

Contents

Preface	xiv
Contributors	xv
Part I: Basic Principles	
1 Principles of Physics and Technology in Diagnostic Ultrasound	4
<i>Bernhard J. Arnolds, Bernhard Gaßmann, Peter-Michael Klews</i>	
1.1 Introduction	4
1.2 Overview of Ultrasound Techniques	4
1.2.1 A-Mode	5
1.2.2 B-Mode	5
1.2.3 M-Mode	5
1.2.4 Color Duplex Sonography (CDS)	5
1.2.5 Power Doppler	6
1.2.6 Tissue Doppler	6
1.2.7 B-Flow	6
1.2.8 Color M-Mode	6
1.2.9 Doppler Spectral Analysis	7
1.2.10 Three-Dimensional Ultrasound Techniques	7
1.2.11 (Tissue) Harmonic Imaging	8
1.3 General Physical Properties	8
1.4 Formation of the Ultrasound Image	14
1.4.1 Frame Rate, Pulse Repetition Frequency, Penetration Depth, and Number (Density) of Scan Lines	15
1.5 Transducers	17
1.5.1 Transducer “Frequency”	19
1.6 The Doppler Effect	20
1.6.1 Problem of Pulsed Sampling—Aliasing	23
1.7 Components of an Ultrasound System	26
1.7.1 Interpretation of Color Duplex Images	27
1.8 Innovations	27
1.8.1 Harmonic Imaging	27
1.8.2 Tissue Doppler	29
1.8.3 Power Doppler	30
1.8.4 Real-Time Compound B-Mode	30
1.8.5 Spatial Compound Imaging	31
1.8.6 Elastography	31
1.8.7 Plane Wave Imaging	32
1.9 Documentation	34
2 Ultrasound Device Settings, Examination Technique, and Artifacts	38
<i>Reinhard Kubale, Hans-Peter Weskott</i>	
2.1 Introduction	38
2.1.1 Color Flow Imaging (CFI)	38
2.2 Transducer Selection and Instrument Settings	38
2.2.1 Prerequisites	38
2.2.2 Transducer Selection	38
2.2.3 Transducers	38
2.2.4 Optimizing the Image with Operator-Controlled Settings	39
2.3 Examination Technique, Limitations, and Artifacts	46
2.3.1 Examination Protocol	46
2.3.2 Limitations and Artifacts	46
2.4 Effect of Imaging Technique on Spatial Resolution and Lesion Detectability	49

3

Hemodynamics

Bernhard J. Arnolds, Hubert Stiegler

3.1

Introduction

54

3.2

Flow Characteristics in Steady Volume Flow

54

3.2.1

Shear Rate

55

3.2.2

Flow Resistance, Hagen-Poiseuille Law

55

3.2.3

Fahraeus-Lindqvist Effect, Apparent Viscosity, and Axial Migration

55

3.3

Flow Characteristics in Straight Vessels of Constant Cross Section

56

3.3.1

Reynolds Number as the Determinant of Laminar or Turbulent Flow

56

3.4

Flow Characteristics in Vessels of Variable Cross Section

57

3.4.1

Bernoulli Principle

57

3.4.2

Flow Profile at Constrictions and Expansions

58

3.4.3

Flow Separation, Separation Zones, and Turbulent Zones

58

3.5

Characteristics of Pulsatile Volume Flow

59

3.5.1

Velocity Profile of Pulsatile Flow

59

3.5.2

Approach to the Flow Complexity

61

3.5.3

Waveforms of Pulsatile Flow/Helical Flow

61

3.6

Blood Flow through Stenoses

62

3.6.1

Relationship between Vessel Cross Section and Flow Velocity

62

3.6.2

Quantification of Stenosis

63

3.6.3

Intra- and Poststenotic Flow Changes

64

3.6.4

Hemodynamic Significance

66

3.7

Evaluation of Stenoses by Color Duplex Imaging

66

3.7.1

Criteria for Vascular Findings

67

3.7.2

Instrument Settings

67

3.7.3

Envelope Curves of Doppler Spectrum

68

3.7.4

Spectral Window in Doppler Frequency Analysis

68

3.7.5

Timing of Velocity Measurements in Doppler Spectrum

68

3.7.6

Angle Correction

68

3.7.7

Spectral Doppler Waveform Patterns

69

3.7.8

Doppler Waveform Patterns Associated with Stenotic Lesions

69

3.7.9

Color Flow Imaging

73

3.7.10

Integral Display of Flow Velocity and Volume Flow

73

3.7.11

Limitations of Color Duplex Imaging

74

3.7.12

Other Techniques

74

3.8

Flow Indices

75

3.8.1

Analytical Criteria

75

4

Ultrasound Contrast Agents—Fundamentals and Principles of Use

Hans-Peter Weskott, Christian Greis

4.1

Structure and Properties of Ultrasound Contrast Agents

78

4.1.1

Structure

78

4.1.2

Pharmacologic Properties of Ultrasound Contrast Agents

78

4.1.3

Acoustic Properties of Ultrasound Contrast Agents

79

4.2

Equipment and Software: Settings and Transducers

81

4.2.1

Quality Aspects of Contrast-Enhanced Imaging

81

4.2.2

Transducer Selection

82

4.3

Vessel- and Organ-Specific Contrast Doses

82

4.3.1

Abdominal and Peripheral Vessels

82

4.3.2

Abdominal Organs

84

4.3.3

Small Parts

84

4.3.4

Intracavitary Use

85

vi

4.4	Interpretation of Findings	85	4.4.2	Visual Interpretation: Online and Offline	85
4.4.1	Documentation: From JPEG to Digital Raw Data	85	4.4.3	TIC: Software-Assisted Analysis of Enhancement Kinetics	85

Part II: Vascular Ultrasound

5	Extracranial Cerebral Arteries	92			
	<i>Christian Arning, Günter Seidel</i>				
5.1	General Remarks	92	5.3.1	Anatomy, Examination Technique, and Normal Findings.....	111
5.2	Carotid Artery	92	5.3.2	Stenosis.....	114
5.2.1	Anatomy, Examination Technique, and Normal Findings.....	92	5.3.3	Tortuosity and Kinking.....	116
5.2.2	Stenosis.....	97	5.3.4	Occlusion	116
5.2.3	Tortuosity and Kinking.....	102	5.3.5	Subclavian Steal	117
5.2.4	Occlusion	103	5.3.6	Special Pathologies	118
5.2.5	Special Pathologies	105	5.4	Color Duplex Sonography Compared with Other Modalities	120
5.3	Vertebral Artery	111			
6	Intracerebral Arteries and Brain	124			
	<i>Günter Seidel, Christian Arning</i>				
6.1	General Remarks	124	6.3.1	Examination Technique and Normal Findings	144
6.2	Transtemporal Approach	124	6.3.2	Vascular Pathology	145
6.2.1	Examination Technique and Normal Findings	124	6.4	Orbital Approach	149
6.2.2	Vascular Pathology	128	6.4.1	Examination Technique and Normal Findings	149
6.2.3	Parenchymal Pathology.....	138	6.4.2	Pathologic Findings.....	149
6.3	Transnuchal Approach	144			
7	Limbs	156			
7.1	Upper Extremities	156		Conclusion	174
7.1.1	Arteries	156	7.1.2	Veins of the Neck and Upper Extremities	176
	<i>Thomas Karasch, Hubert Stiegler, Rupert Bauersachs</i>			<i>Hubert Stiegler, Viola Hach-Wunderle</i>	
	General Remarks	156		General Remarks	176
	Anatomy and Variants	156		Anatomy and Variants	176
	Examination Technique	158		Examination Technique and Normal Findings	177
	Normal Findings.....	161		Pathologic Findings	179
	Pathologic Findings	162		Documentation.....	183
	Documentation.....	171		Comparison of Color Duplex Sonography with Other Modalities.....	184
	Sources of Error	173		Conclusion	185
	Utility of Color Duplex Sonography Compared with Other Methods.....	173			

7.2	Lower Extremities	186		Examination Technique and Normal Findings	244
7.2.1	Arteries	186		Pathologic Findings	247
	<i>Hubert Stiegler, Thomas Karasch, Rupert Bauersachs</i>			Documentation	252
	General Remarks	186		Efficacy of Color Duplex Sonography Relative to Other Methods	253
	Anatomy and Variants	186	7.3	Hemodialysis Access	260
	Examination Technique	191		<i>Reinhard Kubale, Alexander Maßmann, Gunnar Heine, Gottfried Walker</i>	
	Normal Findings	195	7.3.1	General Remarks	260
	Pathologic Findings	197	7.3.2	Normal Anatomy and Access Types	260
	Follow-Up of Revascularization			Brescia-Cimino Fistula	260
	Procedures	215		ePTFE Graft	262
	Sources of Error	218		Other Types of Prosthetic Access	262
	Documentation	219	7.3.3	Examination Technique and Normal Findings	263
	Utility of Color Duplex Sonography Compared with Other Methods	220		Clinical Examination and History	263
7.2.2	Veins: Superficial Lower Extremity Venous System	225		Examination Protocol and Equipment Settings	263
	<i>Hubert Stiegler, Viola Hach-Wunderle</i>			Normal Findings	266
	General Remarks	225	7.3.4	Pathologic Findings	266
	Anatomy and Variants	225		Preliminary Remarks	266
	Examination Technique and Normal Findings	228		Stenosis and Occlusion	266
	Pathologic Findings	232		Aneurysms and Perivascular Changes	269
	Documentation	239		Functional Problems	271
	Comparison of Color Duplex Sonography with Other Modalities	240	7.3.5	Pre- and Postinterventional Examinations	272
	Conclusion	240		Preinterventional Examination	272
7.2.3	Veins: Deep Venous System	242		Postinterventional Follow-Ups	273
	<i>Hubert Stiegler, Viola Hach-Wunderle</i>		7.3.6	Documentation	275
	General Remarks	242	7.3.7	Comparison of Color Duplex Sonography with Other Modalities	276
	Anatomy and Variants	242			
8	Nonatherosclerotic Arterial Diseases: Vasculitis, Fibromuscular Dysplasia, Cystic Adventitial Disease, Compression Syndromes	280			
	<i>Hubert Stiegler, Wolfgang A. Schmidt</i>				
8.1	General Remarks	280	8.3.4	Cystic Adventitial Degeneration (CAD)	291
8.2	Examination Technique	280	8.3.5	Compression Syndromes	292
8.3	Pathologic Findings	281	8.4	Documentation	300
8.3.1	Vasculitis	281	8.5	Comparison of Color Duplex Sonography with Other Modalities	301
8.3.2	Thromboangiitis obliterans (Winiwarer-Buerger Disease)	288			
8.3.3	Fibromuscular Dysplasia (FMD)	291			
9	Vascular Malformations	308			
	<i>Hubert Stiegler, Peter Urban</i>				
9.1	General Remarks	308	9.2	Etiology and Pathogenesis	308

9.3	Differential Diagnosis	308	9.7	Clinical Manifestations and Typical Color Duplex Findings	314
9.4	Classification	308			
9.5	Pathophysiology	308	9.7.1	Arterial Malformation (AMF)	314
9.5.1	Truncular Malformations	309	9.7.2	Arteriovenous Malformation (AVM)....	314
9.5.2	Extratruncular Malformations	310	9.7.3	Venous Malformation (VMF)	314
9.6	Examination Technique	311	9.7.4	Lymphatic Malformation (LMF)	318
9.6.1	Goals	311	9.7.5	Capillary Malformation (CMF)	318
9.6.2	Necessary Equipment	311	9.7.6	Combined Malformations	318
9.6.3	Examiner Requirements	311	9.8	Documentation	322
9.6.4	Patient and Examiner Positions	311	9.9	Comparison of Color Duplex Sonography with Other Modalities	323
9.6.5	Examination Protocol	313	9.10	Conclusion	324

Part III: Abdominal Organs: Vascularization and Perfusion

10	Aorta and Outgoing Branches	328			
	<i>Dirk-Andre Clevert, Reinhard Kubale, Alexander Maßmann</i>				
10.1	General Remarks	328	10.5.7	Complications	339
10.1.1	Color Duplex Sonography (CDS)	328	10.6	Pre- and Postinterventional Diagnostics	342
10.2	Aortic Anatomy and Variants	328			
10.2.1	Vascular Branches	329	10.6.1	Pre- and Postsurgical Examinations	342
10.2.2	Anatomical Variants	329	10.6.2	Pre- and Postinterventional Examinations	343
10.3	Examination Technique	329	10.6.3	Examination Technique	344
10.3.1	Transducer and Device Settings	329	10.6.4	Procedure in Case of Endoleaks	346
10.3.2	Color Duplex Sonography of the Aorta	329	10.6.5	Findings	346
10.3.3	Color Duplex Sonography of the Aortic Branching Vessels	331	10.6.6	Definition and Classification of Endoleaks	346
10.3.4	Contrast-Enhanced Ultrasound (CEUS) ..	331	10.6.7	Long-Term Follow-up	350
10.4	Normal Findings	331	10.6.8	Image Fusion for the Localization and Characterization of Endoleaks and for Further Intervention Monitoring	350
10.4.1	Abdominal Aorta	331	10.7	Documentation	352
10.5	Pathologic Findings in the CCDS	332	10.8	Value of Color Duplex Sonography in Comparison to Other Imaging Methods	353
10.5.1	Wall Thickenings, Plaques, Stenoses, and Occlusions	333	10.8.1	Computed Tomography	354
10.5.2	Aneurysms	335	10.8.2	Magnetic Resonance Angiography	354
10.5.3	Aneurysm Verum	335	10.8.3	Importance of Color Duplex Sonography and CEUS	355
10.5.4	Aortic Dissection	336			
10.5.5	Inflammatory Aneurysm	338			
10.5.6	Infected or Mycotic Aneurysm	339			

11	Visceral Arteries	362
	<i>Wilma Schierling, Reinhard Kubale, Karin Pfister</i>	
11.1	General Remarks	362
11.2	Anatomy, Variants, and Collaterals	362
11.2.1	Celiac Trunk and Its Branches	363
11.2.2	Superior and Inferior Mesenteric Arteries	364
11.2.3	Preformed Arterial Collaterals	365
11.3	Examination Technique	365
11.3.1	Settings	365
11.3.2	Patient Preparations	365
11.3.3	Color Duplex Sonography	366
11.3.4	Examination Time	368
11.3.5	Contrast-Enhanced Ultrasound	368
11.4	Normal Findings and Variants	368
11.4.1	Normal Findings	368
11.4.2	Variants	369
11.5	Pathologic Findings	370
11.5.1	Plaque, Stenosis, and Occlusion	370
11.5.2	Acute Intestinal Ischemia: Embolism, Thrombosis, Dissection, and Nonocclusive Intestinal Ischemia	374
11.5.3	Aneurysms	376
11.5.4	Arteriovenous Malformation	379
11.5.5	Involvement of Visceral Vessels by Systemic and Inflammatory Diseases	379
11.5.6	Chronic Inflammatory Bowel Disease ..	381
11.5.7	Applications in Vascular Surgery and Interventional Radiology	381
11.5.8	Follow-up after Organ Transplantation	381
11.6	Documentation	382
11.7	Comparison of Color Duplex Sonography with Other Modalities	382
11.7.1	Angiography	382
11.7.2	Sonography	382
11.7.3	Computed Tomography	382
11.7.4	Magnetic Resonance Angiography	382
11.8	Importance of CDS and CEUS in Clinical Diagnosis	383
11.8.1	Aneurysms and Arteriovenous Malformations	383
11.8.2	Stenoses and Occlusions	383
11.8.3	Follow-Up	384
11.8.4	Quantitative Measurements	384
12	Abdominal Veins	388
	<i>Reinhard Kubale, Ernst Michael Jung</i>	
12.1	General Remarks	388
12.2	Anatomy, Variants, and Collaterals	388
12.2.1	Inferior Vena Cava, Lumbar and Pelvic Veins	388
12.2.2	Renal Veins	390
12.2.3	Gonadal Veins	391
12.2.4	Portal Venous System and Mesenteric Venous System	391
12.3	Examination Technique	392
12.3.1	Transducer	392
12.3.2	Protocol	392
12.3.3	Velocity Measurements	394
12.4	Normal Findings	395
12.4.1	Inferior Vena Cava, Lumbar and Iliac Veins	395
12.4.2	Renal Veins	395
12.4.3	Hepatic Veins	395
12.4.4	Portal and Mesenteric Venous System ...	396
12.5	Pathologic Findings	397
12.5.1	Malformations	397
12.5.2	Thrombosis, Stenosis, and Occlusion ...	400
12.6	Applications of CDS in Surgical and Interventional Procedures	411
12.6.1	Vena Cava Filter Placement	411
12.6.2	Extracorporeal Membrane Oxygenation (ECMO)	411
12.6.3	Reconstructive Surgery of Cardiac Anomalies	412
12.7	Documentation	412

12.8	Comparison of Color Duplex Sonography with Other Modalities.	413	12.8.1	Inferior Vena Cava and the Renal, Iliac, and Ovarian Veins	414
			12.8.2	Mesenteric and Splenoportal Axis	415
13	Microcirculation and Tumor Perfusion.....	420			
	<i>Hans-Peter Weskott</i>				
13.1	General Remarks	420	13.3	Tumor Vasculature and Perfusion	420
13.2	Available Imaging Techniques	420			
14	Kidneys and Renal Transplants	428			
	<i>Hans-Peter Weskott, Konrad Friedrich Stock</i>				
14.1	General Remarks	428	14.5.4	Primary Vascular Diseases of the Kidney.....	444
14.2	Anatomy and Variants	428	14.5.5	Acute Renal Failure	452
14.2.1	Orthotopic Kidneys.....	428	14.5.6	Renal Trauma	454
14.2.2	Variants.....	428	14.6	Evaluation of Renal Transplants.....	454
14.3	Examination Technique	428	14.6.1	Protocol for Ultrasound Evaluation of Renal Transplants.....	454
14.3.1	Procedure.....	428	14.6.2	Complications of Renal Transplantation in Clinical Ultrasound.....	457
14.4	Normal Findings	430	14.6.3	Outlook.....	459
14.4.1	Extrarenal Arteries	430	14.7	Documentation.....	459
14.4.2	Intrarenal Arteries.....	431	14.8	Comparison of Color Duplex Sonography and Contrast-Enhanced Ultrasound	459
14.5	Pathologic Findings.....	432			
14.5.1	Nephrolithiasis and Urolithiasis	432			
14.5.2	Inflammatory Renal Diseases.....	432			
14.5.3	Tumors and Tumor Vascularity	434			
15	Liver and Portal Venous System	464			
	<i>Hans-Peter Weskott, Reinhard Kubale</i>				
15.1	General Remarks	464	15.3.2	Equipment Settings and Flow Detection Techniques.....	467
15.2	Anatomy and Common Variants	464	15.3.3	Contrast Examination.....	468
15.2.1	Oxygen and Nutrient Supply of the Liver.....	464	15.4	Normal Findings, Variants, and Hemodynamics.....	470
15.2.2	Arterial Blood Supply	464	15.4.1	Hemodynamics.....	470
15.2.3	Portal Vein	464	15.5	Pathologic Findings.....	474
15.2.4	Intrahepatic Vascular Distribution and the Hepatic Segments.....	465	15.5.1	Aneurysms.....	474
15.3	Examination Technique Including Contrast Administration	466	15.5.2	Malformations of the Portal Venous System	474
15.3.1	Examination Protocol and Doppler Measurements	466	15.5.3	Hereditary Hemorrhagic Telangiectasia (Osler-Weber-Rendu Disease).....	475

15.5.4	Obstruction of the Hepatic Veins	476	15.7	Comparison of Color Duplex Sonography and CEUS with Other Modalities	502
15.5.5	Circumscribed Hepatic Vein Stenosis . . .	478	15.7.1	Primary Vascular Diseases of the Liver	503
15.5.6	Thrombosis of the Splenoportal Axis, Portal Vein Thrombosis	478	15.7.2	Secondary Vascular Changes in Diffuse Liver Diseases	503
15.5.7	Diffuse Liver Diseases	481	15.7.3	Focal Hepatic Lesions	504
15.5.8	Portal Hypertension	485	15.8	Conclusion	504
15.5.9	Benign Focal Hepatic Lesions	488			
15.5.10	Focal Hepatic Malignancies	494			
15.5.11	Liver Transplantation	497			
15.5.12	Shunt Procedures	498			
15.5.13	Cancer Therapy	500			
15.6	Diagnosis in Surgical and Interventional Percutaneous Procedures	502			
16	Contrast-Enhanced Ultrasound (CEUS) in Biliary Diseases	510			
	<i>Hans-Peter Weskott</i>				
16.1	Background	510	16.3.1	Cholecystitis and Cholangitis	510
16.2	Examination Technique	510	16.3.2	Tumors of the Gallbladder Wall	510
16.3	Pathologic Findings	510			
17	Contrast-Enhanced Ultrasound (CEUS) in Intestinal Diseases	516			
	<i>Hans-Peter Weskott</i>				
17.1	General Remarks	516	17.3.1	Diverticulitis	516
17.2	Examination Technique	516	17.3.2	Inflammatory Bowel Disease	518
17.3	Pathologic Findings	516	17.3.3	Ischemia and Infarction	518
			17.3.4	Intestinal Tumors	518
18	Contrast-Enhanced Ultrasound (CEUS) in Pancreatic Diseases	522			
	<i>Hans-Peter Weskott, Reinhard Kubale</i>				
18.1	General Remarks	522	18.4	Pancreatic Masses	522
18.2	Examination Technique	522	18.4.1	Solid Pancreatic Tumors	522
18.3	Acute Pancreatitis	522	18.4.2	Cystic Pancreatic Lesions	524
19	Contrast-Enhanced Ultrasound (CEUS) in Splenic Diseases	528			
	<i>Hans-Peter Weskott</i>				
19.1	General Remarks	528	19.3	Pathologic Findings	529
19.2	Examination Technique, Normal Findings, and Indications for CEUS	528	19.3.1	Benign Solid Lesions	529
			19.3.2	Malignant Lesions	529
			19.3.3	Splenic Infarction and Bleeding	529

20	Contrast-Enhanced Ultrasound (CEUS) in Pediatric Diseases	536
	<i>Doris Franke</i>	
20.1	General Remarks	536
20.2	Contrast-Enhanced Ultrasound (CEUS) in Children	536
20.2.1	Voiding Urosonography (VUS) Using Ultrasound Contrast Agents (US-CA)...	536
20.2.2	Potential Indications for Intravenous Use of CEUS in Children	537
20.2.3	Indications for Contrast-Enhanced Ultrasound (CEUS) in Children.....	537
20.3	Technical Aspects and Practical Approach	537
20.4	Dosage of the Ultrasound Contrast Media.....	538
20.5	Safety, Side Effects, and Contraindications.....	541
20.6	Limitations.....	541
21	Novel and Upcoming Ultrasound Techniques	544
	<i>Hans-Peter Weskott, Reinhard Kubale</i>	
21.1	B-Flow and B-Flow CEUS	544
21.2	Superb Microvascular Imaging (SMI) ...	544
21.3	Plane Wave Imaging, Ultrafast Doppler, Vector Flow Imaging (VFI).....	545
21.4	Novel Calculation Techniques for Arterial Stiffness.....	545
21.5	Novel Ultrasound Contrast Agents	546
21.6	Novel Dynamic B-Mode Techniques to Evaluate Arterial Stiffness	547
21.7	Fusion Imaging	547
Index.....		551