# Table of Contents


## I Diagnostic Cardiac Catheterization 1

### 1 Indications for Diagnostic Cardiac Catheterization ..... 2

### 2 Risks and Complications ..... 4

### 3 Preparation for Cardiac Catheterization ..... 5

Informed Consent ..... 5
Examinations Prior to Catheterization ..... 6
Specific Patient Preparation ..... 6
Immediate Preparation for Examination ..... 7
Special Features of Cardiac Catheterization in Awake Patients ..... 7

### 4 The Laboratory ..... 8

Equipment ..... 8
Personnel ..... 12
Emergency Equipment ..... 13
Radiation Technology and Radiation Safety ..... 13

### 5 Interpretation of Findings ..... 17

### 6 Contrast Media ..... 19

Adverse Reactions to Contrast Media ..... 20

### 7 Arterial and Venous Access ..... 25

**Arterial Access** ..... 26
Techniques and General Approach ..... 26
Puncture of the Femoral Artery ..... 27
Puncture of the Radial Artery ..... 29
Puncture of the Brachial Artery ..... 30

**Venous Puncture** ..... 31
Puncture of the Femoral Vein ..... 31
Other Vascular Access Sites ..... 31

**Vascular Complications after Cardiac Catheterization** ..... 31

**Vascular Closure Devices for Immediate Hemostasis after Cardiac Catheterization and Coronary Intervention** ..... 33
Collagen-based Vascular Closure Devices ..... 34
Percutaneous Suture-mediated Vascular Closure Devices ..... 35
Clip-based Vascular Closure Devices ..... 35

### 8 Coronary Angiography ..... 38

Catheterization Technique ..... 42

**The Normal Coronary Angiogram** ..... 49
Injection Technique ..... 49
Coronary Anatomy ..... 49
Projections ..... 51
Problems and Potential Mistakes ..... 57
Complications of Coronary Angiography ..... 61
Coronary Anomalies ..... 63
Vasospastic Angina ..... 65
Noninvasive Coronary Angiography (Cardiac MRI and Cardiac CT) ..... 66

## 9 Catheterization of the Cardiac Chambers ... 71

**Left Heart Catheterization** ... 71
Retrograde Left Heart Catheterization ... 71
The Left Ventricular Angiogram ... 72
Transseptal Left Heart Catheterization ... 82

**Right Heart Catheterization** ... 87
Right Ventriculogram ... 90
The Right Atrial Angiogram ... 91

## 10 Aortography ... 94

Procedure ... 94
The Normal Aortogram ... 95

## 11 Angiography of the Pulmonary Artery ... 97

Procedure ... 97
Noninvasive Pulmonary Angiography ... 98

## 12 Hemodynamics ... 99

**Basic Physics of Pressure Measurement** ... 99

**Pressure Curves** ... 102
Pulmonary Capillary Wedge Pressure ... 104
Arterial and Pulmonary Arterial Pressure ... 104
Ventricular Pressure ... 106

**Pressure Gradient** ... 107

**Cardiac Output, Cardiac Index** ... 110
Fick Method (Oxygen Consumption) ... 110
Thermodilution Method ... 111
Angiographic Method ... 113

**Vascular Resistances** ... 113

**Valve Area** ... 114

**Measurement of Valvular Regurgitation** ... 114

**Shunt Detection and Measurement** ... 115
Shunt Quantification Using Fick's Principle with Diagnostic Saturation Run ... 115
The Dye Dilution Method ... 118
Angiographic Shunt Diagnosis ... 119
Noninvasive Shunt Diagnosis ... 119

## 13 Endomyocardial Biopsy ... 122

# II Cardiac Catheterization in the Diagnostic of Specific Diseases 125

## 14 Valvular Disease ... 126

**Mitral Valve Stenosis** ... 126

**Mitral Regurgitation** ... 132

**Aortic Valve Stenosis** ... 139

**Aortic Regurgitation** ... 147

**Tricuspid Stenosis** ... 153

**Tricuspid Regurgitation** ... 156

## 15 Cardiomyopathies ... 162

**Dilated Cardiomyopathy** ... 162

**Hypertrophic Cardiomyopathy** ... 165
Alcohol Septal Ablation ... 170

**Restrictive Cardiomyopathy** ... 173

**Arrhythmogenic Right Ventricular Cardiomyopathy** ... 178

**Takotsubo Cardiomyopathy ("Apical Ballooning Syndrome")** ... 180

## 16 Coronary Artery Disease ... 183

**Coronary Insufficiency** ... 183

**Coronary Stenosis** ... 184

**Collateral Circulation** ... 188

**Special Characteristics of Coronary Angiography and Cardiac Catheterization in Coronary Artery Disease** ... 191
Coronary Angiography in Left Main Stem Stenosis ... 191

Coronary Angiography in Acute Coronary Syndrome . . . 192
Coronary Angiography in Unstable Angina Pectoris and NSTEMI . . . 192
Coronary Angiography in Acute Myocardial Infarction . . . 194
Acute Mitral Regurgitation . . . 196
Ventricular Septal Rupture . . . 197
Rupture of the Free Wall . . . 199
**Special Characteristics of Coronary Angiography after Heart Transplantation** . . . 200

**17 Pericardial Disease** . . . 204
**Constrictive Pericarditis** . . . 204
**Pericardial Effusion and Pericardial Tamponade** 207
Pericardiocentesis . . . 209
Cardiac Catheterization with Pericardial Tamponade . . . 211

**18 Aortic Dissection** . . . 214
**Aortic Dissection** . . . 214
**Ruptured Sinus of Valsalva Aneurysm** . . . 217

**19 Congenital Heart Disease** . . . 221
**Atrial Septal Defect** . . . 221
**Ventricular Septal Defect** . . . 225
**Aortic Coarctation** . . . 228
**Pulmonary Valve Stenosis** . . . 230

**20 Acute Pulmonary Embolism** . . . 234
Mechanical Thrombolysis . . . 237

**21 Myocarditis** . . . 240

**III Interventional Cardiac Catheterization 243**

**22 Percutaneous Coronary Intervention and Coronary Stent Implantation** . . . 244
**Percutaneous Coronary Intervention (PCI)** . . . 244
**Coronary Stent Implantation** . . . 269
**Characteristics of Different Stents** . . . 280
Balloon-expandable Bare-metal Stents . . . 280
Self-expanding Metal Stent without/with Drugs . . . 280
Bifurcation Stents . . . 280
Stent Grafts . . . 280
Drug-eluting Stents . . . 280
Absorbable Vascular Scaffolds . . . 281

**23 Percutaneous Coronary Intervention in Acute Coronary Syndrome** . . . 289
Acute Coronary Syndrome without ST-segment Elevation . . . 289
Acute Coronary Syndrome with ST-segment Elevation . . . 289
Primary PCI . . . 290
Rescue PCI . . . 294
“Facilitated” PCI . . . 294

**24 Cutting Balloon Angioplasty** . . . 296
Cutting Balloon . . . 296
AngioSculpt Balloon . . . 297
SafeCut Balloon . . . 298

**25 Rotational Atherectomy** . . . 299

## 26 Laser Angioplasty ... 307

Recanalization of Chronic Occlusions with the "Laser Wire" ... 310

## 27 Thrombectomy and Protection Systems ... 311

Aspiration Catheter ... 311
Mechanical Thrombectomy ... 312
X-Sizer ... 313
AngioJet ... 315

**Coronary Protection Systems** ... 316

**Characteristics of a Variety of Protection Systems** ... 318
Occlusion System ... 318
Filter System ... 319

## 28 Peri- and Postinterventional Antithrombotic Therapy for Coronary Interventions ... 324

Unfractionated Heparin ... 326
Low-molecular-weight Heparins ... 327
Direct Thrombin Inhibitors ... 327
Pentasaccharides ... 327
Aspirin ... 327
P2Y12 Inhibitors ... 328
Glycoprotein IIb/IIIa Inhibitor ... 328
Fibrinolytics ... 329
Specific clinical situations ... 330

Diagnostic Coronary Angiography ... 330
PCI in Stable Angina ... 330
PCI in Acute Coronary Syndrome ... 330
Therapy after Stent Implantation ... 331
Patients in Cardiogenic Shock ... 331
Patients with an Indication for Oral Anticoagulation ... 331
Non-cardiac Surgeries after Stent Implantation ... 331

## 29 Special Examination Techniques ... 333

**Intravascular Ultrasound** ... 333

**Intracoronary Pressure and Doppler Measurements** ... 337
Intracoronary Pressure Measurement ... 337

Doppler Guidewire ... 341

**Intracardiac Echocardiography** ... 342

**Optical Coherence Tomography (OCT)** ... 343

## 30 Percutaneous Cardiac Support Systems ... 346

**Intra-aortic Balloon Pump** ... 346

**Impella Pump** ... 349

**TandemHeart Pump** ... 351

## 31 Heart Valve Interventions ... 353

**Percutaneous Mitral Commissurotomy** ... 353

**Mitral Valve Interventions for Mitral Regurgitation** ... 361

**Pulmonary Valvuloplasty** ... 366

**Aortic Valvuloplasty** ... 368

**Transcatheter Aortic Valve Implantation (TAVI)** ... 372

## 32 Occlusion of Septal Defects ... 380

**Atrial Septal Defect** ... 380

**Patent Foramen Ovale** ... 383

## 33 Other Interventional Techniques ... 389

**Occlusion of the Left Atrial Appendage (LAA Occlusion)** ... 389

**Renal Nerve Ablation for Resistant Arterial Hypertension** ... 393

## 34 Percutaneous Retrieval of Foreign Bodies in the Cardiovascular System ... 398

# List of Videos and Other Online Resources

**Coronary Angiography**

Normal finding

Coronary angiography and PTCA with gadolinium MRI contrast medium because of severe renal insufficiency

Two examples of coronary spasm

Coronary anomalies

Situs inversus

Coronary aneurysm

Intramyocardial bridging

Other findings

**Ventriculography**

Left ventricular thrombus

Left ventricular apical thrombus

Ventricular septal defect

Left ventricular assist device

**Diseases of the Aorta**

Normal finding

Atheromatous aorta

Aortic dissection

Kinking of the aorta

**Pulmonary Angiography**

Pulmonary angiogram for pulmonary embolism with shock

Interventional fragmentation of the embolus

Repeat angiography

**Endomyocardial Biopsy**

Endomyocardial biopsy

**Valvular Heart Disease**

Aortic valve

Mitral valve

Pulmonary valve

Aortic valve prosthesis

Ductus arteriosus

Coarctation of the aorta

**Cardiomyopathies**

Hypertensive heart disease

Dilated cardiomyopathy

Hypertrophic cardiomyopathy

Restrictive cardiomyopathy

Arrhythmogenic right ventricular cardiomyopathy

Takotsubo cardiomyopathy

**Coronary Artery Disease**

Coronary sclerosis

**Pericardial Diseases**

Constrictive pericarditis

Pericardial tamponade

Pericardiocentesis

Pneumopericardium

**Congenital Heart Disease**

Atrial septal defect type II: interventional occlusion

Patent foramen ovale: interventional occlusion

Cryptogenic stroke

**Pulmonary Embolism**

Pulmonary angiogram

Thrombus fragmentation with the Clot-Buster device

Pulmonary angiogram

**Percutaneous Coronary Interventions**

PCI of a vein graft: bifurcation at a Y-bypass

LCX-PCI: bifurcation with a marginal branch

Bifurcation stenosis of the left coronary main stem

Direct stent implantation into the main stem

Complex multivessel intervention

Recanalization of a chronically occluded RCA: guiding catheter selection

Transradial RCA recanalization

Recanalization of a chronically occluded RCA: contralateral injection

Recanalization of a chronically occluded intermediate branch with contrast medium imaging of the periphery by recanalization balloon

Transradial PCI of the RCA with occlusion of the subclavian artery

**PCI for Acute Coronary Syndrome**

Acute inferior infarction, STEMI: symptoms after 2 hours; patient in shock – sequence of the intervention

Acute STEMI of the anterior wall: cardiogenic shock – main stem occlusion

Acute inferior reinfarction 3 weeks after primary RCA PCI with implantation of a 2.5-mm stent

Acute inferior infarction after premature discontinuation of dual antiplatelet therapy

Unstable angina with deep ST-segment depressions over the anterior wall: status post CABG with vein grafts to RCA and obtuse marginal as well as LIMA to LAD

Acute STEMI: cardiogenic shock, cardiac catheterization and intervention under ongoing resuscitation

Acute STEMI of the anterior wall: cardiogenic shock: main stem occlusion; IABP and micro-axial pump

**Coronary Stent Implantation**

Bifurcation stenosis in a Y-vein graft

**Rotational Atherectomy**

RCA stenosis

Rotablation of the main stem and LCX

**Thrombectomy**

Mechanical thrombectomy in an anterior myocardial infarction > 24 hours

Protection system for PCI of a degenerated vein graft

Distal protection system using balloon occlusion

Filter protection system with transient no-flow

**Percutaneous Cardiac Assist Device**

Intra-aortic balloon pump

Impella 2.5 micro-axial pump

**Percutaneous Valvular Interventions**

Mitral valvuloplasty

Mitral valvuloplasty under TEE guidance

Aortic valvuloplasty

Percutaneous transfemoral aortic valve replacement

**Percutaneous Occlusion of Septal Defects**

Patent foramen ovale

Atrial septal defect type II: interventional occlusion

**Percutaneous Extraction of Cardiovascular Foreign Bodies**

Port extraction

**Cardiac Resynchronization Therapy**

Implantation of a left ventricular lead

**Complications**

Coronary air injection

Catheter kinking

Ventricular perforation

Septal branch perforation

Retrograde vessel dissection

Coronary perforation and stent graft implantation