Imaging of coronary heart disease after treatment: bypasses and stents

Marco Francone MD, PhD
Department of Radiological Sciences
Sapienza University of Rome
Detection of Patent Coronary Bypass Grafts by Computed Tomography
A Preliminary Report

BRUCE H. BRUNDAGE, M.D., MARTIN J. LITTON, M.D., ROBERT J. HERKESSE, M.D.,
WALTER H. BERNINGER, Ph.D., ROLAND W. REDINGTON, Ph.D., KANU CHATTERJEE, M.B.,
AND ERIC CARLSSON, M.D.

SUMMARY Twenty-three coronary bypass graft patients were evaluated by a contrast-enhanced computed
tomography (CT) technique to determine graft patency. Four to six 4.8-second sequential scans with a 1-
second interscan interval were obtained in each patient during the hand injection of 25-30 ml of contrast
medium in a peripheral vein. Patency of grafts was determined by a characteristic contrast enhancement.
The CT technique correlated with angiographic assessment of graft patency in 5 of 52 grafts (98%). We conclude
that this relatively noninvasive technique shows promise as a method for determining coronary bypass graft
patency.

Brundage et al Circulation 1980

Non-invasive assessment of coronary Palmaz-Schatz stents by contrast enhanced electron beam computed
tomography

A. Schmermund, M. Haude, D. Baumgart, G. Görge, D. Gröneweyer*, R. Seibel*,
C. Sehnert* and R. Erbel

Department of Cardiology, University Clinic Essen, Essen, Germany. *Institute for Diagnostic and Interventional
Radiology, University Witten/Herdecke, Mülheim an der Ruhr, Germany

The aim of the study was the evaluation of electron beam
tomography as a non-invasive method to localize
quantitative coronary angiography confirmed that
coronary stents and to document patency in stented vessel
the stented vessel segments were not stented. Densitometric curves obtained in 16 of these 18 patients yielded
contrast enhancement distal to the stented vessel segment of

Schmermund et al Eur Heart J 1996
Coronary Stent and CABG

from past...

...to 2013
Coronary Stent and CABG

**Topic Outlines**

- Clinical Background
- Acquisition Technique
- Current Limitations
- Literature results
- Improvements and future
Clinical Background

• Stent implantation most important nonsurgical coronary revascularization therapy:
  537,000 stents in the US in 2002*, 247% increase 2005-2009*

• 1977 First Percutaneuos Transluminal Angioplasty

• 1986 First Coronary Stent Implantation

• 1996 Initial EBCT data for stent assessment

* AHA statistical update 2010
Clinical Background

-Stent placement is followed by a vascular neointimal proliferation and after 6 months in stent restenosis occurs in 11-46% of the patients.

Antoniucci D et al Am Heart J 1998

- Clinical symptoms and exercise electrocardiography show only low to moderate sensitivity for the diagnosis of in-stent restenosis

Galassi AR et al Am Heart J 2000

-Selective coronary angiography still represents the gold standard for the 6 months-follow up and assessment of stent patency but the procedure is invasive with a mortality of 0.12% and a morbidity of 80%, and highly cost effective.

Bono D . Br Heart J 1993

NON INVASIVE ASSESSMENT OF STENT PATENCY IS HIGHLY DESIDERABLE!!!!!
In-Stent Restenosis

Drug eluted Stents (DES)

Restenosis/occlusion predictors

Coronary Stent: MDCT issues and drawbacks

- Stent Structure (beam hardening artefacts)
- Spatial Resolution of the scanner
- Importance of reconstruction kernel
- Bifurcation lesions (Y shaped stents)
- Imaging of complications (stent fracture and occlusion)
Stent Structure: the catalogue

## Stent Structure

<table>
<thead>
<tr>
<th>Stent</th>
<th>Diameter (%)</th>
<th>Attenuation (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wiktor</td>
<td>3,3</td>
<td>483</td>
</tr>
<tr>
<td>Mansfield</td>
<td>23,3</td>
<td>410</td>
</tr>
<tr>
<td>Tantal alloy</td>
<td>30,0</td>
<td>231</td>
</tr>
<tr>
<td>Nir royal</td>
<td>33,0</td>
<td>179</td>
</tr>
<tr>
<td>Micro</td>
<td>36,7</td>
<td>477</td>
</tr>
<tr>
<td>Herkulink</td>
<td>40,0</td>
<td>252</td>
</tr>
<tr>
<td>Nir royal (adv.)</td>
<td>43,3</td>
<td>236</td>
</tr>
<tr>
<td>Duett</td>
<td>46,7</td>
<td>245</td>
</tr>
<tr>
<td>Sonic</td>
<td>46,7</td>
<td>256</td>
</tr>
<tr>
<td>Tantalum sandw.</td>
<td>46,7</td>
<td>379</td>
</tr>
<tr>
<td>Express 2</td>
<td>50,0</td>
<td>225</td>
</tr>
<tr>
<td>Pixel</td>
<td>50,0</td>
<td>206</td>
</tr>
<tr>
<td>RithronXR</td>
<td>50,0</td>
<td>297</td>
</tr>
<tr>
<td>Sito</td>
<td>50,0</td>
<td>231</td>
</tr>
<tr>
<td>Be stent 2</td>
<td>53,3</td>
<td>215</td>
</tr>
<tr>
<td>Coroflex blue</td>
<td>53,3</td>
<td>340</td>
</tr>
<tr>
<td>Crossflex LC</td>
<td>53,3</td>
<td>189</td>
</tr>
<tr>
<td>Flex AS</td>
<td>53,3</td>
<td>247</td>
</tr>
<tr>
<td>Liberte</td>
<td>53,3</td>
<td>195</td>
</tr>
<tr>
<td>Palmaz</td>
<td>53,3</td>
<td>239</td>
</tr>
<tr>
<td>Palmaz crown</td>
<td>53,3</td>
<td>200</td>
</tr>
<tr>
<td>Sirius</td>
<td>53,3</td>
<td>154</td>
</tr>
<tr>
<td>Synchro</td>
<td>53,3</td>
<td>237</td>
</tr>
<tr>
<td>Tecnic</td>
<td>53,3</td>
<td>237</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stent</th>
<th>%</th>
<th>HU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetra</td>
<td>53,3</td>
<td>227</td>
</tr>
<tr>
<td>ACS</td>
<td>56,7</td>
<td>190</td>
</tr>
<tr>
<td>CSG standard</td>
<td>56,7</td>
<td>261</td>
</tr>
<tr>
<td>Cypher</td>
<td>56,7</td>
<td>194</td>
</tr>
<tr>
<td>Jografia</td>
<td>56,7</td>
<td>307</td>
</tr>
<tr>
<td>Jostent</td>
<td>56,7</td>
<td>199</td>
</tr>
<tr>
<td>Mini</td>
<td>56,7</td>
<td>205</td>
</tr>
<tr>
<td>Nir primo</td>
<td>56,7</td>
<td>225</td>
</tr>
<tr>
<td>Taxus</td>
<td>56,7</td>
<td>142</td>
</tr>
<tr>
<td>Tsunami</td>
<td>56,7</td>
<td>200</td>
</tr>
<tr>
<td>V - Flex</td>
<td>56,7</td>
<td>256</td>
</tr>
<tr>
<td>CCSV</td>
<td>60,0</td>
<td>199</td>
</tr>
<tr>
<td>Coroflex delta</td>
<td>60,0</td>
<td>221</td>
</tr>
<tr>
<td>Crossflex</td>
<td>60,0</td>
<td>224</td>
</tr>
<tr>
<td>Lekton</td>
<td>60,0</td>
<td>217</td>
</tr>
<tr>
<td>MSM</td>
<td>60,0</td>
<td>195</td>
</tr>
<tr>
<td>Nexus</td>
<td>60,0</td>
<td>212</td>
</tr>
<tr>
<td>Penta</td>
<td>60,0</td>
<td>183</td>
</tr>
<tr>
<td>Tsunami gold</td>
<td>60,0</td>
<td>203</td>
</tr>
<tr>
<td>Velocity</td>
<td>60,0</td>
<td>120</td>
</tr>
<tr>
<td>Arthos inert</td>
<td>63,3</td>
<td>200</td>
</tr>
<tr>
<td>BiodivYsio</td>
<td>63,3</td>
<td>212</td>
</tr>
<tr>
<td>Coroflex</td>
<td>63,3</td>
<td>247</td>
</tr>
<tr>
<td>F1 large</td>
<td>63,3</td>
<td>215</td>
</tr>
</tbody>
</table>

**Results for Protocol B46f 0.6**

- F1 medium: 63.3, 244 HU
- R - Stent: 63.3, 218 HU
- Tenax XR: 63.3, 188 HU
- Wallstent: 63.3, 156 HU
- Arthos pico: 66.7, 191 HU
- Driver: 66.7, 242 HU
- Flex small: 66.7, 245 HU
- Nexus 2: 66.7, 156 HU
- S7: 66.7, 127 HU
- Tenax complete: 66.7, 178 HU
- Vision: 66.7, 211 HU
- Flex standard: 70.0, 223 HU
- Symbiot: 70.0, 197 HU
- Teneo: 70.0, 208 HU
- Radius: 73.3, 147 HU

Heart-Phantom Simulation
Clinical CAD-Model

Coronary Stent: spatial resolution

2.5 mm. sl. resol.

1 mm. sl. resol.

1 mm. sl. resol.

0.5 mm. sl. resol.

plaque

lumen

lipid

Courtesy of W. Kalender
Spatial resolution and stent caliber...

3.3 mm: interpretable stent

2.6 mm: ?
### Spatial resolution and stent caliber...

<table>
<thead>
<tr>
<th></th>
<th>PPV</th>
<th>NPV</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypher Select (n = 34)</td>
<td>10.5% (2/19)</td>
<td>100% (15/15)</td>
<td>100% (2/2)</td>
<td>46.9% (15/32)</td>
</tr>
<tr>
<td>Nominal diameter ≥ 3 mm (n = 21)</td>
<td>14.3% (1/7)</td>
<td>100% (14/14)</td>
<td>100% (1/1)</td>
<td>70% (14/20)</td>
</tr>
<tr>
<td>Nominal diameter &lt; 3 mm (n = 13)</td>
<td>8.3% (1/12)</td>
<td>100% (1/1)</td>
<td>100% (1/1)</td>
<td>8.3% (1/12)</td>
</tr>
<tr>
<td>Taxus Liberte (n = 56)</td>
<td>25% (5/20)</td>
<td>100% (36/36)</td>
<td>100% (5/5)</td>
<td>70.6% (36/51)</td>
</tr>
<tr>
<td>Nominal diameter ≥ 3 mm (n = 28)</td>
<td>75% (3/4)</td>
<td>100% (24/24)</td>
<td>100% (3/3)</td>
<td>96% (24/25)</td>
</tr>
<tr>
<td>Nominal diameter &lt; 3 mm (n = 28)</td>
<td>12.5% (2/16)</td>
<td>100% (12/12)</td>
<td>100% (2/2)</td>
<td>46.2% (12/26)</td>
</tr>
<tr>
<td>Endeavor (n = 33)</td>
<td>25% (3/12)</td>
<td>100% (21/21)</td>
<td>100% (3/3)</td>
<td>70% (21/30)</td>
</tr>
<tr>
<td>Nominal diameter ≥ 3 mm (n = 20)</td>
<td>66.7% (2/3)</td>
<td>100% (17/17)</td>
<td>100% (2/2)</td>
<td>94.4% (17/18)</td>
</tr>
<tr>
<td>Nominal diameter &lt; 3 mm (n = 13)</td>
<td>11.1% (1/9)</td>
<td>100% (4/4)</td>
<td>100% (1/1)</td>
<td>33.3% (4/12)</td>
</tr>
<tr>
<td>Firebird2 (n = 48)</td>
<td>46.2% (6/13)</td>
<td>100% (35/35)</td>
<td>100% (6/6)</td>
<td>83.3% (35/42)</td>
</tr>
<tr>
<td>Nominal diameter ≥ 3 mm (n = 26)</td>
<td>80% (4/5)</td>
<td>100% (21/21)</td>
<td>100% (4/4)</td>
<td>95.5% (21/22)</td>
</tr>
<tr>
<td>Nominal diameter &lt; 3 mm (n = 22)</td>
<td>25% (2/8)</td>
<td>100% (14/14)</td>
<td>100% (2/2)</td>
<td>70% (14/20)</td>
</tr>
</tbody>
</table>

*CTCA computed tomography coronary angiography, ICA invasive coronary angiography, ISR in-stent restenosis, PPV positive predictive value, NPV negative predictive value*
Importance of Reconstruction filter

B20f

B46f

B70f

Wolf D. et al ECR 2008
Results

Artificial Lumen Narrowing (%)
Importance of Reconstruction filter

Pugliese F et al. Radiographics 2006;26:887-904
In-Stent Restenosis with different Kernels
Bifurcation Lesions

• Coronary bifurcations vulnerable to atherosclerotic process and its complications

• Higher restenosis rates than is stent placement for simple lesions

• Different techniques for treatment depending on the bifurcation anatomy and angles

• Excess of metal produces marked hyperattenuation at the bifurcation on MDCT image potentially preventing visualization of the lumen.
Bifurcation Lesions

T Stent
≈90°

Y Stent
<70°

V stent
LM + side branch

Y Stent
<70°
<table>
<thead>
<tr>
<th>Author</th>
<th>MDCT</th>
<th>Year</th>
<th>Pts</th>
<th>Stents</th>
<th>Unassessable</th>
<th>Sens</th>
<th>Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schuijf</td>
<td>16</td>
<td>2004</td>
<td>22</td>
<td>68</td>
<td>26.5%</td>
<td>78%</td>
<td>100%</td>
</tr>
<tr>
<td>Cademartiri</td>
<td>16</td>
<td>2005</td>
<td>51</td>
<td>76</td>
<td>2.6%</td>
<td>84%</td>
<td>99%</td>
</tr>
<tr>
<td>Kitagawa</td>
<td>16</td>
<td>2005</td>
<td>16</td>
<td>21</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Gilard</td>
<td>16</td>
<td>2005</td>
<td>29</td>
<td>29</td>
<td>6.9%</td>
<td>100%</td>
<td>92%</td>
</tr>
<tr>
<td>Gilard</td>
<td>16</td>
<td>2006</td>
<td>143</td>
<td>232</td>
<td>45.6%</td>
<td>86%</td>
<td>100%</td>
</tr>
<tr>
<td>Van Mieghem</td>
<td>64</td>
<td>2006</td>
<td>70</td>
<td>70</td>
<td>0%</td>
<td>100%</td>
<td>91%</td>
</tr>
<tr>
<td>Rixe</td>
<td>64</td>
<td>2006</td>
<td>64</td>
<td>102</td>
<td>42%</td>
<td>86%</td>
<td>98%</td>
</tr>
<tr>
<td>Rist</td>
<td>64</td>
<td>2005</td>
<td>25</td>
<td>46</td>
<td>2.2%</td>
<td>75%</td>
<td>92%</td>
</tr>
<tr>
<td>Ehara</td>
<td>64</td>
<td>2007</td>
<td>81</td>
<td>125</td>
<td>12%</td>
<td>92%</td>
<td>81%</td>
</tr>
<tr>
<td>Oncel</td>
<td>64</td>
<td>2007</td>
<td>30</td>
<td>39</td>
<td>0%</td>
<td>89%</td>
<td>95%</td>
</tr>
<tr>
<td>Carbone</td>
<td>64</td>
<td>2008</td>
<td>55</td>
<td>97 (88)</td>
<td>21(23%)</td>
<td>75%</td>
<td>86%</td>
</tr>
</tbody>
</table>
Diagnostic accuracy of 64-slice computed tomography coronary angiography for the detection of in-stent restenosis: A meta-analysis

Average SE: 86%
SP: 93%

Nonassessable stents 9%

Carrabba et al. J Nucl Cardiol 2010
Table 2 Summary of pooled estimates in different subgroups (LR+ positive likelihood ratio, LR- negative likelihood ratio, DOR diagnostic odds ratio)

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (95% CI)</th>
<th>Specificity (95% CI)</th>
<th>LR+ (95% CI)</th>
<th>LR- (95% CI)</th>
<th>DOR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All studies</td>
<td>0.84 (0.77–0.89)</td>
<td>0.91 (0.89–0.93)</td>
<td>12.2 (6.6–22.6)</td>
<td>0.23 (0.17–0.31)</td>
<td>67.9 (34.4–134.1)</td>
</tr>
<tr>
<td>Left main</td>
<td>1.0 (0.77–1.0)</td>
<td>0.92 (0.83–0.97)</td>
<td>9.9 (5.1–19.5)</td>
<td>0.07 (0.01–0.50)</td>
<td>133.1 (15.1–1173.4)</td>
</tr>
<tr>
<td>16-slice</td>
<td>0.82 (0.72–0.89)</td>
<td>0.92 (0.88–0.94)</td>
<td>16.1 (5.1–50.6)</td>
<td>0.24 (0.16–0.37)</td>
<td>69.9 (30.3–161.3)</td>
</tr>
<tr>
<td>&gt;16-slice</td>
<td>0.85 (0.76–0.92)</td>
<td>0.91 (0.88–0.94)</td>
<td>10.0 (5.5–18.2)</td>
<td>0.20 (0.11–0.33)</td>
<td>67.7 (21.2–215.8)</td>
</tr>
</tbody>
</table>
«It should be noted that at present a consensus on follow-up time and modalities of patients who underwent stent placement still has not been reached…»

**AHA Scientific Statement**

*(Circulation 2006; 114: 1761-1791)*

Several small studies have assessed the value of MDCT for detecting restenosis after stent placement. At this time, however, imaging of patients to follow up stent placement cannot be recommended

*(Class III, Level of Evidence: C)*
<table>
<thead>
<tr>
<th>Indication</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of patients after PTCA/stenting</td>
<td></td>
</tr>
<tr>
<td>Symptomatic patient/ischaemic equivalent (diameter &lt; 3 mm or unknown)</td>
<td>III</td>
</tr>
<tr>
<td>Symptomatic patient/ischaemic equivalent (diameter ≥3 mm)</td>
<td>II</td>
</tr>
<tr>
<td>Asymptomatic patient (common trunk; &gt;3mm)</td>
<td>I</td>
</tr>
<tr>
<td>Asymptomatic patient (diameter ≥3 mm)</td>
<td>III</td>
</tr>
</tbody>
</table>

**Table 8** Cardiac computed tomography (CCT) evaluation of known coronary artery disease
Literature Results: MDCT vs SCA

Study Population: 55 Pz with 97 stents

Qualitative Analysis: 21/74 (28.4%) stented segments, 8/41 subjects (19.5%) excluded for stent unassessability

In-Stent Restenosis $>50\%$
How to improve MDCTA accuracy?

Original Research Article

Additional value of dipyridamole stress myocardial perfusion by 64-row computed tomography in patients with coronary stents

Tiago A. Magalhães, MD<sup>a,b</sup>, Roberto C. Cury, MD<sup>a,b</sup>, Alexandre C. Pereira, MD<sup>c</sup>, Valéria de Melo Moreira, MD<sup>a,b</sup>, Pedro A. Lemos, MD<sup>d</sup>, Roberto Kalil-Filho, MD<sup>e</sup>, Carlos E. Rochitte, MD, PhD<sup>a,b</sup>,

Table 3 Diagnostic accuracy of coronary CTA alone and after association to myocardial CTP, in a per-territory analysis, considering all the territories, territories with stents, and territories with stent and impaired luminal evaluation

<table>
<thead>
<tr>
<th></th>
<th>Coronary CTA</th>
<th>Coronary CTA + Myocardial CTP</th>
<th>Coronary CTA</th>
<th>Coronary CTA + Myocardial CTP</th>
<th>Coronary CTA</th>
<th>Coronary CTA + Myocardial CTP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All territories (n = 138)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SENS</strong></td>
<td>85% (74.3–92.1%)</td>
<td>88% (77.6–94.1%)</td>
<td>85% (70.2–94.3%)</td>
<td>88% (73.2–95.8%)</td>
<td>83% (61.2–95.1%)</td>
<td>87% (66.4–97.2%)</td>
</tr>
<tr>
<td><strong>SPEC</strong></td>
<td>83% (72.1–91.4%)</td>
<td>92% (83.2–97.5%)</td>
<td>77% (54.6–92.2%)</td>
<td>95% (77.2–100%)</td>
<td>72% (46.5–90.3%)</td>
<td>94% (72.7–100%)</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>85% (74.3–92.1%)</td>
<td>93% (83.7–97.6%)</td>
<td>87% (72.6–95.7%)</td>
<td>97% (85.5–100%)</td>
<td>79% (57.9–92.9%)</td>
<td>95% (76.2–100%)</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>83% (72.1–91.4%)</td>
<td>87% (76.9–93.9%)</td>
<td>74% (51.6–89.8%)</td>
<td>81% (60.6–93.4%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>AUC</strong></td>
<td>0.84 (0.76–0.9)</td>
<td>0.90 (0.84–0.94)</td>
<td>0.81 (0.69–0.9)</td>
<td>0.91 (0.82–0.97)</td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
</tr>
<tr>
<td><strong>Stent territories (n = 62)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SENS</strong></td>
<td>85% (70.2–94.3%)</td>
<td>88% (73.2–95.8%)</td>
<td>82% (62.1–95.1%)</td>
<td>87% (66.4–97.2%)</td>
<td>72% (46.5–90.3%)</td>
<td>94% (72.7–100%)</td>
</tr>
<tr>
<td><strong>SPEC</strong></td>
<td>77% (54.6–92.2%)</td>
<td>95% (77.2–100%)</td>
<td>74% (51.6–89.8%)</td>
<td>81% (60.6–93.4%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>87% (72.6–95.7%)</td>
<td>97% (85.5–100%)</td>
<td>74% (51.6–89.8%)</td>
<td>81% (60.6–93.4%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>74% (51.6–89.8%)</td>
<td>81% (60.6–93.4%)</td>
<td>74% (51.6–89.8%)</td>
<td>81% (60.6–93.4%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>AUC</strong></td>
<td>0.81 (0.69–0.9)</td>
<td>0.91 (0.82–0.97)</td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
</tr>
<tr>
<td><strong>Stent with impaired evaluation territories (n = 41)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SENS</strong></td>
<td>83% (61.2–95.1%)</td>
<td>87% (66.4–97.2%)</td>
<td>72% (46.5–90.3%)</td>
<td>94% (72.7–100%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>SPEC</strong></td>
<td>72% (46.5–90.3%)</td>
<td>94% (72.7–100%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>79% (57.9–92.9%)</td>
<td>95% (76.2–100%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
<td>76% (50.1–93.2%)</td>
<td>85% (62.1–96.8%)</td>
</tr>
<tr>
<td><strong>AUC</strong></td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
<td>0.77 (0.62–0.89)</td>
<td>0.91 (0.82–0.99)</td>
</tr>
</tbody>
</table>
How to improve accuracy to depict restenosis?

Occlusion
64-MDCT showing a cracked bare-metal stent
Current Developments: Higher Resolution

320-MDCT $\rightarrow$ Sl Thick: 0.5mm $\rightarrow$ 8% nondiagnostic
  (Stent no: 89; SE/SP = 92%/83%)
  (de Graaf et al. Invest Rad 2010)

128-DSCT $\rightarrow$ Temp Res: 75ms $\rightarrow$ 4-5% nondiagnostic
  (Stent no: 56-59; SE/SP =100%/84.1%)
  (Zhao et al. Eur J Rad 2011)

HDCT (Gemstone Tech ©) $\rightarrow$ Spa Res: <300μm $\rightarrow$ 12% nondiagnostic
  (Mihara et al. AHA/ASA Congress 2010)
Current technical developments

Table 2. Comparison of Measurements between HDCT and SDCT

<table>
<thead>
<tr>
<th>Scanner</th>
<th>ISD (mm)</th>
<th>ALN (%)</th>
<th>(\text{AV}_{\text{in-stent}}) (HU)</th>
<th>(\text{AV}_{\text{in-vessel}}) (HU)</th>
<th>AAI (HU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDCT</td>
<td>2.06 ± 0.26</td>
<td>30 ± 5.7</td>
<td>301.1 ± 125.4</td>
<td>285.4 ± 68.0</td>
<td>15.7 ± 81.4</td>
</tr>
<tr>
<td>SDCT</td>
<td>1.90 ± 0.23</td>
<td>35 ± 5.4</td>
<td>346.2 ± 52.5</td>
<td>274.8 ± 56.1</td>
<td>71.4 ± 90.5</td>
</tr>
<tr>
<td>(p)</td>
<td>&lt; 0.05</td>
<td>&lt; 0.05</td>
<td>&lt; 0.05</td>
<td>0.345</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

Note.— All values are presented as mean ± standard deviation. AAI = artificial attenuation increase between in-stent and in-vessel, ALN = artificial lumen narrowing, AV = attenuation value, HDCT = high-definition CT, ISD = inner stent diameter, HU = Hounsfield unit, SDCT = standard-definition CT.
Integrated Detector Circuit

0.28 mm!!!

Siemens 2012
Integrated Detector Circuit

![Box plot and images showing integrated detector circuit results with 0.6 mm FBP and 0.5 mm FBP]

Invest Radiol 2013; 48: 32–40
Current technical developments

Prospective ECG-triggered axial CT at 140-kV tube voltage improves coronary in-stent restenosis visibility at a lower radiation dose compared with conventional retrospective ECG-gated helical CT
Current technical developments

The „invisible“ coronary stent
Coronary Arteries By-pass Graft

**Topic Outlines**

- Clinical Background
- Acquisition Technique
- Current Limitations
- Literature results
- Improvements and future
Clinical Indications to CABG

- Three-vessel disease with LV dysfunction
- Left Main stenosis
- Unsuccessful PTCA
- Chronic stable angina not responding to medical treatment
- Unstable Angina
- Post-MI Angina
- NSTEMI MIs
- Acute MIs
- MIs with cardiogenic shock
- Association with others surgical procedures (valves, aorta ect)

ESC 2007 Guidelines
Clinical Background

ACC/AHA Guidelines for coronary artery bypass graft surgery JACC 1999;34:1262
Venous CABG

Great Safenous Vein

- Used to perform the first CABG operation in 1962.
- Easiest surgical procedure for CABG
- No spasm
- Metallic clips rarely used
- Caliber > arterial grafts
- RCA and marginal branches
- Grafted from the ascending aorta to the distal coronary artery beyond the obstructive lesion
Venous CABG

Double CABG

GSV on 2nd Marginal Patent

GSV on distal RCA: patent
Great Saphenous Veins

- Surgical Clips Rare
- High rates of occlusion:
  - Occlusion during 1° week: 7%
  - Occlusion at 1 year: 12-20% *
  - 50% occluded after 10 years*
  - 50% of patent grafts after 10 years show no signs of disease**

* Bourassa MG. Circulation 1985; 72: v71-8
** ACC/AHA J Am Coll Cardiol 1999; 34: 1262-1347
Great Saphenous Vein

IMA on LAD: patent

GSV: proximal mild stenosis

Double CABG
Great Saphenous Vein

IMA on LAD patent

Proximal GSV occlusion
Great Saphenous Vein

Proximal GSV occlusion
Arterial CABG

Internal Mammary Artery

- Left/Right IMA “in situ”
- Right IMA “free-graft”
- Decreased postoperative mortality
- Improved cardiac event–free survival rates
- Patency after 10 years: 80-90 %*
- Occlusion after 1° year < 5 %*

LAD Grafts

LIMA CABG
LIMA CABG
Selected because of its ease of procurement from the forearm
Used for marginal branches as 3d graft or alternatively to AMI when SVG cannot be used
“Free-graft” [“Y”]
Non dominating arm
Muscolar artery charactrized by a thick tunica media.
! High vasoreactivity (spasms) and early occlusion
! Numerous metallic clips used
Arterial CABG

Right Gastroepiploic artery

- Used as III-IVth graft or for 2nd surgery
- Biological Behaviour comparable to AMI
- “In situ” for revascularization of PDA
  - Long procedural time
  - Abdominal cavity involved
  - Contraindications: previous gastric surgery of mesenteric ischemia
Off-pump Techniques

✓ Mechanical aortovenous connector allows quicker attachment of venous grafts to the aorta without use of clamps or sutures

✓ Reduced risk of stroke and other embolic complications

✓ Requires a 90° angle between graft vessel and aorta

✓ Usual site of the proximal graft anastomosis at the anterior aspect of the aorta altered to support course of emerging graft
Symmetry CABG
Indications for follow-up after CABG surgery

- Angina

- Evidence of ischemia with provocative tests:
  - in previously revascularized territories (graft occlusion/stenosis)
  - in non-revascularized territories (CAD progression in native vessels: 5% pz./anno*)

- Ischaemic symptoms after CABG: 4-8 % pts/year

* Cameron A. J Am Coll Cardiol 1995; 26: 895-899
Literature Results

<table>
<thead>
<tr>
<th>Analysis Type and No. of Studies (n = 15)</th>
<th>No. of Grafts</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Positive Predictive Value (%)</th>
<th>Negative Predictive Value (%)</th>
<th>Positive LR</th>
<th>Negative LR</th>
<th>Diagnostic OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graft obstruction, 15</td>
<td>2023</td>
<td>97.6 (96.0, 98.6)</td>
<td>96.7 (95.6, 97.5)</td>
<td>92.7 (90.5, 94.6)</td>
<td>98.9 (98.2, 99.4)</td>
<td>23.42</td>
<td>0.045 (0.026, 0.071)</td>
<td>780.32 (379.12, 1606.1)</td>
</tr>
<tr>
<td>16-section, nine</td>
<td>1047</td>
<td>96.9 (94.2, 98.6)</td>
<td>96.4 (94.8, 97.6)</td>
<td>91.3 (87.6, 94.2)</td>
<td>98.8 (97.7, 99.4)</td>
<td>23.79</td>
<td>0.05 (0.03, 0.11)</td>
<td>569.02 (187.64, 1725.6)</td>
</tr>
<tr>
<td>64-section, six</td>
<td>976</td>
<td>98.1 (96.0, 99.3)</td>
<td>96.9 (95.3, 98.1)</td>
<td>94.1 (91.0, 96.3)</td>
<td>99.1 (98.0, 99.7)</td>
<td>24.05</td>
<td>0.03 (0.01, 0.06)</td>
<td>1295.3 (515.47, 3255.1)</td>
</tr>
<tr>
<td>Occlusion, 10</td>
<td>1308</td>
<td>99.3 (97.3, 99.9)</td>
<td>98.7 (97.9, 99.3)</td>
<td>95.4 (92.2, 97.5)</td>
<td>99.8 (99.3, 100)</td>
<td>85.19</td>
<td>0.04 (0.019, 0.087)</td>
<td>2756.8 (879.02, 8745.5)</td>
</tr>
<tr>
<td>Stenosis, nine</td>
<td>871</td>
<td>94.4 (87.5, 98.2)</td>
<td>98.0 (96.7, 98.8)</td>
<td>84.2 (75.6, 90.7)</td>
<td>99.4 (98.5, 99.8)</td>
<td>33.05</td>
<td>0.14 (0.065, 0.258)</td>
<td>355.89 (87.26, 1451.3)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study and Year</th>
<th>CT Scanner</th>
<th>No. of Sections</th>
<th>Rotation Time (msec)</th>
<th>Collimation (mm)</th>
<th>No. of Patients</th>
<th>Mean Age (y)</th>
<th>Heart Rate*</th>
<th>No. of Grafts</th>
<th>Graft Fully Assessable (%)</th>
<th>Mean Time Since Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Martuscelli et al, 2004 (11)</td>
<td>GE</td>
<td>16</td>
<td>500</td>
<td>0.75</td>
<td>53</td>
<td>62</td>
<td>68 ± 5</td>
<td>285 (94/166)</td>
<td>88</td>
<td>7</td>
</tr>
<tr>
<td>Schlosser et al, 2004 (12)</td>
<td>Siemens</td>
<td>16</td>
<td>420</td>
<td>0.75</td>
<td>36</td>
<td>65</td>
<td>64 ± 5</td>
<td>131 (40/91)</td>
<td>78</td>
<td>6</td>
</tr>
<tr>
<td>Chiurla et al, 2005 (13)</td>
<td>GE</td>
<td>16</td>
<td>36</td>
<td>0.75</td>
<td>36-45</td>
<td>63</td>
<td>58 ± 6</td>
<td>166 (48/117)</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Salm et al, 2005 (14)</td>
<td>Toshiba</td>
<td>16</td>
<td>400-500</td>
<td>0.625</td>
<td>...</td>
<td>67</td>
<td>64 ± 9</td>
<td>67 (14/53)</td>
<td>91</td>
<td>9</td>
</tr>
<tr>
<td>Trigo Bautista et al, 2005 (15)</td>
<td>GE</td>
<td>16</td>
<td>500</td>
<td>0.75</td>
<td>43</td>
<td>67</td>
<td>62 ± 6</td>
<td>117 (42/75)</td>
<td>93</td>
<td>9</td>
</tr>
<tr>
<td>Vernhet-Kovacsik et al, 2006 (16)</td>
<td>GE</td>
<td>16</td>
<td>...</td>
<td>0.75</td>
<td>42</td>
<td>72</td>
<td>...</td>
<td>29 (24/5)</td>
<td>66</td>
<td>&lt;1 month</td>
</tr>
<tr>
<td>Anders et al, 2006 (17)</td>
<td>Siemens</td>
<td>16</td>
<td>420</td>
<td>0.75</td>
<td>37</td>
<td>67</td>
<td>63</td>
<td>94 (20/74)</td>
<td>89</td>
<td>&lt;1 month</td>
</tr>
<tr>
<td>Burgshahler et al, 2006 (18)</td>
<td>Philips</td>
<td>16</td>
<td>375</td>
<td>0.75</td>
<td>32</td>
<td>62</td>
<td>68 ± 11</td>
<td>43 (11/32)</td>
<td>95</td>
<td>...</td>
</tr>
<tr>
<td>Yamamoto et al, 2006 (19)</td>
<td>GE</td>
<td>16</td>
<td>500-600</td>
<td>0.75</td>
<td>37</td>
<td>64</td>
<td>67 ± 10</td>
<td>101 (96/5)</td>
<td>92</td>
<td>&lt;1 month</td>
</tr>
<tr>
<td>Malaguti et al, 2006 (20)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.6</td>
<td>40</td>
<td>65</td>
<td>60 ± 7</td>
<td>109 (45/64)</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Pache et al, 2006 (21)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.6</td>
<td>37</td>
<td>68</td>
<td>63 ± 7</td>
<td>96 (23/73)</td>
<td>94</td>
<td>8</td>
</tr>
<tr>
<td>Dikkert et al, 2006 (22)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.6</td>
<td>52-60</td>
<td>63</td>
<td>61 ± 9</td>
<td>69 (52/17)</td>
<td>96</td>
<td>7</td>
</tr>
<tr>
<td>Ropers et al, 2006 (23)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.6</td>
<td>30</td>
<td>67</td>
<td>59 ± 9</td>
<td>138 (37/101)</td>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>Meyer et al, 2007 (24)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.6</td>
<td>31-71</td>
<td>68</td>
<td>63 ± 11</td>
<td>406 (147/259)</td>
<td>98</td>
<td>8</td>
</tr>
<tr>
<td>Jabara et al, 2007 (25)</td>
<td>Siemens</td>
<td>64</td>
<td>330</td>
<td>0.5</td>
<td>38.5</td>
<td>64</td>
<td>60 ± 6</td>
<td>147 (47/100)</td>
<td>87</td>
<td>8</td>
</tr>
</tbody>
</table>
Literature Results


Sensitivity (95% CI)

- Martuscelli (2004): 0.97 (0.91 - 1.00)
- Schlosser (2004): 0.96 (0.78 - 1.00)
- Chiurlia (2005): 0.99 (0.93 - 1.00)
- Salm (2005): 1.00 (0.88 - 1.00)
- Trigo Bautista (2005): 0.92 (0.74 - 0.99)
- Vernhet-Kovacsik (2006): 0.75 (0.19 - 0.99)
- Anders (2006): 0.95 (0.82 - 0.99)
- Burgsthaler (2006): 1.00 (0.79 - 1.00)
- Yamamoto (2006): 1.00 (0.59 - 1.00)
- Malagutti (2006): 1.00 (0.93 - 1.00)
- Pache (2006): 0.98 (0.88 - 1.00)
- Dikkers (2006): 1.00 (0.80 - 1.00)
- Ropers (2006): 1.00 (0.93 - 1.00)
- Meyer (2007): 0.97 (0.93 - 0.99)
- Jabara (2007): 0.95 (0.84 - 0.99)

Pooled Sensitivity = 0.98 (0.96 to 0.99)
Chi-square = 16.09; df = 14 (p = 0.3077)
Inconsistency (I-square) = 13.0 %
Pooled Specificity = 0.97 (0.96 to 0.98)
Chi-square = 55.39; df = 14 (p = 0.0000)
Inconsistency (I-square) = 74.7 %
Numerous studies have shown that EBCT and MDCT permit assessment of coronary bypass graft occlusion and patency with high accuracy. In most studies, the accuracy to detect bypass occlusion approached 100% …»

**AHA Scientific Statement**

(Circulation 2006; 114: 1761-1791)

Reasonable not only to assess patency of the bypass graft but also the presence of coronary stenoses in the course of the bypass graft or at the anastomotic site, as well as in the native coronary artery system

(Class IIb, Level of Evidence: C)
## DSCT: Acquisition Protocol

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collimation</strong></td>
<td>32x2x2x0.6</td>
</tr>
<tr>
<td><strong>Gantry rotation time</strong></td>
<td>330 ms</td>
</tr>
<tr>
<td><strong>kV, mAs</strong></td>
<td>120, 800</td>
</tr>
<tr>
<td><strong>Slice Thickness</strong></td>
<td>0.75 mm</td>
</tr>
<tr>
<td><strong>Recon Interval</strong></td>
<td>0.5 mm</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Kernel</strong></td>
<td>B 20-B46</td>
</tr>
<tr>
<td><strong>Acquisition Time</strong></td>
<td>13-16 seconds</td>
</tr>
<tr>
<td><strong>C.M. administration protocol</strong></td>
<td>80-90 ml ; 4 ml/s + 30 ml saline</td>
</tr>
<tr>
<td><strong>Delay</strong></td>
<td>Bolus Tracking</td>
</tr>
<tr>
<td><strong>ECG gating</strong></td>
<td>Prosp vs retrospect</td>
</tr>
</tbody>
</table>
Low Dose High-Pitch Spiral Acquisition 128-Slice Dual-Source Computed Tomography for the Evaluation of Coronary Artery Bypass Graft Patency

Goetti et al. Inv Rad 2010

Helical 64sCT (Pitch: 0.2-0.5)
→ 18.9 mSv (entire thorax)

Prospective DSCT
→ 5-7 mSv

High-pitch DSCT (Pitch: 3.2)
→ 2.3 mSv (entire thorax)
Collimation | 320 x 0,5
---|---
Gantry rotation time | 350 ms
kV, mAs | 120, 800
Slice Thickness | 0,75 mm
Recon Interval | 0,5 mm
Pitch | 0,2
Kernel | B 20-B46
Acquisition Time | 13-16 seconds
C.M. administration protocol | 60-80 ml ;5 ml/s+30 ml saline
ECG gating | Prospective
Image Analysis

- Graft Anatomy
- Arterial/Venous
- Anastomosis:
  - proximal
  - distal
- Graft disease
- Native coronaries:
  CAD progression
From diagnosis to prognosis...

Risk-Adjusted Event-Free Survival

$n = 250\, \text{pts}; \, \text{FU} \, 3 \, \text{yrs}$

Prognostic Value of CT Angiography in Coronary Bypass Patients

Benjamin J. W. Chow, MD,*† Osman Ahmed, BSc,* Gary Small, MBChB,*
Abdul-Aziz Alghamdi, MBBS,* Yeung Yam, BSc,* Li Chen, MSc,‡ George A. Wells, PtiD‡

*Ottawa, Ontario, Canada
Conclusions

- Coronary Stents:

Technical limitations related to stent structure and vessel caliber.

Recent experiences with 64-MDCT scanners suggest improved assessability of in-stent lumen with the capability to appreciate more subtle degrees of in-stent neointimal hyperplasia.

Mandatory to know spectrum of different artefacts and technique to compensate.

Present/Future: “CT-compatible” stents and dual energy capabilities of DSCT scanners.

- Coronary arteries By-pass Graft:

Mature technique with high sensitivity/specificity already with previous MDCT generations.
Grazie per l’attenzione!!!
PCI vs Medical Therapy

Figure 2. Kaplan–Meier Survival Curves.
Imaging of coronary heart disease after treatment: bypasses and stents

Marco Franccone MD, PhD
Department of Radiological Sciences
Sapienza University of Rome
Predictors of coronary stent fractures (n=382 patients)

- Right coronary artery lesions: p = 0.022
- Multivessel disease: p = 0.719
- Ca-antagonist use: p = 0.126
- No. of stents per lesion: p = 0.828
- Angle of lesion at baseline (per 10 degrees increase): p = 0.086
- Change in angulation of lesion after stenting (per 10 degrees increase): p = 0.020
- Total stent length (per 10 mm increase): p = 0.007
- Minimal lumen diameter after procedure: p = 0.078
Effects of CABG on myocardial perfusion

Before CABG surgery

After CABG surgery

MR Images from Prof. C Higgins UCSF
Clinical Indications to PTCA and stenting

*AHA Class I Reccomendations*

• Asymptomatic/ stable angina

Treated diabetes with asymptomatic ischemia or mild angina with 1 or more significant lesions in 1 or 2 coronary arteries suitable for PCI with a high likelihood of success and a low risk of morbidity and mortality

• Unstable Angina:

Patients with 1 or more significant lesions in 1 or more coronary arteries suitable for PCI with a high likelihood of success and low risk of morbidity or mortality

Alternative to thrombolytic therapy in patients with AMI and ST-segment elevation or left bundle branch block who can undergo PTCA of the infarct artery <12 h from the onset of symptoms or >12 h if symptoms persist, if performed in a timely fashion

• Acute Myocardial Infarction:

In patients who are within 36 h of an acute ST elevation/Q-wave or new left bundle branch block MI who develop cardiogenic shock, are <75 years of age, and revascularization can be performed within 18 h

*AHA updated Giudelines fot PTCA 2007*