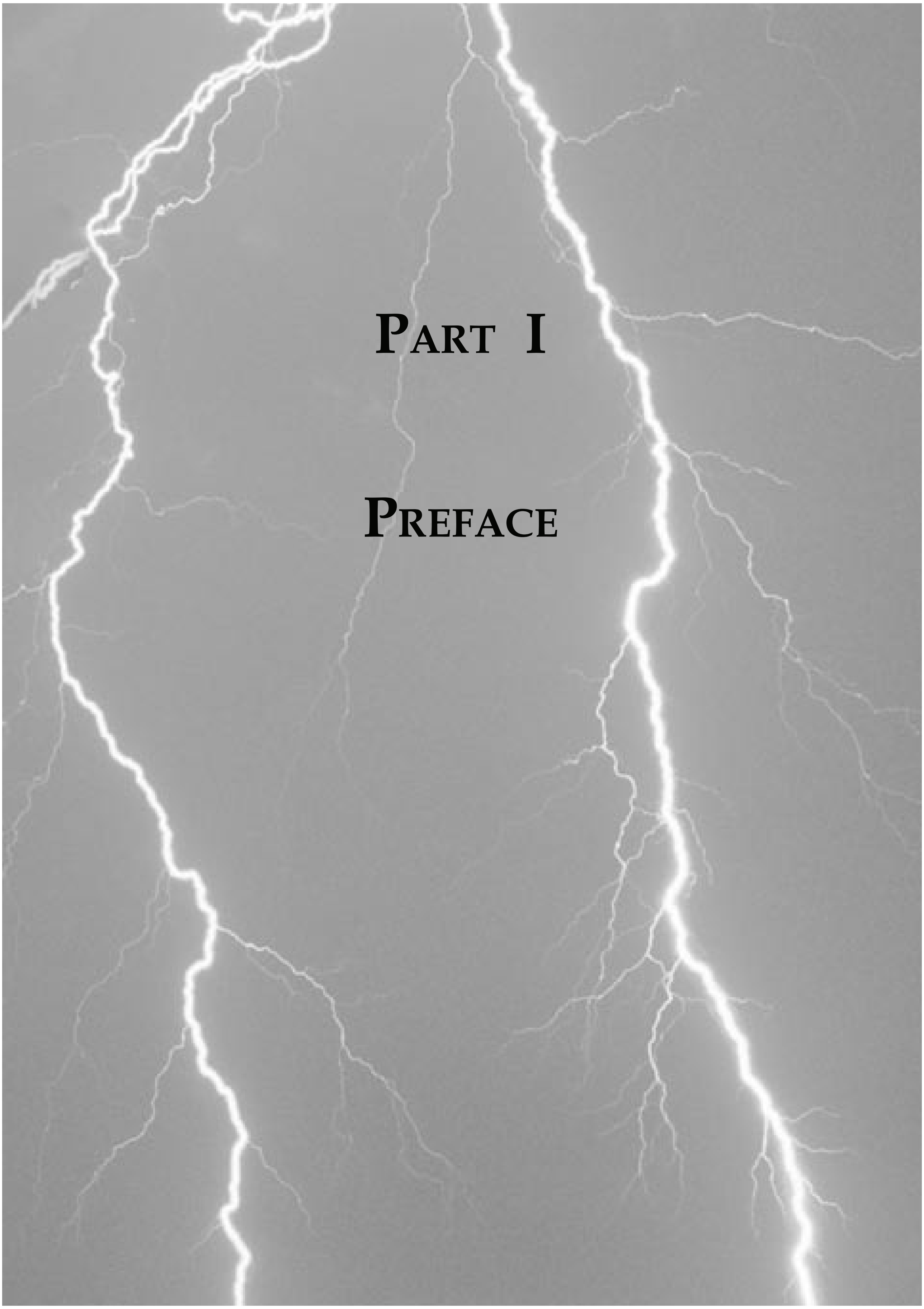
Multimodality imaging of coronary artery bypass grafts
Salm, L.P.

PART I

PREFACE



Chapter 1

Introduction

Coronary artery bypass graft surgery

Coronary heart disease (CHD) is the most common cause of death worldwide, accounting for nearly 2 million deaths each year in Europe alone (1). CHD is most commonly due to obstruction of the coronary arteries by an atheromatous plaque (2). Manifestations of CHD include unstable and chronic angina pectoris, and myocardial infarction. Therapeutic options for CHD are directed towards prevention of further progression of disease or symptom-relief. This is achieved by obtaining revascularization either by percutaneous coronary intervention or coronary artery bypass graft surgery (CABG), if pharmacological treatment alone is insufficient.

In CABG, revascularization of the myocardium is obtained by rerouting or bypassing the bloodstream around the coronary obstruction. Garrett et al. performed the first human CABG in 1967 as a "bailout" procedure (3). Since then, the surgical technique is further developed and refined. At first, graft material was harvested from the saphenous veins in the lower limbs. Subsequently, arteries were also used as bypass grafts, such as left and right internal mammary arteries (IMA), radial artery and gastro-epiploic artery.

CABG was demonstrated to be an effective treatment for CHD in short- and intermediate-term (4;5). However, graft disease occurs frequently, beginning with accelerated atherosclerosis early after surgery in vein grafts (6;7). Arterial grafts have a superior outcome compared with vein grafts, still obstruction and occlusion do occur (8;9). In a recent study, comparing the outcome of vein and IMA grafts, patency at 10 years was 61% for vein grafts compared with 85% for IMA grafts ($p<0.001$) (10).

The gold standard for evaluating bypass grafts is coronary angiography. Although coronary angiography offers a rapid and complete exploration of the native coronary arteries and grafts, it is an invasive procedure, requiring arterial puncture, x-ray exposition, and hospitalization. Complications include ventricular arrhythmias, myocardial infarction, cardiac perforation, necessary emergency CABG, and death, even though the risk is small (11;12). Furthermore, coronary angiography does not provide a functional assessment of the myocardial region, perfused by the respective coronary artery or graft. A noninvasive anatomical and functional examination of the coronary arteries and bypass grafts would be preferable to detect insufficiency and identify a target for re-intervention.

Noninvasive imaging of coronary artery bypass grafts

Several noninvasive imaging modalities are available in order to detect bypass graft insufficiency. Using cardiovascular magnetic resonance (CMR), anatomy and function of bypass grafts may be assessed. MR angiography allows an accurate evaluation of patency in both arterial and vein grafts (13-15). The degree of graft stenosis can, thus far, only be evaluated in vein graft bodies, excluding the recipient coronary arteries (16).

A functional parameter that may be evaluated by CMR is the blood flow velocity. Blood flow velocity of native coronary arteries and bypass grafts can be derived invasively at rest and during pharmacological stress using the Doppler flow wire (17). Subsequent calculation of the coronary flow velocity reserve (CFVR) by dividing the stress by the rest parameter provides insight in the physiological condition of the vessel (18;19). Previous studies have shown that flow velocity measurements may be used to evaluate the

hemodynamic consequences of stenoses in native coronary arteries (20;21), and bypass grafts (22), although studies focusing on bypass grafts are few. Using the phase-contrast MR technique, it is feasible to perform flow velocity measurements noninvasively by CMR in both vein (15;23) and arterial grafts (24). The value of CMR flow velocity measurements in predicting the presence of a stenosis in vein grafts was successfully researched (25;26). CMR flow velocity measurements of arterial grafts remain challenging because of the small luminal diameter of the internal mammary arteries, and metal clip artefacts. In earlier studies demonstrating the feasibility to measure flow in left IMA grafts, CMR sequences were limited by low spatial and temporal resolution (24;27;28).
With computed tomography (CT) angiography, assessment of bypass graft patency was extensively investigated (29-31).When it became possible to use multiple detectors in a single spiral CT acquisition, graft patency could be assessed with very high accuracy (32;33). The evaluation of stenoses in grafts by multi-detector row CT is still a challenge because of motion artefacts, metal clip artefacts or beam hardening from calcium deposits (32-34). Since a cardiac CT examination to evaluate native coronary arteries and bypass grafts requires scanning of the entire heart, reconstruction of the left ventricular (LV) function is also achievable. Several studies showed that 4-detector row CT allowed accurate assessment of global and regional LV function (35;36). Validation of the next generation CT equipment in assessing LV function has yet to be conducted.
Single-photon emission computed tomography (SPECT) perfusion imaging is a well-established technique by which to detect CHD by evaluating regional myocardial perfusion at rest and during stress. Excellent sensitivities and specificities of SPECT to detect stenoses in native coronary arteries (37;38) and bypass grafts (39) were demonstrated. More recently, for SPECT imaging the emphasis has shifted from detection of CHD to hemodynamic evaluation of stenoses. Comparative studies between SPECT imaging and invasive assessment using the Doppler flow wire have been performed, demonstrating a good agreement (ranging from 72% to 96%) between these two techniques for the evaluation of the hemodynamic consequence of an intermediate native coronary artery stenosis (21;40;41). Studies evaluating the hemodynamic consequences of bypass graft lesions are lacking.

Outline of the thesis

The aim of the thesis was to describe multiple modalities to examine coronary artery bypass grafts, and to further develop noninvasive imaging techniques to detect or exclude stenoses in native coronary arteries and bypass grafts in patients who experienced recurrent chest pain after CABG.

Part I of the thesis provides an introduction to noninvasive imaging. In chapter 2, noninvasive imaging of coronary artery bypass grafts by CMR and CT is reviewed in detail.
Part II of the thesis focuses on CMR flow velocity imaging in vein and arterial grafts. In chapter 3, a model to detect or exclude stenoses in vein grafts by CMR volumetric flow measurements is described. In chapter 4, two analysis methods for the CMR flow velocity maps, i.e. velocity and volumetric flow, are compared, using flow velocity

maps of vein grafts. In chapter 5, the functional significance of bypass graft stenoses is investigated by SPECT perfusion imaging and CMR, and compared with findings at coronary angiography. In chapter 6, a novel CMR phase-contrast sequence to measure flow velocity in arterial and vein grafts is introduced and validated.
Part III of the thesis concentrates on multi-detector row CT imaging of coronary artery bypass grafts. In chapter 7, a comprehensive assessment by 16-detector row CT of patients after CABG is investigated. In chapter 8, global and regional LV function evaluated by 16-detector row CT is compared with evaluation by echocardiography and CMR.
Part IV focuses on the hemodynamic consequences of vein graft lesions. In chapter 9, the relative merits of invasive Doppler flow velocity measurements and SPECT perfusion imaging are studied in assessing the hemodynamic significance of stenoses in vein grafts, and the results are related to coronary angiography.

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