmation of portal vein patency
    - Color Doppler US evaluates direction of portal flow (e.g., hepatopetal vs. hepatofugal flow)
    - Presence/absence of ascites
  - Cross-sectional imaging: CT or MR
    - Confirms portal vein patency
    - Presence/absence of ascites
    - Evaluates for competing portosystemic shunts
    - Demonstrates location/extent of varices
    - Shows portal/hepatic vein anatomic relationships
    - Optimal hepatic to portal vein puncture trajectory
    - Evaluates for extrahepatic portal venous division; risk of intraperitoneal hemorrhage if portal vein punctured outside liver parenchyma

Uterine Artery Embolization

- Transcatheter delivery of embolic particles to block uterine artery blood supply for various indications
  - Pre-procedure contrast-enhanced MR evaluation of fibroids/adenomyosis
    - Position of fibroids: Pedunculated vs. sessile, submucosal vs. subserosal
    - Fibroid size; compression of adjacent structures
    - Vascularity of fibroid; predictive of UAE response
    - Adenomyosis: Junctional zone > 12 mm
    - Exclusion of other abnormalities
  - CT if claustrophobic patient/MR contraindication
  - Doppler ultrasound examination of uterine cavity
    - Obstetric and gynecologic emergencies (e.g., postpartum hemorrhage)
  - Digital subtraction angiography
    - Evaluation of utero-ovarian anastomoses
    - Performed concurrently with embolization

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