The prevalence of obesity is increasing rapidly in the industrialized world and in the United States in particular [1]. For adults, a body mass index (BMI) of more than 25 is considered “overweight”, with a BMI of more than 30 classifying them as “obese”. The most rapidly growing sections of the obese population are in those with a BMI of more than 40, classified as severely and morbidly obese [2].

Obesity is not only a risk factor for multiple pulmonary and cardiovascular conditions, with morbidly obese adults having the highest cardiovascular mortality risk [3], but also complicates the treatment of otherwise unrelated conditions. A recent advisory from the American Heart Association has dealt with the evaluation and management of severely obese patients [2]. Coronary artery disease (CAD), heart failure, systemic hypertension and pulmonary hypertension, associated with sleep apnea and obesity-related hypoventilation, are just a few of the related conditions commonly present in obese patients.

In addition, a specific cardiomyopathy of obesity has also been described [4]. A high incidence of CAD events was reported in women with BMI of more than 35 in the Women’s Health Initiative Observational Study (11.6% had prior myocardial infarction, angina pectoris or revascularization) [5] and these findings were related to the increasing prevalence of type 2 diabetes mellitus and systemic hypertension associated with increasing BMI.

In addition to their weight posing logistical challenges [6], the body habitus of the morbidly obese severely limits the signal-to-noise ratio (SNR), which prevents reliable diagnostic imaging. In cardiac catheterization laboratories, image quality is limited by the power of the X-ray generators. Invasive coronary angiography in the extremely obese may be compromised both by poor image quality as well as by the technical difficulty of access, requiring special attention to the entry site to maintain a low complication rate [7].

Non-invasive imaging modalities such as current generation echocardiography, multi-detector computed tomography (MDCT), nuclear medicine and magnetic resonance imaging are superior in morbidly obese patients. The introduction of the 64-slice Brilliance iCT scanner (Philips Healthcare, USA) is a major advancement in this field, enabling high-quality imaging in this group of patients. This imaging modality has been employed in clinical practice at the Lady Davis Carmel Medical Center, Haifa, Israel (Figure 1) and has proven to be effective in accurately assessing cardiovascular disease.

The Lady Davis Carmel Medical Center, Haifa, Israel (Figure 1) is a leading medical institution in Israel. It is affiliated to the Rappaport School of Medicine at the Technion, Israel Institute of Technology, and is a major referral center for cardiovascular medicine and surgery.

Clinical applications

Non-invasive cardiac imaging of morbidly obese patients using the Brilliance iCT

L. Domachevsky
T. Gaspar
N. Peled
M. Shnapp
D.A. Halon
Carmel B.S. Lewis
R. Rubinshtein
D. Hazzan
M. Vembar
S. Samoilov

Departments of Radiology, Lady Davis Carmel Medical Center, Haifa, Israel.
Department of Cardiovascular Medicine, Lady Davis Medical Center, Haifa, Israel.
Department of General Surgery, Lady Davis Carmel Medical Center, Haifa, Israel.
Philips Healthcare, Highland Heights, OH, USA.

Figure 1. The Lady Davis Carmel Medical Center, Haifa, Israel.
scanners face similar challenges [8], with pharmacological functional and perfusion tests performing poorly in ruling out coronary artery disease in morbidly obese patients [7]. Lastly, because of the limited exercise capacity of these patients, exercise stress is often not possible.

At the Lady Davis Carmel Medical Center in Haifa, Israel, we have had prior experience in the cardiovascular care of challenging patient cohorts. We were among the first to use the Philips’ Brilliance 40 MDCT scanner in a patient cohort with implanted coronary stents [9] and the Brilliance 64 in the Emergency Department [10, 11]. We have also had recent experience with invasive coronary angiography in moderately obese patients [12].

Currently, with over 12 months experience with the use of the Brilliance iCT scanner, we have now turned our attention to tackling the challenge of non-invasive imaging of morbidly obese patients. Investigations have studied risks of bariatric surgical procedures and proposed ways to improve decision making for the treatment of obesity [13]. We are now increasingly using the Brilliance iCT for coronary assessment in this patient category, and in the pre-procedural assessment of patients prior to bariatric surgical intervention.

In the following sections, we present our experiences with cardiovascular MDCT imaging of morbidly obese patients using the Brilliance iCT scanner. All post-processed images shown were generated via Comprehensive Cardiac Analysis (CCA) on the Philips Brilliance Workspace CT workstation.

**The Brilliance iCT**

With a longitudinal coverage of 8 cm and the medical industry’s fastest rotation time of 0.27 seconds (resulting in a standard temporal resolution of 135 msec), the Brilliance iCT has significantly reduced the breath hold and acquisition times in chest CT angiography (CTA) scans [14]. At the same time it shows the capability of accommodating a wider range of heart rates for coronary CTA applications with contrast optimization [15, 16].

The detector system is equipped with a 2D antiscatter grid (ClearRay Collimator) as shown in Figure 2a. This reduces the scatter radiation, thereby improving the Hounsfield Unit (HU) uniformity and contrast resolution over a larger z-axis coverage. Other innovations include radiation dose saving technologies across the entire imaging chain. For instance, low-dose prospectively-gated axial scans (“Step & Shoot Cardiac”) using the Brilliance iCT have been successfully applied for not only coronary and aorta applications [14, 15] but also as an ultra-low dose option in the imaging of infant/pediatric population to assess congenital defects [16].

Additionally, a dynamic z-collimator (“Eclipse DoseRight Collimator”) and an adaptive z-collimator offer significant radiation dose savings in helical and axial modes of scans respectively, by reducing z-overscanning at the ends of the acquisitions [17]. Lastly, in contrast to other commercially available scanners, the Brilliance iCT has a 120 kW tube (iMRC).
The availability of high instantaneous power from the tube and generator system now provides us with the capability to image morbidly obese patients. At the same time, dose management tools (“DoseRight Cardiac”) are available that enable radiation dose savings of approximately 40% depending on the heart rate during the acquisition. Typical acquisition parameters are:

- \( 128 \times 0.625 \text{ mm collimation} \)
- \( 0.27-0.33 \text{ seconds rotation time} \)
- \( 120-140 \text{ kVp} \)
- \( 900-1500 \text{ mAs} \)
- \( 0.16-0.18 \text{ pitch} \)
- \( 0.8-1.0 \text{ mm reconstructed slice thickness} \).

(Figure 2b) and generator system, providing the high instantaneous power needed for the short duration cardiac scans, thus making it easier to image obese and morbidly obese patients [18].

**Imaging morbidly obese patients**

**Retrospectively-gated helical coronary CTA**

With this commonly used protocol, the entire cardiac anatomy of interest (12 cm) can now be covered in 5 seconds or less using the Brilliance iCT. Optimizing temporal resolution via advanced adaptive multi-slice reconstruction algorithms [19] and using a variable delay algorithm to capture the same physiological phase during the acquisition [20, 21] provides high-quality imaging of coronary artery segments.

The availability of high instantaneous power from the tube and generator system now provides us with the capability to image morbidly obese patients. At the same time, dose management tools (“DoseRight Cardiac”) are available that enable radiation dose savings of approximately 40% depending on the heart rate during the acquisition. Typical acquisition parameters are:

- \( 128 \times 0.625 \text{ mm collimation} \)
- \( 0.27-0.33 \text{ seconds rotation time} \)
  (with the option of the slower rotation time for obese patients)
- \( 120-140 \text{ kVp} \)
- \( 900-1500 \text{ mAs} \)
- \( 0.16-0.18 \text{ pitch} \)
- \( 0.8-1.0 \text{ mm reconstructed slice thickness} \).
Automatic bolus tracking (BolusPro) is employed in all patients, with a region of interest (ROI) placed in the descending aorta. Scans are triggered when the contrast enhancement reaches a pre-set threshold (for example, 150 HU). 80-100 cc of non-ionic contrast is injected at 5-7 cc/sec, with the volume adjusted depending on the length of the scan.

If the resting heart rate is greater than 65 bpm, beta blockers are administered in order to stabilize and reduce the heart rate (provided that there is no contraindication for the use of beta blockers). All patients are given sublingual nitroglycerin to dilate the coronary arteries, thereby improving arterial definition and resolution.

Figure 3 shows the coronary arteries of a 60-year-old woman referred for bariatric surgery who suffered from atypical chest pain and had a history of hypertension and hypercholesterolemia. Her weight was 106 kg and height 163 cm (BMI ≈ 40). The CT acquisition was performed using a volume of 90 cc of contrast (Ultravist 370, Bayer Schering Pharma AG) injected at 7 cc/sec. The average heart rate during the acquisition was 73 ± 2 bpm. An acquisition length of 14 cm was covered in six seconds. The image quality was diagnostic and sufficient to exclude any significant CAD and the study obviated the need for any further coronary investigation prior to surgery.

**Low-dose prospectively-gated coronary CTA**

One approach to mitigate the risk of radiation dose is to use prospectively-gated axial acquisition (“Step & Shoot Cardiac”), where the X-rays are only emitted during the quiescent cardiac phase (for example, ventricular diastasis).

This approach has been shown to reduce radiation dose by 80% compared with the standard retrospectively-gated helical approach [22]. While recent literature has shown the success of this approach at lower heart rates [22, 23], preliminary experience with the Brilliance iCT has shown promise of it being applicable over an expanded range of heart rates with diagnostic image quality [15].

Typical Step & Shoot Cardiac acquisition parameters are:

- **128 x 0.625 mm collimation**
- **0.27-0.33 sec rotation time (with the option of the slower rotation time for obese patients)**
- **120-140 kVp**
- **160-300 mAs** (with the higher mAs applicable at the slower rotation time for obese patients)
- **0.8-1.0 mm reconstructed slice thickness**

Automatic bolus tracking is employed as described earlier.

Figure 4 shows the right coronary artery of a 48-year-old female who had a history of stable angina pectoris, but was hospitalized acutely due to increasingly severe chest pain. She was obese (height 170 cm, weight 105 kg, BMI ≈ 36) and had a history of hypertension, hypercholesterolemia and a family history of CAD. She had a treadmill stress test shortly before hospitalization that showed exercise-induced ischemic changes on the electrocardiogram.

The CT acquisition (Figure 4a, b) was performed using a prospectively-gated (“Step & Shoot Cardiac”) protocol with a volume of 90 cc of contrast (Omnipaque 350, GE Healthcare) injected at 7 cc/sec. The average heart rate during the acquisition was 48 ± 0.6 bpm. Using a k value of 0.014 applicable to chest CT, the estimated effective radiation dose was 6.4 mSv, much lower than that attainable in such patients using the conventional retrospectively-gated protocol.

The image shows a tight proximal narrowing of the right coronary artery with predominantly non-calcified plaque with a localized spot of calcification and positive remodeling of the coronary artery. These three features have been described as markers of elevated risk when assessed by CT angiography or intravascular ultrasound imaging [24-26].

The speed and coverage of the Brilliance iCT has thus expanded the use of cardiovascular applications, accommodating not only a wider range of heart rates [15] but also a diverse patient population, such as pediatric patients with congenital anomalies [16]. Extending this further, we have now shown that by appropriately harnessing the power of the tube and generator system it is possible to perform high-quality cardiovascular imaging of obese and morbidly obese patients who have previously presented challenges for reliable diagnostic assessment of their underlying symptoms.
Conclusion

With the increasing prevalence of obesity, diabetes mellitus and hypertension and their co-morbidities, the need for assessment of the coronary arteries in obese patients is on the rise. We have defined a protocol to harness the power of the iCT scanner to this end and the results show that imaging of the coronary arteries utilizing the high output of this novel scanner makes scanning of the coronary arteries in the very obese a clinically useful reality.

Prospective data-driven studies are currently under way, investigating the diagnostic image quality of coronary arteries, such as the percentage of assessable coronary segments in this challenging cohort of patients.
References


