Cardiac CT Imaging

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Cardiac CT Imaging

Diagnosis of Cardiovascular Disease

With 299 Figures
including 168 Color Plates

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Dedication

If I have been able to see further, it was only because I stood on the shoulders of giants.

Sir Isaac Newton

To fully appreciate the current stature of cardiac computed tomography (CT) as both a radiological procedure and cardiology tool, one must acknowledge the pioneering efforts of the original luminaries in the field. British-born visionary David G. King was the lead engineer in the development of the original CT scanner that resulted in a Nobel Prize for his colleague, Sir Godfrey Hounsfield. Their combined “broad shoulders” became a springboard for the worldwide development and commercial success of CT. King introduced CT imaging to the United States, installing and commissioning a “head scanner” at the Mayo Clinic in 1973. David King’s scientific career began at the EMI Research Labs in Middlesex (UK). It ended at General Electric, after he shepherded electron beam tomography at Imatron. He became the intellectual centerpiece of a fertile “brain trust,” which stimulated the research and coordinated the clinical activities of a new generation of cardiologists and radiologists. The authors dedicate this edition to David King, an inspirational friend and the “father of coronary calcium imaging.”

David G. King (1946–2004)
Scientist, Mentor, Friend

Foreword

Cardiac CT has finally come of age. After nearly 30 years of development and growth, tomographic X-ray is being embraced by cardiologists as a useful imaging technology. Thirty years ago, Doug Boyd envisioned a unique CT scanner that would have sufficient temporal resolution to permit motion-artifact-free images of the heart. In the late 1970s I had the good fortune to work closely with Dr. Boyd, Marty Lipton, and Bob Herkens who had the vision to recognize the potential of CT imaging for the diagnosis of heart disease. In the early 1980s, when electron beam CT became available, others, including Mel Marcus, †John Rumberger, Arthur Agatston, and †Dave King, were instrumental in making clinical cardiologists aware of the potential of cardiac CT.

In 1985 several investigators recognized the potential of cardiac CT for identifying and quantifying coronary artery calcium. Now, 20 years later, there is wide recognition of the value of coronary calcium quantification for the prediction of future coronary events in asymptomatic people. It has been a long and arduous road, but finally widespread screening may significantly reduce the 150,000 sudden deaths and 300,000 myocardial infarctions that occur each year in the United States as the first symptom of heart disease.

In the late 1970s, it was thought that a 2.4-sec scan time was very fast CT scanning. With the development of electron beam technology, scan times of 50 msec became possible giving rise to terms such as fast CT, ultrafast CT and RACAT (rapid acquisition computed axial tomography). Now, with the development of multidetector scanners capable of 64, 128, 256, and beyond simultaneous slices, spatial resolution is approaching that of conventional cineangiography and the holy grail, non-invasive coronary arteriography, appears attainable.

In this book, Drs. Matt Budoff and Jerold Shinbane, preeminent leaders in the field of cardiac CT, have described the many and varied uses of the technology in the diagnosis of cardiovascular disease. The book clearly documents that cardiac CT has not only arrived but has become a very valuable and potent diagnostic tool.

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†Deceased

Preface

Since its introduction in the early 1970s, computed tomography (CT) has become a robust modality to evaluate extracranial, thoracic, and abdominal vascular distributions. It has become a gold standard to non-invasively image the aorta, pulmonary arteries, great vessels, renal and peripheral arteries. However, cardiac anatomy evaluation with this modality was not possible, due to rapid cardiac motion and slow image acquisition times. Since the introduction of the first dedicated cardiac CT scanner, the electron beam CT (EBCT), the diagnosis and workup of cardiac structures has become possible. The lack of movement of the X-ray source allowed for images at a rate of 20 per second – 100 times faster than conventional CT at that time. Dr. Douglas Boyd, the inventor of EBCT, created this technology specifically with cardiac imaging in mind, and first published clinical data in 1982 [1]. However, limited reimbursement, high cost of acquisition, and very limited industry support kept this technology from expanding. The number of EBCT scanners in operation at any time never exceeded 100 worldwide, and physician exposure to the technology was very limited. Despite these hurdles, functional cardiac analysis (wall motion, cardiac output, wall thickening, and ejection fraction), perfusion imaging, non-invasive angiography, and coronary calcium assessment were validated, each with at least ten years of experience. To date, over 1000 scientific papers have been published in English, and three scientific statements from the American Heart Association have been written specifically on this modality. With the advent of helical CT in the mid-1990s and multidetector CT (MDCT) in 1999, the widespread availability of scanners to thousands of centers created a marked increase in utilization of and interest in cardiac CT. By 2004, three professional societies were vying for membership of potential cardiac CT physicians, and guidelines and credentialing standards were developed at a record pace.

Despite coronary calcium reports since 1989, and non-invasive coronary angiographic imaging reports with EBCT since 1995 [2], these applications did not gain widespread appeal until studies with MDCT became available. The preliminary studies (with sub-second single slice “helical” CT), had very limited cardiac applications and significant motion artifacts. The comparisons to EBCT were modest at best, and most investigators were quite concerned about applying the results of helical CT to clinical patients [3]. The early exposure MDCT, specifically the 4-slice scanner, was also disappointing with limited temporal resolution, volume coverage, collimation, and z-axis imaging. Due to the rapid coronary motion and limited scan speeds available with these early scanners, accurate and reliable imaging of the heart and coronary arteries has been significantly limited [4]. Diagnostic accuracy for cardiac 4-slice MDCT angiography, the most promising new application of these machines, was severely limited. Several studies reported diagnostic rates of only 30%, mostly due to cardiac motion [5]. However, evolution of MDCT with increased detectors, allowing for thinner slices and improved spatial resolution, has made this a most robust technology. Cardiac CT (with either MDCT or EBCT) offers several advantages over other diagnostic methodologies and is quite complementary to more common or traditional tests performed today. Clearly, the ability to see the lumen and vessel wall adds quite a lot to the assessment of the cardiac patient. Yet cardiac CT does not readily afford functional assessment of the patient under stress (exercise), and that information, garnered most commonly with treadmill testing, stress thallium, or echocardiography, adds vital information to the cardiac assessment. Thus, cardiac CT

has been seen as a mostly complementary modality, adding anatomic information to the functional data acquired with stress testing.

Magnetic resonance imaging garnered quite a bit of interest in the early 1990s with the promise of a non-invasive angiogram with high accuracy. However, the next decade brought little improvement in the diagnostic accuracy of this technique, most likely due to limitations in slice thickness, temporal and spatial resolution. As compared to MRI, EBCT and MDCT allow for higher spatial and temporal resolution. The ease of use and robustness allow for fairly easy application to a variety of cardiac diagnoses. This book will highlight the vast array of cardiac (and vascular) applications of CT, updating the reader on the methodology employed by a variety of experts with a cumulative 100 or more years of cardiac CT experience.

We are forever indebted to the experts (both cardiologists and radiologists) who have spent the last 10 to 20 years of their lives dedicated to studying and publishing in this particular field of interest. Some of the experts who originated this work in the mid-1980s and allowed us to progress to where we are today include Bruce Brundage, William Stanford, Ralph Haberl, Geoff Rubin, Robert Detrano, Warren Janowitz, Arthur Agatston, John Rumberger, Marty Lipton, and Ruping Dai. This is clearly a very incomplete list, yet these are some of the early investigators who had to literally fight against a medical community that thought cardiac CT posed a threat to their more traditional tests. There has been significant controversy regarding cardiac CT over the years, with raging debates at national meetings and policies by the professional organizations sometimes swayed against the technology more by emotion than science.

The pathway that cardiac CT had to endure over the last 20 years is reminiscent of a quote by Arthur Schopenhauer. He stated:

All truth passes through three stages.

First, it is ridiculed.

Second, it is violently opposed.

Third, it is accepted as being self-evident.

A prominent cardiologist and past president of the American College of Cardiology recently told me that he thought some of the early investigators in the 1980s were clearly out of their mind when suggesting widespread use of cardiac CT, whether for coronary calcium assessment as a “mammogram of the heart,” or CT angiography as a possible replacement for some conventional angiograms (ridicule stage). Violent opposition to this modality came in the late 1990s, when debates at the American College of Cardiology and AHA centered on the inappropriate advertising of these tests, rather than the science. Today, we are approaching the third stage, with the acceptance that cardiac CT has an important role in risk stratification (coronary artery calcification) and diagnosis of obstructive coronary artery disease (CT angiography).

As you will see, cardiac CT has matured significantly. It has become a powerful risk stratifying tool for the early detection of atherosclerosis, a possible substitute for coronary angiography or non-invasive exercise testing in certain clinical situations, and a powerful tool to image the heart for congenital heart disease, pre- and post-electrophysiologic testing and peripheral angiography. Future directions include possibly replacing some conventional catheterizations, and non-invasive tracking of atherosclerosis (progression/regression of either calcified plaque or non-calcified or “soft plaque”). The promise of CT includes non-invasive coronary plaque characterization, as well as accurate stenosis identification. It is highly likely that if these goals are obtained, CT coronary angiography may become the most valuable tool to evaluate the coronary arteries non-invasively. It is possible that direct non-invasive CT visualization of the arteries will partially replace both nuclear cardiology and diagnostic angiography in certain clinical situations, with a subsequent increase in coronary revascularizations.

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Most importantly, I would like to thank my family, who have put up with me writing or editing this book for the past 8 months, working at times when I should have been with them. Thank you, Vicky, Daniel, and Garrett. Your support has made this book possible.

Matthew J. Budoff, MD, FACC, FAHA

I would like to thank Matthew Budoff for introducing me to the art and science of cardiovascular CT, and having the vision to see the applications for a multitude of disciplines within Cardiovascular Medicine. Your intelligence and enthusiasm have truly moved the field in novel directions. I would also like to thank Songshou Mao for his great insights and expertise in defining cardiovascular CT techniques. To the Harbor-UCLA EBCT Center staff, thank you for your excellence in providing CT services. Thank you to my family for your encouragement throughout my career. Most of all, to Rosemary, Anna, and Laura, thank you for your love and support.

Jerold S. Shinbane, MD, FACC

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