

6 Erweiterte morphologische und funktionelle Koronardiagnostik

6.1 Quantitative Koronarangiografie (QCA)

- [1] Feyter PJd, Serruys PW, Davies MJ et al. Quantitative coronary angiography to measure progression and regression of coronary atherosclerosis. Value, limitations, and implications for clinical trials. *Circulation* 84:412–423, 1991
- [2] Tonino PA, Bruyne Bd, Pijls NH et al. FAME Study Investigators. Fractional flow reserve versus angiography for guiding percutaneous coronary intervention. *N Engl J Med* 60(3):213–224, 2009
- [3] Liao R, Luc D, Sun Y et al. 3-D reconstruction of the coronary artery tree from multiple views of a rotational X-ray angiography. *Int J Cardiovasc Imaging* 26:733–749, 2010
- [4] Pijls NH, van Son JAM, Kirkeeide RL et al. Experimental basis of determining maximum coronary, myocardial, and collateral blood flow by pressure measurements for assessing functional stenosis severity before and after percutaneous transluminal coronary angioplasty. *Circulation* 87: 1354–1367, 1993
- [5] Pellicano M, Lavi I, De Bruyne B et al. Validation study of image-based fractional flow reserve during coronary angiography. *Circ Cardiovasc Interv* 10:e005259, 2017
- [3] Cole JS, Hartley CJ. The pulsed Doppler coronary artery catheter: Preliminary report of a new technique for measuring rapid changes in coronary artery flow velocity in man. *Circulation* 56:18–25, 1977
- [4] Wilson RF, Laughlin DE, Ackell PH et al. Transluminal, subselective measurement of coronary artery blood flow velocity and vasodilator reserve in man. *Circulation* 72:82–92, 1985
- [5] Sibley DH, Millar HD, Hartley CJ et al. Subselective measurement of coronary blood flow velocity using a steerable Doppler catheter. *J Am Coll Cardiol* 8:1332–40, 1986
- [6] Serruys PW, Juillière Y, Zijlstra F et al. Coronary blood flow velocity during percutaneous transluminal coronary angioplasty as a guide for assessment of the functional result. *Am J Cardiol* 61:253–9, 1988
- [7] Johnson EL, Yock PG, Hargrave VK et al. Assessment of severity of coronary stenoses using a Doppler catheter. Validation of a method based on the continuity equation. *Circulation* 80:625–35, 1989
- [8] McGinn AL, White CW, Wilson RF. Interstudy variability of coronary flow reserve. Influence of heart rate, arterial pressure, and ventricular preload. *Circulation* 81:1319–30, 1990
- [9] Di Mario C, Slager CJ, Linker DT et al. Quantitative assessment of coronary artery stenosis by intravascular Doppler catheter technique. *Circulation* 86:2016–7, 1992

6.2 Intrakoronarer Doppler (ICD)

- [1] White CW, Wright CB, Doty DB et al. Does visual interpretation of the coronary arteriogram predict the physiologic importance of a coronary stenosis? *N Engl J Med* 310:819–24, 1984
- [2] Hartley CJ, Cole JS. An ultrasound pulsed Doppler system for measuring blood flow in small vessels. *J Am Physiol* 37:626–9, 1974
- [10] Erbel R, Rupprecht HJ, Ge J et al. Coronary artery shape and flow changes induced by myocardial bridging. *Echocardiography* 10:71–7, 1993
- [11] Ge J, Erbel R, Rupprecht HJ et al. Comparison of intravascular ultrasound and angiography in the assessment of myocardial bridging. *Circulation* 89:1725–32, 1994

- [12] Doucette JW, Corl PD, Payne HM et al. Validation of a Doppler guide for intravascular measurement of coronary artery flow velocity. *Circulation* 85:1899–911, 1992
- [13] Dagres N, Haude M, Kurreck S et al. The EchoMap System: online integration of intracoronary ultrasound and Doppler images into angiographic images during cardiac catheterization. Influence on radiation exposure and procedure parameters. *J Interv Cardiol* 17:321–5, 2004
- [14] Baumgart D, Haude M, Ge J et al. New modular system for the determination of coronary blood flow velocity. *Cathet Cardiovasc Diagn* 35:378–9, 1995
- [15] Qian J, Ge J, Baumgart D et al. Safety of intracoronary Doppler flow measurement. *Am Heart J* 140:501–10, 2000
- [16] Klocke FJ. Coronary blood flow in man. *Prog Cardiovasc Dis* 19:117–66, 1976
- [17] Hoffman JI. Maximal coronary flow and the concept of coronary vascular reserve. *Circulation* 70:153–9, 1984
- [18] Baumgart D, Haude M, Liu F et al. Current concepts of coronary flow reserve for clinical decision making during cardiac catheterization. *Am Heart J* 136:136–49, 1998
- [19] Hoffman JI. Determinants and prediction of transmural myocardial perfusion. *Circulation* 8:381–91, 1978
- [20] Gould KL, Lipscomb K, Hamilton GW. Physiologic basis for assessing critical coronary stenosis. Instantaneous flow response and regional distribution during coronary hyperemia as measures of coronary flow reserve. *Am J Cardiol* 33:87–94, 1974
- [21] Gould KL, Lipscomb K. Effects of coronary stenoses on coronary flow reserve and resistance. *Am J Cardiol* 34:48–55, 1974
- [22] Gould KL, Kelley KO, Bolson EL. Experimental validation of quantitative coronary arteriography for determining pressure-flow characteristics of coronary stenosis. *Circulation* 66:930–7, 1982
- [23] Gould KL. Assessment of coronary stenoses with myocardial perfusion imaging during pharmacologic coronary vasodilatation. IV. Limits of detection of stenosis with idealized experimental cross-sectional myocardial imaging. *Am J Cardiol* 42:761–8, 1978
- [24] Gould KL. Coronary flow reserve and pharmacologic stress perfusion imaging: beginnings and evolution. *JACC Cardiovasc Imaging* 2:664–9, 2009
- [25] Dayanikli F, Grambow D, Muzik O et al. Early detection of abnormal coronary flow reserve in asymptomatic men at high risk for coronary artery disease using positron emission tomography. *Circulation* 90:808–17, 1994
- [26] Gould KL, Schlebert HR, Phelps ME et al. Noninvasive assessment of coronary stenosis with myocardial perfusion imaging during pharmacologic coronary vasodilatation. V. Detection of 47 percent diameter coronary stenosis with intravenous nitrogen-13 ammonia and emission-computed tomography in intact dogs. *Am J Cardiol* 3(2):200–8, 1979
- [27] Zeiher AM, Drexler H, Saurbier J et al. Endothelium-mediated coronary blood flow modulation in humans: effects of age, atherosclerosis, hypercholesterolemia and hypertension. *J Clin Invest* 92:652–62, 1993
- [28] Erbel R, Ge J, Bockisch A et al. Value of intracoronary ultrasound and Doppler in the differentiation of angiographically normal coronary arteries: a prospective study in patients with angina pectoris. *Eur Heart J* 17:880–9, 1996
- [29] Qian JY, Ge JB, Fan B et al. Identification of syndrome X using intravascular ultrasound imaging and Doppler flow mapping. *Chin Med J* 17:521–7, 2004
- [30] Haude M, Caspari G, Baumgart D et al. Comparison of myocardial perfusion reserve before and after coronary balloon predilatation and after stent implantation in patients with postangioplasty restenosis. *Circulation* 94:286–97, 1996
- [31] Kern MJ. Applying coronary physiology for the nuclear cardiologist: new observations from intracoronary flow velocity and reserve in patients. *J Nucl Cardiol* 1:561–6, 1994
- [32] Kern MJ. Meaning of relative coronary flow reserve. *Am J Cardiol* 77:329–30, 1996
- [33] Miller DD, Donohue TJ, Wolford TL et al. Assessment of blood flow distal to coronary artery stenoses. Correlations between myocardial positron emission tomography and poststenotic intracoronary Dopp-

- ler flow reserve. *Circulation* 94(10):2447–54, 1996
- [34] Kern MJ, Puri S, Craig WR et al. Hemodynamic rounds series II: Coronary hemodynamics for angioplasty and stenting after myocardial infarction: use of absolute, relative coronary velocity and fractional flow reserve. *Cathet Cardiovasc Diagn* 45:174–82, 1998
- [35] Kern MJ, Puri S, Bach RG et al. Abnormal coronary flow velocity reserve after coronary artery stenting in patients: role of relative coronary reserve to assess potential mechanisms. *Circulation* 100:2491–8, 1999
- [36] Jeremias A, Whitbourn RJ, Filardo SD et al. Adequacy of intracoronary versus intravenous adenosine-induced maximal coronary hyperemia for fractional flow reserve measurements. *Am Heart J* 140: 651–7, 2000
- ### 6.3 Intrakoronare Druckmessung (ICP): Bestimmung von FFR, iFR und QFR
- [1] Freudenberg H, Lichtlen PR. The normal wall segment in coronary stenoses – a postmortal study (author's transl). *Z Kardiol* 70:863–9, 1981
- [2] Arnett EN, Isner JM, Redwood DR et al. Coronary artery narrowing in coronary heart disease: comparison of cineangiographic and necropsy findings. *Ann Intern Med* 91:350–6, 1979
- [3] Isner JM, Kishel J, Kent KM et al. Accuracy of angiographic determination of left main coronary arterial narrowing Angiographic – histologic correlative analysis in 28 patients. *Circulation* 63:1056–64, 1981
- [4] Bergelson BA, Tommaso CL. Left main coronary artery disease: assessment, diagnosis, and therapy. *Am Heart J* 129:350–9, 1995
- [5] Lee Th, Boucher CA. Clinical practice. Noninvasive tests in patients with stable coronary artery disease. *N Engl J Med* 344:1840–5, 2001
- [6] Aarnoudse WH, Botman KJ, Pijls NH. False-negative myocardial scintigraphy in balanced three-vessel disease, revealed by coronary pressure measurement. *Int J Cardiovasc Intervent* 5:67–71, 2003
- [7] Fisher LD, Judkins MP, Lesperance J et al. Reproducibility of coronary arteriographic reading in the coronary artery surgery study (CASS). *Cathet Cardiovasc Diagn* 8:565–75, 1982
- [8] Jandt U, Schäfer D, Grass M et al. Automatic generation of 3D coronary artery centerlines using rotational X-ray angiography. *Med Image Anal* 13:846–58, 2009
- [9] Chaitman BR, Fisher LD, Bourassa MG et al. Effect of coronary bypass surgery on survival patterns in subsets of patients with left main coronary artery disease. Report of the Collaborative Study in Coronary Artery Surgery (CASS). *Am J Cardiol* 48:765–77, 1981
- [10] Campeau L, Corbara F, Crochet D et al. Left main coronary artery stenosis: the influence of aortocoronary bypass surgery on survival. *Circulation* 57:1111–5, 1978
- [11] Taylor HA, Deumite NJ, Chaitman BR et al. Asymptomatic left main coronary artery disease in the Coronary Artery Surgery Study (CASS) registry. *Circulation* 79:1171–9, 1989
- [12] Caracciolo EA, Davis KB, Sopko G et al. Comparison of surgical and medical group survival in patients with left main coronary artery disease. Long-term CASS experience. *Circulation* 91:2325–34, 1995
- [13] Stone GW, Sabik JF, Serruys PW et al. Everolimus-eluting stents or bypass surgery for left main coronary artery disease. *N Engl J Med* 375:2223–35, 2016
- [14] Mäkilä T, Holm NR, Lindsay M et al. Percutaneous coronary angioplasty versus coronary artery bypass grafting in treatment of unprotected left main stenosis (NOBLE): a prospective, randomised, open-label, non-inferiority trial. *Lancet* 388:2743–52, 2016
- [15] Pijls NH, van Son JAM, Kirkeeide RL et al. Experimental basis of determining maximum coronary, myocardial, and collateral blood flow by pressure measurements for assessing functional stenosis severity before and after percutaneous transluminal coronary angioplasty. *Circulation* 87:1354–1367, 1993
- [16] Pijls NH, Kern MJ, Yock PG et al. Practice and potential pitfalls of coronary pressure measurement. *Catheter Cardiovasc Interv* 2000 Jan; 9(1):1–16. Review. Erratum in: *Catheter Cardiovasc Interv* 50:157, 2000

- [17] Pijls N, De Bruyne B. Coronary pressure. Kluwer Academic Publishers, Dordrecht, 1997
- [18] Baumgart D, Haude M, Gorge G et al. Improved assessment of coronary stenosis severity using the relative flow velocity reserve. *Circulation* 98:40–6, 1998
- [19] van de Hoef TP, van Lavieren MA, Dammann P et al. Physiological basis and long-term clinical outcome of discordance between fractional flow reserve and coronary flow velocity reserve in coronary stenoses of intermediate severity. *Circ Cardiovasc Interv* 7:301–11, 2014
- [20] Matsuo H, Kawase Y. FFR and iFR guided percutaneous coronary intervention. *Cardiovasc Interv and Ther* 31:183–95, 2016
- [21] De Bruyne B, Fearon WF, Pijls NH et al., and FAME 2 Trial Investigators. Fractional flow reserve-guided PCI for stable coronary artery disease. *N Engl J Med* 371:1208–17, 2014; Erratum in: *N Engl J Med* 371:1465, 2014
- [22] Bech GJ, Droste H, Pijls NH et al. Value of fractional flow reserve in making decisions about bypass surgery for equivocal left main coronary artery disease. *Heart* 86:547–52, 2001
- [23] Kern MJ. Coronary physiology revisited: practical insights from the cardiac catheterization laboratory. *Circulation* 101:1344–51, 2000
- [24] Klauss V, Erdin P, Rieber J et al. Fractional flow reserve for the prediction of cardiac events after coronary stent implantation: results of a multivariate analysis. *Heart* 91:203–6, 2005
- [25] Lindstaedt M, Yazar A, Germing A et al. Clinical outcome in patients with intermediate or equivocal left main coronary artery disease after deferral of surgical revascularization on the basis of fractional flow reserve measurements. *Am Heart J* 152:156.e1–9, 2006
- [26] Tamita K, Akasaka T, Takagi T et al. Effects of microvascular dysfunction on myocardial fractional flow reserve after percutaneous coronary intervention in patients with acute myocardial infarction. *Catheter Cardiovasc Interv* 57:452–9, 2002
- [27] Yanagisawa H, Chikamori T, Tanaka N et al. Correlation between thallium-201 myocardial perfusion defects and the functional severity of coronary artery stenosis as assessed by pressure-derived myocardial fractional flow reserve. *Circ J* 66:1105–9, 2002
- [28] Davies RF, Goldberg AD, Forman S et al. Asymptomatic Cardiac Ischemia Pilot (ACIP) study two-year follow-up: outcomes of patients randomized to initial strategies of medical therapy versus revascularization. *Circulation* 95:2037–43, 1997
- [29] Shaw LJ, Iskandrian AE. Prognostic value of gated myocardial perfusion SPECT. *J Nucl Cardiol* 11:171–85, 2004
- [30] Shaw LJ, Berman DS, Maron DJ et al. Optimal medical therapy with or without percutaneous coronary intervention to reduce ischemic burden: results from the Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation (COURAGE) trial nuclear substudy. *Circulation* 117:1283–91, 2008
- [31] Matsumoto H, Ushimaru S, Matsuda T et al. Is caffeine abstention necessary before adenosine-induced fractional flow reserve measurement? *J Am Coll Cardiol* 66:1943–5, 2015
- [32] Rzczuch K, Jankowska E, Kaczmarek A et al. Measurement of coronary fractional flow reserve. Standard doses of intracoronary adenosine are insufficient to induce maximal hyperaemia. *Kardiol Pol* 58:269–74, 2003
- [33] Murtagh B, Higano S, Lennon R et al. Role of incremental doses of intracoronary adenosine for fractional flow reserve assessment. *Am Heart J* 146:99–105, 2003
- [34] Casella G, Rieber J, Schiele TM et al. A randomized comparison of 4 doses of intracoronary adenosine in the assessment of fractional flow reserve. *Z Kardiol* 92:627–32, 2003
- [35] Usui Y, Chikamori T, Yanagisawa H et al. Reliability of pressure-derived myocardial fractional flow reserve in assessing coronary artery stenosis in patients with previous myocardial infarction. *Am J Cardiol* 92:699–702, 2003
- [36] Lopez-Palop R, Saura D, Pinar E et al. Adequate intracoronary adenosine doses to achieve maximum hyperaemia in coronary functional studies by pressure derived fractional flow reserve: a dose response study. *Heart* 90:95–6, 2004
- [37] Bishop AH, Samady H. Fractional flow reserve: critical review of an important physiologic adjunct to angiography. *Am Heart J* 147:792–802, 2004

- [38] Berger A, Botman KJ, MacCarthy PA et al. Long-term clinical outcome after fractional flow reserve-guided percutaneous coronary intervention in patients with multivessel disease. *J Am Coll Cardiol* 46:438–42, 2005
- [39] Wongpraparut N, Yalamanchili V, Pasnoori V et al. Thirty-month outcome after fractional flow reserve-guided versus conventional multivessel percutaneous coronary intervention. *Am J Cardiol* 96:877–84, 2005
- [40] Legalery P, Schiele F, Seronde MF et al. One-year outcome of patients submitted to routine fractional flow reserve assessment to determine the need for angioplasty. *Eur Heart J* 26:2623–9, 2005
- [41] Pijls NH, Schaardenburgh Pv, Manoharan G et al. Percutaneous coronary intervention of functionally nonsignificant stenosis: 5-year follow-up of the DEFER Study. *J Am Coll Cardiol* 49:2105–11, 2007
- [42] Tonino PA, De Bruyne B, Pijls NH et al. Fractional flow reserve versus angiography for guiding percutaneous coronary intervention. *N Engl J Med* 360:213–24, 2009
- [43] Lim HS, Tonino PA, De Bruyne B et al. The impact of age on fractional flow reserve-guided percutaneous coronary intervention: a FAME (Fractional Flow Reserve versus Angiography for Multivessel Evaluation) trial substudy. *Int J Cardiol* 177:66–70, 2014
- [43] Fearon WF, Nishi T, De Bruyne B et al. Clinical outcomes and cost-effectiveness of fractional flow reserve-guided percutaneous coronary intervention in patients with stable coronary artery disease: three-year follow-up of the FAME 2 Trial (Fractional Flow Reserve Versus Angiography for Multivessel Evaluation). *Circulation* 137:480–7, 2018
- [44] Nijjer SS, de Waard GA, Sen S et al. Coronary pressure and flow relationships in humans: phasic analysis of normal and pathological vessels and the implications for stenosis assessment: a report from the Iberian-Dutch-English (IDEAL) collaborators. *Eur Heart J* 37:2069–80, 2016
- [45] Jeremias A, Kirtane AJ, Stone GW. A test in context: fractional flow reserve: accuracy, prognostic implications, and limitations. *J Am Coll Cardiol* 69:2748–58, 2017
- [46] Zimmermann FM, De Bruyne B, Pijls NH et al. Rationale and design of the Fractional Flow Reserve versus Angiography for Multivessel Evaluation (FAME) 3 Trial: a comparison of fractional flow reserve-guided percutaneous coronary intervention and coronary artery bypass graft surgery in patients with multivessel coronary artery disease. *Am Heart J* 170:619–26.e2, 2015
- [46a] Kobayashi Y, Takahashi T, Zimmermann FM et al. FAME 3 Trial Investigators. Outcomes Based on Angiographic vs Functional Significance of Complex 3-Vessel Coronary Disease: FAME 3 Trial. *JACC Cardiovasc Interv* 16:2112–2119, 2023
- [47] Montalescot G, Sechtem U, Achenbach S et al. 2013 ESC guidelines on the management of stable coronary artery disease: the Task Force on the management of stable coronary artery disease of the European Society of Cardiology. *Eur Heart J* 34:2949–3003, 2013
- [48] Windecker S, Kolh P, Alfonso F et al. 2014 ESC/EACTS Guidelines on myocardial revascularization: The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Developed with the special contribution of the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur Heart J* 35:2541–619, 2014
- [49] Matsuo H, Kawase Y. FFR and iFR guided percutaneous coronary intervention. *Cardiovasc Interv Ther* 31:183–95, 2016
- [50] Sen S, Asress KN, Nijjer S et al. Diagnostic classification of the instantaneous wave-free ratio is equivalent to fractional flow reserve and is not improved with adenosine administration. Results of CLARIFY (Classification Accuracy of Pressure-Only Ratios Against Indices Using Flow Study). *J Am Coll Cardiol* 61:1409–20, 2013
- [51] Petraco R, Escaned J, Sen S et al. Classification performance of instantaneous wave-free ratio (iFR) and fractional flow reserve in a clinical population of intermediate coronary stenoses: results of the ADVISE registry. *EuroIntervention* 9:91–101, 2013
- [52] Sen S, Escaned J, Malik IS et al. Development and validation of a new adenosine-independent index of stenosis severity from coronary wave-intensity analysis: results of the ADVISE (ADenosine Vasodilator Independent Stenosis Evaluation)

- study. *J Am Coll Cardiol* 59:1392–402, 2012
- [53] Davies JE, Sen S, Broyd C et al. Arterial pulse wave dynamics after percutaneous aortic valve replacement: fall in coronary diastolic suction with increasing heart rate as a basis for angina symptoms in aortic stenosis. *Circulation* 124:1565–72, 2011
- [54] Maini R, Moscona J, Katigbak P et al. Instantaneous wave-free ratio as an alternative to fractional flow reserve in assessment of moderate coronary stenosis: a meta-analysis of diagnostic accuracy studies. *Cardiovasc Revasc Med* 19(5 Pt B):613–20, 2018
- [55] Davies JE, Sen S, Dehbi HM et al. Use of the instantaneous wave-free ratio or fractional flow reserve in PCI. *N Engl J Med* 376:1824–34, 2017
- [56] Götzberg M, Christiansen EH, Gudmundsdottir IJ et al., and iFR-SWEDEHEART investigator. Instantaneous wave-free ratio versus fractional flow reserve to guide PCI. *N Engl J Med* 376:1813–23, 2017
- [57] Berry C, McClure JD, Oldroyd KG. Meta-analysis of death and myocardial infarction in the DEFINE-FLAIR and iFR-SWEDEHEART Trials. *Circulation* 136:2389–91, 2017
- [58] Pijls NH. Optimum guidance of complex PCI by coronary pressure measurement. *Heart* 90:1085–93, 2004
- [59] Iwasaki K, Matsumoto T. Coronary pressure measurement identifies patients with diffuse coronary artery disease who benefit from coronary revascularization. *Coron Artery Dis* 22:81–6, 2011
- [60] Bhatt DL. Fractional flow reserve measurement for the physiological assessment of coronary artery stenosis severity. *JAMA* 320:1275–76, 2018
- [60a] De Rosa S, Polimeni A, Petraco R et al. Diagnostic Performance of the Instantaneous Wave-Free Ratio: Comparison With Fractional Flow Reserve. *Circ Cardiovasc Interv* 11:e004613, 2018
- [60b] DEFINE-FLAIR Trial Investigators et al. Comparison of Major Adverse Cardiac Events Between Instantaneous Wave-Free Ratio and Fractional Flow Reserve-Guided Strategy in Patients With or Without Type 2 Diabetes: A Secondary Analysis of a Randomized Clinical Trial. *JAMA Cardiol* 4:857–864, 2019
- [60c] Modi BN, Rahman H, Ryan M et al. Comparison of fractional flow reserve, instantaneous wave-free ratio and a novel technique for assessing coronary arteries with serial lesions. *EuroIntervention* 16:577–583, 2020
- [61] Fermor U, Huber H, Neuhaus KL et al. Measurement of flow velocity in the model circulation by videodensitometry. *Methodological investigations. Basic Res Cardiol* 74:361–77, 1979
- [62] Schmiel FK, Hackbarth W, Körfer R et al. Flow measurements and simultaneously performed angiography of aorto-coronary bypass grafts during bypass surgery. *Thorac Cardiovasc Surg* 27:386–9, 1979
- [63] Block M, Jehle J, Pölit B et al. [Determination of phasic flow speeds in the coronary vessels by means of a simple photo-densitometric technique (author's transl)]. *Rofo* 136:283–90, 1982
- [64] Spiller P, Schmiel FK, Pölit B et al. Measurement of systolic and diastolic flow rates in the coronary artery system by x-ray densitometry. *Circulation* 68:337–47, 1983
- [65] Sauer G, Krause H, Burmeister A et al. [Determination of flow velocities in the human coronary system using a computer-assisted cine-videodensitometric system]. *Z Kardiol* 72:207–14, 1983
- [66] Machnig T, Jehle J, Pölit B et al. [The determination of myocardial perfusion parameters from coronary angiograms by analysing the passage of contrast media through the myocardium]. *Rofo* 153:252–9, 1990
- [67] Pellicano M, Lavi I, De Bruyne B et al. Validation study of image-based fractional flow reserve during coronary angiography. *Circ Cardiovasc Interv* 10:e005259, 2017
- [68] Smit JM, El Mahdiui M, van Rosendaal AR et al. Comparison of diagnostic performance of quantitative flow ratio in patients with versus without diabetes mellitus. *Am J Cardiol* 123:1722–8, 2019
- [69] Zhang Y, Zhang S, Westra J et al. Automatic coronary flow computation: validation in quantitative flow ratio from coronary angiography. *Int J Cardiol* 35:587–95, 2019
- [70] Morris PD, Gunn JP. Computing fractional flow reserve from invasive coronary angiography. *Circ Cardiovasc Interv* 10:e005806, 2017
- [71] Morris PD1, Ryan D, Morton AC et al. Virtual fractional flow reserve from coronary

- angiography: modeling the significance of coronary lesions: results from the VIRTU-1 (VIRTUal Fractional Flow Reserve From Coronary Angiography) study. *JACC Cardiovasc Interv* 6:149–57, 2013
- [72] Morris PD, Silva Sato DA, Feher JFA et al. Fast virtual fractional flow reserve based upon steady-state computational fluid dynamics analysis: results from the VIRTU-Fast study. *JACC Basic Transl Sci* 2:34–446, 2017
- [73] Papafaklis MI, Muramatsu T, Ishibashi Y et al. Fast virtual functional assessment of intermediate coronary lesions using routine angiographic data and blood flow simulation in humans: comparison with pressure wire – fractional flow reserve. *EuroIntervention* 10:574–83, 2014
- [74] Schuurbiers JC, Lopez NG, Ligthart J et al. In vivo validation of CAAS QCA-3D coronary reconstruction using fusion of angiography and intravascular ultrasound (ANGUS). *Catheter Cardiovasc Interv* 73:620–6, 2009
- [75] Kern MJ, Bach RG, Mechem CJ et al. Variations in normal coronary vasodilatory reserve stratified by artery, gender, heart transplantation and coronary artery disease. *J Am Coll Cardiol* 28:1154–60, 1996
- [76] Tu S, Barbato E, Köszegi Z et al. Fractional flow reserve calculation from 3-dimensional quantitative coronary angiography and TIMI (Thrombolysis in Myocardial Infarction) frame count: a fast computer model to quantify the functional significance of moderately obstructed coronary arteries. *J Am Coll Cardiol Interv* 7:768–77, 2014
- [77] Tu S, Westra J, Yang J et al., FAVOR Pilot Trial Study Group. diagnostic accuracy of fast computational approaches to derive fractional flow reserve from diagnostic coronary angiography: the international multicenter FAVOR Pilot Study. *JACC Cardiovasc Interv* 9:2024–35, 2016
- [78] Dodge JT Jr, Rizzo M, Nykiel M et al. Impact of injection rate on the Thrombolysis in Myocardial Infarction (TIMI) trial frame count. *Am J Cardiol* 81:1268–70, 1998
- [79] Stoel MG, Zijlstra F, Visser CA. Frame count reserve. *Circulation* 107:3034–9, 2003
- [80] Zhang Y, Zhang S, Westra J et al. Automatic coronary blood flow computation: validation in quantitative flow ratio from coronary angiography. *Int J Cardiovasc Imaging* 35:587–95, 2019
- [80a] Biscaglia S, Tebaldi M, Brugaletta S et al. Prognostic value of QFR measured immediately after successful stent implantation: the international multicenter prospective HAWKEYE Study. *JACC Cardiovasc Interv* 12:2079–88, 2019
- [80b] Cerrato E, Mejía-Rentería H, Franzè A et al. Quantitative flow ratio as a new tool for angiography-based physiological evaluation of coronary artery disease: a review. *Future Cardiol Future Cardiol* 17:1435–1452, 2021
- [81] Tröbs M, Achenbach S, Röther J et al. Comparison of fractional flow reserve based on computational fluid dynamics modeling using coronary angiographic vessel morphology versus invasively measured fractional flow reserve. *Am J Cardiol* 117:29–35, 2016
- [82] Ammon F, Tröls M, Bittner D et al. Diagnostic accuracy of on-site FFRCT and the new concept of FFRangio: a head to head comparison with invasively measured FFR. *J Cardiovasc Comput Tomogr* 13(1)(Suppl):S28, 2019
- [83] Pellicano M, Lavi I, De Bruyne B et al. Validation study of image-based fractional flow reserve during coronary angiography. *Circ Cardiovasc Interv* 10(9):e005259, 2017
- [84] Kirkeeide RL. Coronary obstructions, morphology physiologic significance. In: Reiber JHC, Serruys PW (Eds), *Quantitative coronary arteriography*. Kluwer Academic Publishers, Dordrecht, pp. 229–244, 1991
- [85] Tu S, Westra J, Yang J et al. Diagnostic accuracy of fast computational approaches to derive fractional flow reserve from diagnostic coronary angiography: the international multicenter FAVOR Pilot Study. *JACC Cardiovasc Interv* 9:2024–35, 2016
- [86] Ties D, van Dijk R, Pundziute G et al. Computational quantitative flow ratio to assess functional severity of coronary artery stenosis. *Int J Cardiol* 271:36–41, 2018
- [87] Johnson NP, Jeremias A, Zimmermann FM et al. Continuum of vasodilator stress from rest to contrast medium to adenosine hyperemia for fractional flow reserve assessment. *JACC Cardiovasc Interv* 9:757–67, 2016

- [88] Westra J, Tu S, Campo G et al. Diagnostic performance of quantitative flow ratio in prospectively enrolled patients: An individual patient-data meta-analysis. *Catheter Cardiovasc Interv* 94:693–701, 2019
- [89] Westra J, Andersen BK, Campo G et al. Diagnostic performance of in-procedure angiography-derived quantitative flow reserve compared to pressure-derived fractional flow reserve: The FAVOR II Europe-Japan Study. *J Am Heart Assoc* 7(14):e009603, 2018
- [90] Westra J, Tu S, Winther S et al. Evaluation of coronary artery stenosis by quantitative flow ratio during invasive coronary angiography: the WIFI II Study (Wire-Free Functional Imaging II). *Circ Cardiovasc Imaging* 11:e007107, 2018
- [91] Xu B, Tu S, Qiao S et al. Diagnostic accuracy of angiography-based quantitative flow ratio measurements for online assessment of coronary stenosis. *J Am Coll Cardiol* 70:3077–87, 2017
- heit des intraluminalen Ultraschalls. *Z Kardiol* 80:595–601, 1991
- [8] Lookwood G, Ryan L, Gotlieb A et al. In vitro high resolution intravascular imaging in muscular and elastic arteries. *J Am Coll Cardiol* 20:153–160, 1992
- [9] Tobis JM, Mallery J, Mahon D. Intravascular ultrasound imaging of human coronary arteries in vivo. *Circulation* 83:913–926, 1991
- [10] Sievers B, Böse D, Sack S et al. Online PC-based integration of digital intracoronary ultrasound images into angiographic images during cardiac catheterization. *Int J Cardiol* 128:289–293, 2008
- [11] Di Mario C, The SH, Madretsma S et al. Detection and characterization of vascular lesions by intravascular ultrasound: an in vitro study correlated with histology. *J Am Echocardiogr* 5:135–146, 1992
- [12] Friedewald VE, Ambrose JA, Stone GW et al. The editor's roundtable: the vulnerable plaque. *Am J Cardiol* 102:1644–1653, 2008
- [13] Görges G, Erbel R, Schuster S et al. Intravascular ultrasound in diagnosis of acute pulmonary embolism. *Lancet* 337:623–624, 1991

6.4 Intravaskulärer Ultraschall (IVUS)

- [1] Freudenberg H, Lichtlen PR. The normal wall segment in coronary stenoses. A post-mortal study. *Z Kardiol* 70:863–869, 1981
- [2] Isner JM, Kishel J, Kent KM. Accuracy of angiographic determination of the left main coronary arterial narrowing. *Circulation* 63:1065–1061, 1981
- [3] Vlodover Z, Edwards JE. Pathology of coronary atherosclerosis. *Progr Cardiovasc Dis* 14:256–274, 1971
- [4] Glagov S, Weisenberg E, Zarins CK et al. Compensatory enlargement of human atherosclerotic coronary arteries. *New Engl J Med* 316:1371–1375, 1987
- [5] Zarins CK, Weisenberg E, Kolettis G et al. Differential enlargement of artery segments in response to enlarging atherosclerotic plaques. *J Vasc Surg Suppl* 7:386–394, 1988
- [6] Di Mario C, The SHK, Madretsma S. Detection and characterization of vascular lesions by intravascular ultrasound. An in vitro study correlated with histology. *J Am Soc Echocard* 5:135–146, 1992
- [7] Ge J, Erbel R, Seidel I et al. Experimentelle Überprüfung der Genauigkeit und Sicherheit des intraluminalen Ultraschalls. *Z Kardiol* 80:595–601, 1991
- [8] Lookwood G, Ryan L, Gotlieb A et al. In vitro high resolution intravascular imaging in muscular and elastic arteries. *J Am Coll Cardiol* 20:153–160, 1992
- [9] Tobis JM, Mallery J, Mahon D. Intravascular ultrasound imaging of human coronary arteries in vivo. *Circulation* 83:913–926, 1991
- [10] Sievers B, Böse D, Sack S et al. Online PC-based integration of digital intracoronary ultrasound images into angiographic images during cardiac catheterization. *Int J Cardiol* 128:289–293, 2008
- [11] Di Mario C, The SH, Madretsma S et al. Detection and characterization of vascular lesions by intravascular ultrasound: an in vitro study correlated with histology. *J Am Echocardiogr* 5:135–146, 1992
- [12] Friedewald VE, Ambrose JA, Stone GW et al. The editor's roundtable: the vulnerable plaque. *Am J Cardiol* 102:1644–1653, 2008
- [13] Görges G, Erbel R, Schuster S et al. Intravascular ultrasound in diagnosis of acute pulmonary embolism. *Lancet* 337:623–624, 1991
- [14] Boksch WG, Scharthl M, Beckmann SH et al. Intravascular ultrasound imaging in patients with acute myocardial infarction: comparison with chronic stable angina pectoris. *Coron Artery Dis* 5:727–735, 1994
- [15] Kearney P, Erbel R, Rupprecht HJ et al. Differences in morphology of unstable coronary lesions and their impact on the mechanisms of angioplasty – An in vivo study with intravascular ultrasound. *Eur Heart J* 17:721–730, 1996
- [16] Ge J, Chirillo F, Schwedtmann J et al. Screening of ruptured plaques in patients with coronary artery disease by intravascular ultrasound. *Heart* 81:621–627, 1999
- [17] Gussenhoven WJ, Essed CE, Frietman P et al. Intravascular echographic assessment of vessel wall characteristics: a correlation with histology. *Int J Card Imag* 4:105–116, 1989
- [18] Erbel R, Ge J, Kearney P et al. Intravaskuläre Sonographie bei koronarer Herzkrankheit. *DMW* 120:847–854, 1995
- [19] Erbel R, Ge J, Görges G et al. Intravascular ultrasound classification of atherosclerotic lesions according to American Heart Asso-

- ciation recommendation. *Coron Artery Dis* 10:489–499, 1999
- [20] Zamorano J, Erbel R, Ge J et al. Spontaneous plaque rupture visualized by intravascular ultrasound examination. *Eur Heart J* 15:710–712, 1994
 - [21] Ge J, Liu F, Kearney P et al. Intravascular ultrasound approach to the diagnosis of coronary artery aneurysms. *Am Heart J* 130:765–771, 1995
 - [22] Montenegro MR, Eggen DA. Topography of atherosclerosis in the coronary arteries. *Lab Invest* 18:586–593, 1968
 - [23] Wolhoff K. Über die Atherosklerose der Koronararterien des Herzens. *Beitr Path Anat* 82:555–596, 1929
 - [24] Stary HC. The sequency of cell and matrix chatges in atherosclerotic lesions of coronary arteries in the first forty years of life. *Europ Heart J* 11(Suppl):3–19, 1990
 - [25] Stary HC, Chandler AB, Dinsmore RE et al. A definition of advanced types of atherosclerotic lesions and a histological classification of atherosclerosis. *Circulation* 92:1355–1374, 1995
 - [26] Virmani R, Kolodgie FD, Burke AP, Farb A, Schwartz SM. Lessons from sudden coronary death: a Comprehensive Morphological Classification Scheme for Atherosclerotic Lesions. *Arterioscler, Thromb Vasc Biol* 20:1262–1275, 2000
 - [27] Schaar JA, Regar E, Mastik F et al. Incidence of high-strain patterns in human coronary arteries: assessment with three-dimensional intravascular palpography and correlation with clinical presentation. *Circulation* 109:2716–2719, 2004
 - [28] Schaar JA, van der Steen AF, Mastik F et al. Intravascular palpography for vulnerable plaque assessment. *J Am Cardiol* 28 (Suppl 8):C86–91, 2006
 - [29] Nair A, Kuban BD, Tuzcu EM et al. Coronary plaque classification with intravascular ultrasound radiofrequency data analysis. *Circulation* 106:2200–2206, 2002
 - [30] Nair A, Margolis M, Kuban B et al. Automated coronary plaque characterisation with intravascular ultrasound backscatter: ex vivo validation. *EuroIntervention* 3:113–120, 2007
 - [31] Philipp S, Böse D, Wijns W et al. Do systemic risk factors impact invasive findings from virtual histology? Insights from the international virtual histology registry. *Eur Heart J* 31(2):196–202, 2010
 - [32] Qian J, Maehara A, Mintz GS et al. Relation between individual plaque components and overall plaque burden in the prospective, multicenter virtual histology intravascular ultrasound registry. *Am J Cardiol* 104:501–506, 2009
 - [33] Qian J, Maehara A, Mintz GS et al. Impact of gender and age on in vivo virtual histology-intravascular ultrasound imaging plaque characterization (from the global Virtual Histology Intravascular Ultrasound [VH-IVUS] registry). *Am J Cardiol* 103:1210–1214, 2009
 - [34] Garcia-Garcia HM, Gonzalo N, Regar E et al. Virtual histology and optical coherence tomography: from research to a broad clinical application. *Heart* 95:1362–1374, 2009
 - [35] Pundziute G, Schuijff JD, Jukema JW et al. Type 2 diabetes is associated with more advanced coronary atherosclerosis on multislice computed tomography and virtual histology intravascular ultrasound. *J Nucl Cardiol* 16:376–383, 2009
 - [36] Nasu K, Tsuchikane E, Katoh O et al. Effect of fluvastatin on progression of coronary atherosclerotic plaque evaluated by virtual histology intravascular ultrasound. *JACC Cardiovasc Interv* 2:689–696, 2009
 - [37] Böse D, von Birgelen C, Zhou XY et al. Impact of atherosclerotic plaque composition on coronary microembolization during percutaneous coronary interventions. *Basic Res Cardiol* 103:587–597, 2008
 - [38] Garcia-Garcia H, Mintz G, Lerman A et al. Tissue characterization using intravascular radiofrequency data analysis: recommendations for acquisition, analysis, interpretation and reporting. *Eur Interv* 5:177–189, 2009
 - [39] Zarins CK, Zatina MA, Giddens DP et al. Shear stress regulation of artery lumen diameter in experimental atherogenesis. *J Vasc Surg* 5:413–420, 1987
 - [40] Ge J, Erbel R, Zamorano J et al. Coronary artery remodeling in atherosclerotic disease: an intravascular ultrasonic study in vivo. *Coron Artery Dis* 4:981–986, 1993
 - [41] Gerber T, Erbel R, Gorge G et al. Extent of atherosclerosis and remodelling of the left main coronary artery determined by intravascular ultrasound. *Am J Cardiol* 73:666–671, 1994
 - [42] Gerber TC, Erbel R, Gorge G et al. Classification of morphologic effects of percuta-

- neous transluminal coronary angioplasty assessed by intravascular ultrasound. *Am J Cardiol* 70:1546–1554, 1992
- [43] von Birgelen C, Mintz GS, Eggebrecht H et al. Preintervention arterial remodeling affects vessel stretch and plaque extrusion during coronary stent deployment as demonstrated by three-dimensional intravascular ultrasound. *Am J Cardiol* 92:130–135, 2003
- [44] von Birgelen C, Mintz GS, Sieling C et al. Relation between plaque composition and vascular remodeling in coronary lesions with different degrees of lumen narrowing as assessed with three-dimensional intravascular ultrasound in patients with stable angina pectoris. *Am J Cardiol* 91:1103–1107, 2003
- [45] von Birgelen C, Hartmann M, Mintz GS et al. Remodeling index compared to actual vascular remodeling in atherosclerotic left main coronary arteries as assessed with long-term (> or = 12 months) serial intravascular ultrasound. *J Am Coll Cardiol* 47:1363–1368, 2006
- [46] Mintz GS, Nissen SE, Anderson WD et al. American College of Cardiology Clinical Expert Consensus Document on Standards for Acquisition, Measurement and Reporting of Intravascular Ultrasound Studies (IVUS). A report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. *J Am Coll Cardiol* 37:1478–1492, 2001
- [47] Hong MK, Mintz GS, Lee CW et al. Intravascular ultrasound assessment of patterns of arterial remodeling in the absence of significant reference segment plaque burden in patients with coronary artery disease. *J Am Coll Cardiol* 42:806–810, 2003
- [48] Mintz GS, Popma JJ, Pichard AD et al. Arterial remodeling after coronary angioplasty: a serial intravascular ultrasound study. *Circulation* 94:35–43, 1996
- [49] Abizaid AS, Mintz GS, Mehran R et al. Long-term follow-up after percutaneous transluminal coronary angioplasty was not performed based on intravascular ultrasound findings: importance of lumen dimensions. *Circulation* 100:256–261, 1999
- [50] Hong MK, Mintz GS, Lee CW et al. The site of plaque rupture in native coronary arteries: a three-vessel intravascular ultrasound analysis. *J Am Coll Cardiol* 46:261–265, 2005
- [51] von Birgelen C, Mintz GS, de Vrey EA et al. Atherosclerotic coronary lesions with inadequate compensatory enlargement have smaller plaque and vessel volumes: observations with three dimensional intravascular ultrasound in vivo. *Heart* 79:137–143, 1998
- [52] Ge J, Erbel R, Gerber T et al. Intravascular ultrasound imaging of angiographically normal coronary arteries: a prospective study in vivo. *Br Heart J* 71:572–578, 1994
- [53] Hausmann D, Erbel R, Alibelli-Chemarin MJ et al. The safety of intracoronary ultrasound. a multicenter survey of 2207 examinations. *Circulation* 91:623–630, 1995
- [54] Ge J, Liu F, Kearney P et al. Acute coronary artery closure following intracoronary ultrasound examination. *Cathet Cardiovasc Diagn* 35:232–235, 1995
- [54] Parise H, Maehara A, Stone GW et al. Meta-analysis of randomized studies comparing intravascular ultrasound versus angiographic guidance of percutaneous coronary intervention in pre-drug-eluting stent era. *Am J Cardiol* 107:374–382, 2011
- [55] Steinvil A, Zhang Y, Lee SA et al. Intravascular ultrasound-guided drug eluting stent implantation: an updated meta-analysis of randomized control trials and observational studies. *Int J Cardiol* 216:133–139, 2016
- [56] Bavishi C, Sardar P, Chatterjee S et al. Intravascular ultrasound-guided vs angiography-guided drug-eluting stent implantation in complex coronary lesions: met-analysis of randomized trials. *Am Heart J* 185:26–34, 2017
- [57] de la Torre Hernandez JM, Hernandez Hernandez F, Alfonso F et al. Prospective application of pre-defined intravascular ultrasound criteria for assessment of intermediate left main coronary artery lesions results from the multicenter LITRO study. *J Am Coll Cardiol* 58:351–358, 2011
- [58] Neumann FJ, Sousa-Uva M, Ahlsson A et al. 2018 ESC/EACTS Guidelines on myocardial revascularization. *Eur Heart J* 40:87–165, 2019
- [59] Waksman R, Legutko J, Singh J et al. FIRST: Fractional Flow Reserve and Intravascular Ultrasound Relationship Study. *J Am Coll Cardiol* 61:917–923, 2013

- [60] Fassa AA, Wagatsuma K, Higano ST et al. Intravascular ultrasound-guided treatment for angiographically indeterminate left main coronary artery disease: A long-term follow-up study. *J Am Coll Cardiol* 45:204–211, 2005
- [61] Erbel R. Diagnosis and prevention of cardiovascular diseases, Part 2. Herz 32(7):527–528, 2007
- [62] Velican D, Velican C. Comparative study on age-related changes and atherosclerotic involvement of the coronary arteries of male and female subjects up to 40 years of age. *Atherosclerosis* 38:39–50, 1981

6.5 Optische Kohärenztomografie (OCT)

- [1] Leistner DM, Landmesser U, Frohlich GM. FD-OCT and IVUS for detection of incomplete stent apposition in heavily calcified vessels: novel insights. *Open Heart* 2:e000292, 2015
- [2] Kuku KO, Ekanem E, Azizi V et al. Optical coherence tomography-guided percutaneous coronary intervention compared with other imaging guidance: a meta-analysis. *Int J Cardiovasc Imaging* 34: 503–513, 2018
- [3] Leistner DM, Boeckel JN, Reis SM et al. Transcoronary gradients of vascular miRNAs and coronary atherosclerotic plaque characteristics. *Eur Heart J* 37:1738–1749, 2016
- [4] Kubo T, Imanishi T, Kashiwagi M et al. Multiple coronary lesion instability in patients with acute myocardial infarction as determined by optical coherence tomography. *Am J Cardiol* 105:318–322, 2010
- [5] Jia H, Abtahian F, Aguirre AD et al. In vivo diagnosis of plaque erosion and calcified nodule in patients with acute coronary syndrome by intravascular optical coherence tomography. *J Am Coll Cardiol* 62: 1748–1758, 2013
- [6] Mizukoshi M, Imanishi T, Tanaka A et al. Clinical classification and plaque morphology determined by optical coherence tomography in unstable angina pectoris. *Am J Cardiol* 106:323–328, 2010
- [7] Hu S, Zhu Y, Zhang Y et al. Management and outcome of patients with acute coronary syndrome caused by plaque rupture versus plaque erosion: an intravascular optical coherence tomography study. *J Am Heart Assoc* 6:e004730, 2017
- [8] Tearney GJ, Regar E, Akasaka T et al. Consensus standards for acquisition, measurement, and reporting of intravascular optical coherence tomography studies: a report from the International Working Group for Intravascular Optical Coherence Tomography Standardization and Validation. *J Am Coll Cardiol* 59:1058–1072, 2012
- [9] Sinclair H, Bourantas C, Bagnall A et al. OCT for the identification of vulnerable plaque in acute coronary syndrome. *JACC Cardiovasc Imaging* 8:198–209, 2015
- [10] Niccoli G, Montone RA, Di Vito L et al. Plaque rupture and intact fibrous cap assessed by optical coherence tomography portend different outcomes in patients with acute coronary syndrome. *Eur Heart J* 36:1377–1384, 2015
- [11] Ali ZA, Maehara A, Genereux P et al. Optical coherence tomography compared with intravascular ultrasound and with angiography to guide coronary stent implantation (ILUMIEN III: OPTIMIZE PCI): a randomised controlled trial. *Lancet* 388:2618–2628, 2016
- [12] Chamie D, Bezerra HG, Attizzani GF et al. Incidence, predictors, morphological characteristics, and clinical outcomes of stent edge dissections detected by optical coherence tomography. *JACC Cardiovasc Interv* 6:800–813, 2013
- [13] Leistner DM, Riedel M, Steinbeck L et al. Real-time optical coherence tomography coregistration with angiography in percutaneous coronary intervention-impact on physician decision-making: The OPTICO-integration study. *Catheter Cardiovasc Interv* 92:30–37, 2018
- [14] Di Vito L, Yoon JH, Kato K et al. Comprehensive overview of definitions for optical coherence tomography-based plaque and stent analyses. *Coron Artery Dis* 25:172–185, 2014
- [15] Porto I, Di Vito L, Burzotta F et al. Predictors of periprocedural (type IVa) myocardial infarction, as assessed by frequency-domain optical coherence tomography. *Circulation Cardiovasc Interv* 5:89–96, S1–6, 2012
- [16] Cook S, Wenaweser P, Togni M et al. Incomplete stent apposition and very late

- stent thrombosis after drug-eluting stent implantation. *Circulation* 115:2426–2434, 2007
- [17] Sethi A, Singbal Y, Rastogi U et al. Late incomplete stent apposition is associated with late/very late stent thrombosis: a meta-analysis. *Catheter Cardiovasc Interv* 91:365–375, 2018
 - [18] Souteyrand G, Amabile N, Mangin L et al. Mechanisms of stent thrombosis analysed by optical coherence tomography: insights from the national PESTO French registry. *Eur Heart J* 37:1208–1216, 2016
 - [19] Hong SJ, Kim BK, Shin DH et al. Effect of intravascular ultrasound-guided vs angiography-guided everolimus-eluting stent implantation: the IVUS-XPL Randomized Clinical Trial. *JAMA* 314:2155–2163, 2015
 - [20] Serruys PW, Deshpande NV. Is there MUSIC in IVUS guided stenting? Is this MUSIC going to be a MUST? Multicenter Ultrasound Stenting in Coronaries Study. *Eur Heart J* 19:1122–1124, 1998
 - [21] Kolh P, Windecker S, Alfonso F et al. 2014 ESC/EACTS Guidelines on myocardial revascularization: the Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Developed with the special contribution of the European Association of Percutaneous Cardiovascular Interventions (EAPCI). *Eur J Cardio-thorac Surg* 46:517–592, 2014
 - [22] Komukai K, Kubo T, Kitabata H et al. Effect of atorvastatin therapy on fibrous cap thickness in coronary atherosclerotic plaque as assessed by optical coherence tomography: the EASY-FIT study. *J Am Coll Cardiol* 64:2207–2217, 2014
 - [23] Meneveau N, Souteyrand G, Motreff P et al. Optical coherence tomography to optimize results of percutaneous coronary intervention in patients with non-ST-elevation acute coronary syndrome: results of the multicenter, randomized DOCTORS Study (Does Optical Coherence Tomography Optimize Results of Stenting). *Circulation* 134:906–917, 2016
 - [24] Sheth TN, Kajander OA, Lavi S et al. Optical coherence tomography-guided percutaneous coronary intervention in ST-segment-elevation myocardial infarction: a prospective propensity-matched cohort of the Thrombectomy Versus Percutaneous Coronary Intervention Alone Trial. *Circ Cardiovasc Interv* 9:e003414, 2016
 - [25] Taniwaki M, Radu MD, Garcia-Garcia HM et al. Long-term safety and feasibility of three-vessel multimodality intravascular imaging in patients with ST-elevation myocardial infarction: the IBIS-4 (integrated biomarker and imaging study) sub-study. *Int J Cardiovasc Imaging* 31:915–926, 2015
 - [26] Burzotta F, Dato I, Trani C et al. Frequency domain optical coherence tomography to assess non-ostial left main coronary artery. *EuroIntervention* 10:e1–8, 2015
 - [27] Wijns W, Shite J, Jones MR et al. Optical coherence tomography imaging during percutaneous coronary intervention impacts physician decision-making: ILUMIEN I study. *Eur Heart J* 36:3346–3355, 2015
 - [28] Amabile N, Trouillet C, Meneveau N et al. Mechanical abnormalities associated with first- and second-generation drug-eluting stent thrombosis analyzed by optical coherence tomography in the national PESTO French registry. *Int J Cardiol* 227:161–165, 2016
 - [29] Piroth Z, Toth GG, Tonino PAL et al. Prognostic value of fractional flow reserve measured immediately after drug-eluting stent implantation. *Circ Cardiovasc Interv* 10:e005233, 2017
 - [30] Prati F, Di Vito L, Biondi-Zoccai G et al. Angiography alone versus angiography plus optical coherence tomography to guide decision-making during percutaneous coronary intervention: the Centro per la Lotta contro l'Infarto-Optimisation of Percutaneous Coronary Intervention (CLI-OPCI) study. *EuroIntervention* 8:823–829, 2012
 - [31] Prati F, Romagnoli E, Burzotta F et al. Clinical impact of OCT findings during PCI: the CLI-OPCI II Study. *JACC Cardiovasc Imag* 8:1297–1305, 2015
 - [32] Kubo T. Optical frequency domain imaging vs. intravascular ultrasound in percutaneous coronary intervention. *EuroPCR* 2016
 - [33] Saia F, Komukai K, Capodanno D et al. Eroded versus ruptured plaques at the culprit site of STEMI: in vivo pathophysiological features and response to primary PCI. *JACC Cardiovasc Imag* 8:566–575, 2015

- [34] Wang L, Parodi G, Maehara A et al. Variable underlying morphology of culprit plaques associated with ST-elevation myocardial infarction: an optical coherence tomography analysis from the SMART trial. *Eur Heart J Cardiovasc Imag* 16:1381–1389, 2015
- [35] Higuma T, Soeda T, Abe N et al. A Combined optical coherence tomography and intravascular ultrasound study on plaque rupture, plaque erosion, and calcified nodule in patients with st-segment elevation myocardial infarction: incidence, morphologic characteristics, and outcomes after percutaneous coronary intervention. *JACC Cardiovasc Interv* 8:1166–1176, 2015
- [36] Souteyrand G, Arbustini E, Motreff P et al. Serial optical coherence tomography imaging of ACS-causing culprit plaques. *Euro-Intervention* 11:319–324, 2015
- [37] Jia H, Dai J, Hou J et al. Effective anti-thrombotic therapy without stenting: intravascular optical coherence tomography-based management in plaque erosion (the EROSION study). *Eur Heart J* 38:792–800, 2017
- [38] Burzotta F, Leone AM, Aurigemma C et al. Fractional flow reserve or optical coherence tomography to guide management of angiographically intermediate coronary stenosis: a single-center trial. *JACC Cardiovasc Interv* 13:49–58, 2020
- [4] Arbogast R, Bourassa MG. Myocardial function during atrial pacing in patients with angina pectoris and normal coronary arteriograms. Comparison with patients having significant coronary artery disease. *Am J Cardiol* 32:257–263, 1973
- [5] Cannon RO III. 'Microvascular angina' a cause of chest pain in patients with normal coronary angiograms: the eye of the beholder. *Am J Cardiol* 62:306–308, 1988
- [6] Temkin LP, Marcus FI. Nonatherosclerotic myocardial ischemia. *J Am Coll Cardiol* 1:1534–1535, 1983
- [7] Bugiardini R, Manfrini O, De Ferrari GM. Unanswered questions for management of acute coronary syndrome: risk stratification of patients with minimal disease or normal findings on coronary angiography. *Arch Intern Med* 166:1391–1395, 2006
- [8] Jespersen L, Hvelplund A, Abildstrom SZ et al. Stable angina pectoris with no obstructive coronary artery disease is associated with increased risks of major adverse cardiovascular events. *Eur Heart J* 33:734–744, 2012
- [9] Maddox TM, Stanislawski MA, Grunwald GK et al. Nonobstructive coronary artery disease and risk of myocardial infarction. *Jama* 312:1754–1763, 2014
- [10] Douglas PS, Hoffmann U, Patel MR et al. Outcomes of anatomical versus functional testing for coronary artery disease. *N Engl J Med* 372:1291–1300, 2015
- [11] Bairey Merz CN, Pepine CJ, Walsh MN et al. Ischemia and no obstructive coronary artery disease (INOCA): developing evidence-based therapies and research agenda for the next decade. *Circulation* 135:1075–1092, 2017
- [12] Rahmann H, Corcoran D, Aetesam-ur-Rahman M et al. Diagnosis of patients with angina and non-obstructive coronary disease in the catheter laboratory. *Heart* 105:1536–1542, 2019
- [13] Bugiardini R, Pozzati A, Ottani F et al. Vasotonic angina: a spectrum of ischemic syndromes involving functional abnormalities of the epicardial and microvascular coronary circulation. *J Am Coll Cardiol* 22:417–425, 1993
- [14] Reis SE, Holubkov R, Conrad Smith AJ et al. Coronary microvascular dysfunction is highly prevalent in women with chest pain in the absence of coronary artery

6.6 Nichtobstruktive KHK (NOCAD/INOCA), mikrovaskuläre Myokarderkrankung, „Syndrom X“

- [1] Patel MR, Peterson ED, Dai D et al. Low diagnostic yield of elective coronary angiography. *N Engl J Med* 362:886–895, 2010
- [2] Sullivan AK, Holdright DR, Wright CA et al. Chest pain in women: clinical, investigative and prognostic features. *BMJ* 308:883–886, 1994
- [3] Pepine CJ, Ferdinand KC, Shaw LJ et al. Emergence of nonobstructive coronary artery disease: a woman's problem and need for change in definition on angiography. *J Am Coll Cardiol* 66:1918–1933, 2015

- disease: results from the NHLBI WISE study. *Am Heart J* 141:735–741, 2001
- [15] Hasdai D, Gibbons RJ, Holmes DR Jr et al. Coronary endothelial dysfunction in humans is associated with myocardial perfusion defects. *Circulation* 96:3390–3395, 1997
 - [16] Erbel R, Ge J, Bockisch A et al. Value of intracoronary ultrasound and Doppler in the differentiation of angiographically normal coronary arteries: a prospective study in patients with angina pectoris. *Eur Heart J* 17:880–889, 1996
 - [17] Qian J, Ge J, Baumgart D et al. Prevalence of microvascular disease in patients with significant coronary artery disease. *Herz* 24:548–57, 1999
 - [18] Qian JY, Ge JB, Fan B et al. Identification of syndrome X using intravascular ultrasound imaging and Doppler flow mapping. *Chin Med J* 17:521–527, 2004
 - [19] van de Hoef TP, van Lavieren MA, Damman P et al. Physiological basis and long-term clinical outcome of discordance between fractional flow reserve and coronary flow velocity reserve in coronary stenoses of intermediate severity. *Circ Cardiovasc Interv* 7:301–311, 2014
 - [20] Vogt M, Motz W, Scheler S et al. Disorders of coronary microcirculation and arrhythmias in systemic arterial hypertension. *Am J Cardiol* 65:45G–50G, 1990
 - [21] Motz W, Strauer BE. Therapy of hypertensive cardiac hypertrophy and impaired coronary microcirculation. *J Cardiovasc Pharmacol* 24(Suppl 1):S34–S38, 1994
 - [22] Bartel T, Yang Y, Müller S et al. Noninvasive assessment of microvascular function in arterial hypertension by transthoracic Doppler harmonic echocardiography. *J Am Coll Cardiol* 39:2012–2018, 2002
 - [23] Zeiher AM, Drexler H, Wollschläger H et al. Endothelial dysfunction of the coronary microvasculature is associated with impaired coronary blood flow regulation in patients with early atherosclerosis. *Circulation* 84:1984–1992, 1991
 - [24] Baumgart D, Haude M, Gorge G et al. Augmented alpha-adrenergic constriction of atherosclerotic human coronary arteries. *Circulation* 99:2090–2097, 1999
 - [25] Heusch G, Baumgart D, Camici P et al. Alpha-adrenergic coronary vasoconstriction and myocardial ischemia in humans. *Circulation* 101(6):689–694, 2000
 - [26] Lanza GA, Stazi F, Colonna G et al. Circadian variation of ischemic threshold in syndrome X. *Am J Cardiol* 75:683–686, 1955
 - [27] Balady G, Weiner DA, McCabe CH et al. Value of arm exercise testing in detecting coronary artery disease. *Am J Cardiol* 55:37–39, 1985
 - [28] Harris KF, Matthews KA. Interaction between autonomic nervous system activity and endothelial function: a model for the development of cardiovascular disease. *Psychosom Med* 66:153–164, 2004
 - [29] Kaski JC, Elliott PM, Salomone O et al. Concentration of circulating plasma endothelin in patients with angina and normal coronary angiograms. *Br Heart J* 74:620–624, 1995
 - [30] Tousoulis D, Davies GJ, Asimakopoulos G et al. Vascular cell adhesion molecule-1 and intercellular adhesion molecule-1 serum level in patients with chest pain and normal coronary arteries (syndrome X). *Clin Cardiol* 24:301–304, 2001
 - [31] Lerman A, Edwards BF, Hallet JYW et al. Circulating and tissue endothelin immunoreactivity in advanced atherosclerosis. *N Engl J Med* 325:997–1001, 1991
 - [32] Suwaidi JA, Hamasaki S, Higano ST et al. Long-term follow-up of patients with mild coronary artery disease and endothelial dysfunction. *Circulation* 101:948–954, 2000
 - [33] Mering GOv, Arant CB, Wessel TR et al. Abnormal coronary vasomotion as a prognostic indicator of cardiovascular events in women: results from the National Heart, Lung and Blood Institute-Sponsored Women's Ischemia Syndrome Evaluation (WISE). *Circulation* 109:722–725, 2004
 - [34] Suwaidi JA, Hamasaki S, Higano ST et al. Long-term follow-up of patients with mild coronary artery disease and endothelial dysfunction. *Circulation* 101:948–954, 2000
 - [35] Bugiardini R, Manfrini O, De Ferrari GM. Unanswered questions for management of acute coronary syndrome: risk stratification of patients with minimal disease or normal findings on coronary angiography. *Arch Intern Med* 166:1391–1395, 2006
 - [36] Bugiardini R. Women, 'non-specific' chest pain, and normal or near-normal coro-

- nary angiograms are not synonymous with favourable outcome. *Eur Heart J* 27:1387–1389, 2006
- [37] Wieneke H, Schmermund A, Ge J et al. Increased heterogeneity of coronary perfusion in patients with early coronary atherosclerosis. *Am Heart J* 142:691–697, 2001
- [38] Ong P, Camici PG, Beltrame JF et al., the Coronary Vasomotion Disorders International Study Group (COVADIS). International standardization of diagnostic criteria for microvascular angina. *Int J Cardiol* 250:16–20, 2018
- [39] Brainin P, Frestad D, Prescott E. The prognostic value of coronary endothelial and microvascular dysfunction in subjects with normal or non-obstructive coronary artery disease: a systematic review and meta-analysis. *Int J Cardiol* 254:1–9, 2018
- [40] Ong P, Athanasiadis A, Sechtem U. Pharmacotherapy for coronary microvascular dysfunction. *Eur Heart J Cardiovasc Pharmacother* 1:65–71, 2015
- [41] Baumgart D, Haude M, Gorge G et al. Improved assessment of coronary stenosis severity using the relative flow velocity reserve. *Circulation* 98:40–46, 1998
- [42] Lamendola P, Lanza GA, Spinelli A et al. Long-term prognosis of patients with cardiac syndrome X. *Int J Cardiol* 140:197–199, 2010
- [43] Erbel R, Ge J, Gorge G et al. Intravascular ultrasound classification of atherosclerotic lesions according to American Heart Association recommendation. *Coron Artery Dis* 10:489–499, 1999
- [44] Glagov S, Weisenberg E, Zarins CK et al. Compensatory enlargement of human atherosclerotic coronary arteries. *N Engl J Med* 316:1371–1375, 1987
- [45] Zarins CK, Weisenberg E, Kolettis G et al. Differential enlargement of artery segments in response to enlarging atherosclerotic plaques. *J Vasc Surg Suppl* 7:386–394, 1988
- [46] Ge J, Erbel R, Gerber T et al. Intravascular ultrasound imaging of angiographically normal coronary arteries: a prospective study in vivo. *Br Heart J* 71:572–578, 1994
- [47] Gerber TC, Erbel R, Gorge G et al. Extent of atherosclerosis and remodeling of the left main coronary artery determined by intravascular ultrasound. *Am J Cardiol* 73:666–671, 1994
- [48] Haude M, Caspari G, Baumgart D et al. Comparison of myocardial perfusion reserve before and after coronary balloon predilatation and after stent implantation in patients with postangioplasty restenosis. *Circulation* 94:286–297, 1996
- [48a] Haude M, Baumgart D, Verna E et al. Intracoronary Doppler- and quantitative coronary angiography-derived predictors of major adverse cardiac events after stent implantation. *Circulation* 103:1212–1217, 2001
- [49] Bowers TR, Stewart RE, O'Neill WW et al. Effect of Rotablator atherectomy and adjunctive balloon angioplasty on coronary blood flow. *Circulation* 95:1157–1164, 1997
- [50] Hori M, Inoue M, Kitakaze M et al. Role of adenosine in hyperemic response of coronary blood flow in microembolization. *Am J Physiol* 250(3 Pt 2):H509–H518, 1986
- [51] von Liebergen RA, Piek JJ, Koch KT et al. Immediate and long-term effect of balloon angioplasty or stent implantation on the absolute and relative coronary blood flow velocity reserve. *Circulation* 98:2133–2140, 1998
- [52] Piek JJ, Boersma E, Voskuil M et al. The immediate and long-term effect of optimal balloon angioplasty on the absolute coronary blood flow velocity reserve. A subanalysis of the DEBATE study. *Doppler Endpoints Angioplasty Trial Europe*. *Eur Heart J* 2:1725–1732, 2001
- [53] Bahrman P, Werner GS, Heusch G et al. Detection of coronary microembolization by Doppler ultrasound in patients with stable angina pectoris undergoing elective percutaneous coronary interventions. *Circulation* 115:600–608, 2007
- [54] Herrmann J, Haude M, Lerman A et al. Abnormal coronary flow velocity reserve after coronary intervention is associated with cardiac marker elevation. *Circulation* 103:2339–2345, 2001
- [55] Erbel R, Heusch G. Coronary microembolization – its role in acute coronary syndromes and interventions. *Herz* 24:558–575, 1999
- [56] Okamura A, Ito H, Iwakura K et al. Detection of embolic particles with the Doppler guide wire during coronary intervention in patients with acute myocardial infarction.

- tion: efficacy of distal protection device. *J Am Coll Cardiol* 5:212–215, 2005
- [57] Erbel R, Heusch G. Coronary microembolization. *J Am Coll Cardiol* 36:22–24, 2000
- [58] Skyschally A, Schulz R, Erbel R et al. Reduced coronary and inotropic reserves with coronary microembolization. *Am J Physiol Heart Circ Physiol* 282:H611–H614, 2002
- [60] Heusch G, Schulz R, Baumgart D et al. Coronary microembolization. *Prog Cardiovasc Dis* 44:217–230, 2001
- [61] Dörge H, Schulz R, Belosjorow S et al. Coronary microembolization: the role of TNF-alpha in contractile dysfunction. *J Mol Cell Cardiol* 34:51–62, 2002
- [62] Skyschally A, Haude M, Dörge H et al. Glucocorticoid treatment prevents progressive myocardial dysfunction resulting from experimental coronary microembolization. *Circulation* 109:2337–2342, 2004
- [63] Thielmann M, Dörge H, Martin C et al. Myocardial dysfunction with coronary microembolization: signal transduction through a sequence of nitric oxide, tumor necrosis factor-alpha, and sphingosine. *Circ Res* 90:807–813, 2002
- [64] Böse D, von Birgelen C, Zhou XY et al. Impact of atherosclerotic plaque composition on coronary microembolization during percutaneous coronary interventions. *Basic Res Cardiol* 103:587–597, 2008
- [65] Baumgart D, Liu F, Haude M et al. Acute plaque rupture and myocardial stunning in patient with normal coronary arteriography. *Lancet* 346:193–194, 1995
- [66] Montalescot G, Sechtem U, Achenbach S et al. 2013 ESC guidelines on the management of stable coronary artery disease: the Task Force on the management of stable coronary artery disease of the European Society of Cardiology. *Eur Heart J* 34:2949–3003, 2013
- [67] Knuuti J, Wijns W, Saraste A et al. 2019 ESC Guidelines for the diagnosis and management of chronic coronary syndromes. *Eur Heart J* 41:407–477, 2020
- relation with lipid profile. *Herz* 32:329–335, 2007
- [2] Ong P, Athanasiadis A, Hill S et al. Coronary artery spasm as a frequent cause of acute coronary syndrome: The CASPAR (Coronary Artery Spasms in Patients With Acute Coronary Syndrome) Study. *J Am Coll Cardiol* 52:523–527, 2008
- [3] Gutersohn A, Zimmermann U, Bartel T et al. A rare case of “infective” myocardial infarction triggered by acute parvovirus B19 myocarditis. *Nat Clin Pract Cardiovasc Med* 2:167–171, 2005
- [4] Yilmaz A, Marholdt H, Athanasiadis A et al. Coronary vasospasm as the underlying cause for chest pain in patients with PVB19 myocarditis. *Heart* 94:1456–1463, 2008
- [5] Beltrame JF, Crea F, Kaski JC et al. Coronary Vasomotion Disorders International Study Group (COVADIS). International standardization of diagnostic criteria for vasospastic angina. *Eur Heart J* 38:2565–2568, 2017
- [6] Da Costa A, Isaaz K, Faure E et al. Clinical characteristics, aetiological factors and long-term prognosis of myocardial infarction with an absolutely normal coronary angiogram: a 3-year follow-up study of 91 patients. *Eur Heart J* 22:1459–1465, 2001
- [7] Igarashi Y, Tamura Y, Tanabe Y et al. Angina-linked syncope and lack of calcium antagonist therapy predict cardiac arrest before definitive diagnosis of vasospastic angina. *Coron Artery Dis* 5:881–887, 1994
- [8] Igarashi Y, Tamura Y, Suzuki K et al. Coronary artery spasm is a major cause of sudden cardiac arrest in survivors without underlying heart disease. *Coron Artery Dis* 4:177–185, 1993
- [9] Sato K, Kaikita K, Nakayama N et al. Coronary vasomotor response to intracoronary acetylcholine injection, clinical features, and long-term prognosis in 873 consecutive patients with coronary spasm: analysis of a single-center study over 20 years. *J Am Heart Assoc* 2:e000227, 2013
- [10] Nobuyoshi M, Abe M, Nosaka H et al. Statistical analysis of clinical risk factors for coronary artery spasm: identification of the most important determinant. *Am Heart J* 124:32–38, 1992
- [11] Miller D, Waters DD, Warnica W et al. Is variant angina the coronary manifesta-

6.7 Vasospastische Angina (VSA)

- [1] Nedeljkovic MA, Ostojic MC, Beleslin BD et al. Ergonovine-induced changes of coronary artery diameter in patients with nonsignificant coronary artery stenosis:

- tion of a generalized vasospastic disorder? *N Engl J Med* 304:763–766, 1981
- [12] Nakamura Y, Shinozaki N, Hirasawa M et al. Prevalence of migraine and Raynaud's phenomenon in Japanese patients with vasospastic angina. *Jpn Circ J* 64:239–242, 2000
- [13] Prinzmetal M, Kennamer R, Merliss R et al. Angina pectoris. I. A variant form of angina pectoris: preliminary report. *Am J Med* 27:375–388, 1959
- [14] Erbel R, Effert S. Coronary spasm. Clinical significance and therapeutic consequences. *Dtsch Med Wochenschr.* 106:586–592, 1981
- [15] Schmiert G, Schimmler W, Schwalb H et al. Die Coronarerkrankungen. In: von Bergmann G, Frey W, Schwieck H (Hrsg), *Handbuch der Inneren Medizin*, Bd. 9. 4. Aufl. Springer, Berlin, S. 653, 1960
- [16] Osler W. The lumleian lectures on angina pectoris. *Lancet* I: 697, 1910
- [17] Elsner R, Millard RW, Kjekshus JK et al. Coronary blood flow and myocardial segment dimensions during simulated dives in seals. *Am J Physiol* 249:H1119–1126, 1985
- [18] Nelson C, Nowak B, Childs H et al. Provocative testing for coronary arterial spasm: rationale, risk and clinical illustrations. *Am J Cardiol* 40:614–619, 1977
- [19] Bussmann WD, Klug W, Scriba U et al. The influence of ergonovine on coronary artery diameter and hemodynamics in patients with angina pectoris at rest. *Z Kardiol* 69:478–487, 1980
- [20] Buxton A, Goldberg S, Hirshfeld JW et al. Refractory ergonovine-induced coronary vasospasm: importance of intracoronary nitroglycerin. *Amer J Cardiol* 46:329–334, 1980
- [21] JCS Joint Working Group. Guidelines for diagnosis and treatment of patients with vasospastic angina (Coronary Spastic Angina) (JCS 2013). *Circ J* 78:2779–2801, 2014
- [22] Ong P, Athanasiadis A, Borgulya G et al. Clinical usefulness, angiographic characteristics, and safety evaluation of intracoronary acetylcholine provocation testing among 921 consecutive white patients with unobstructed coronary arteries. *Circulation* 129:1723–1730, 2014
- [23] Heupler FA Jr, Proudfit WL, Razavi M et al. Ergonovine maleate provocative test for coronary arterial spasm. *Am J Cardiol* 41:631–640, 1978
- [24] Okumura K, Yasue H, Matsuyama K et al. Sensitivity and specificity of intracoronary injection of acetylcholine for the induction of coronary artery spasm. *J Am Coll Cardiol* 12:883–888, 1988
- [25] Wei J, Mehta PK, Johnson BD et al. Safety of coronary reactivity testing in women with no obstructive coronary artery disease: results from the NHLBI-sponsored WISE (Women's Ischemia Syndrome Evaluation) study. *JACC Cardiovasc Interv* 5:646–653, 2012
- [26] Takagi Y, Yasuda S, Takahashi J et al. Clinical implications of provocation tests for coronary artery spasm: safety, arrhythmic complications, and prognostic impact: multicentre registry study of the Japanese Coronary Spasm Association. *Eur Heart J* 34:258–267, 2013