Current status of CT coronary angiography

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Learning outcomes

• 1. Knowledge of current research into the application of CT coronary angiography for patients with suspected coronary artery disease including stable chest pain and in the emergency department

• 2. Understand the advantages and limitations of CT coronary angiography in the diagnosis of suspected coronary artery disease
Advances in CT imaging

“A further promising field may be the detection of the coronary arteries.”

Godfrey Hounsfield, Nobel Lecture, 1979
Advances in CT imaging

1990 → 1996 → 2002 → 2003 → 2005

1 slice

1 slice
Overlapping algorithm

4 slice
16 slice
64 slice

STABLE CHEST PAIN
SCOT-HEART

Role of multidetector computed tomography in the diagnosis and management of patients attending the rapid access chest pain clinic, The Scottish computed tomography of the heart (SCOT-HEART) trial: study protocol for randomized controlled trial

Newby et al, Trials, 2012:13; 184
Rapid access chest pain clinic

• “One-stop-shop” for the assessment of chest pain

• Referrals from primary care physicians

• Doctor or nurse led
  – Ideally next working day
  – Medical history, examination, ECG, blood tests
  – Exercise tolerance test where indicated

• “National Service Framework for coronary heart disease” 2000

• UK wide since 2004
Study Protocol

- Primary Care Physician Referral
- Clinic Consultation
  - History, Examination, 12-lead ECG
- Exercise ECG if appropriate
- Diagnosis, Investigations and Treatment
  - Plan Documented
- Approached for Study Inclusion
  - Angina Questionnaire
- Randomised 1:1 to
  - CTCA + Standard Care or
  - Standard Care alone

- Computed Tomography
  - Coronary Angiogram
- Cardiovascular Risk Assessment:
  - ASSIGN Score
- Result to Attending Clinician
- 6-Week Attending Clinician
  - Diagnosis, Investigations and Treatment
  - Plan Documented
- 6-Week Patient Review
  - Angina Questionnaire
- Clinical Outcome
  - NHS Health Records

Newby et al, Trials, 2012:13; 184
Twelve centers across Scotland

Recruited 4146 patients:
2073 Standard care
2073 + CTCA

- Perth Royal Infirmary, Perth
- Ninewells, Dundee
- Victoria Hospital, Kirkcaldy
- Royal Infirmary, Edinburgh
- Borders General Hospital, Melrose
- Forth Valley Hospital, Larbert
- St John’s Hospital, Livingston
- Royal Alexandra Hospital, Paisley
- Western Infirmary, Glasgow
- Glasgow Royal Infirmary, Glasgow
- University Hospital, Ayr
Three imaging sites across Scotland

- Ninewells, Dundee
- Royal Infirmary, Edinburgh
- Glasgow Royal Infirmary, Glasgow
### Primary End Point

- **Diagnosis of Coronary Heart Disease**
- **Diagnosis of Angina due to Coronary Heart Disease**

<table>
<thead>
<tr>
<th>Certainty:</th>
<th>Yes/No versus Probable/Unlikely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency:</td>
<td>Yes/Probable versus Unlikely/No</td>
</tr>
</tbody>
</table>

- Yes
- Probable
- Unlikely
- No
CTCA diagnosis
Baseline vs 6 weeks

| Clinician Reporting CTCA: Diagnosis of CHD |  
| --- | --- | --- |  
| Certainty | Frequency | 1.09 | 2.56 |  

| Clinician Reporting CTCA: Diagnosis of Angina due to CHD |  
| --- | --- | --- |  
| Certainty | Frequency | 0.78 | 3.76 |  

| Attending Clinician: Diagnosis of Angina due to CHD (Primary End-point) |  
| --- | --- | --- |  
| Certainty | Frequency | 0.93 | 1.79 |  

Overall Changes in Diagnosis: 25% versus 1%, P<0.001

Newby et al, Lancet, 2015
Investigations
Baseline vs 6 weeks

Overall Changes in Investigations: 15% versus 1%, *P*<0.001

Cancellations

<table>
<thead>
<tr>
<th>Test</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Testing</td>
<td></td>
</tr>
<tr>
<td>Invasive Coronary Angiography</td>
<td></td>
</tr>
<tr>
<td>All Tests</td>
<td>160</td>
</tr>
</tbody>
</table>

New Investigations

<table>
<thead>
<tr>
<th>Test</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress Testing</td>
<td></td>
</tr>
<tr>
<td>Invasive Coronary Angiography</td>
<td></td>
</tr>
<tr>
<td>All Tests</td>
<td></td>
</tr>
</tbody>
</table>

CTCA + Standard Care

Standard Care

Newby et al, Lancet, 2015
Medical therapy
Baseline vs 6 weeks

Overall Changes in Treatments: 23% versus 5%, P<0.001

Cancellations

New Treatments

CTCA + Standard Care
Standard Care

Newby et al, Lancet, 2015
Invasive Angiography and Revascularisation

Newby et al, Lancet, 2015
CHD Death and Non-fatal MI

Post-hoc Landmark Analysis

<table>
<thead>
<tr>
<th>Implementation Delay</th>
<th>Impact of Alterations in Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>- CTCA Performed</td>
<td></td>
</tr>
<tr>
<td>- Result Reviewed</td>
<td></td>
</tr>
<tr>
<td>- Management Changed</td>
<td></td>
</tr>
<tr>
<td>- Invasive Angiography Arranged</td>
<td></td>
</tr>
</tbody>
</table>

Proportion of patients with an event (%)

CTCA vs Standard Care

CTCA

Standard Care

HR 0.50 [0.28-0.88]
P=0.015

Follow Up (years)

Williams et al, JACC, 2016
### SCOT-HEART – economic analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>CTCA</th>
<th>Standard care</th>
<th>Difference</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTCA</td>
<td>372 +/- 163 [416]</td>
<td>0 +/- 16 [0]</td>
<td>372 (363 to 378)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Out patient</td>
<td>219 +/- 655 [0]</td>
<td>192 +/- 584 [0]</td>
<td>27 (-10 to 66)</td>
<td>0.16</td>
</tr>
<tr>
<td>Day case</td>
<td>890 +/- 1196 [0]</td>
<td>827 +/- 1189 [0]</td>
<td>63 (-10 to 136)</td>
<td>0.09</td>
</tr>
<tr>
<td>In patient</td>
<td>379 +/- 1906 [0]</td>
<td>379 +/- 1864 [0]</td>
<td>1 (-113 to 116)</td>
<td>0.98</td>
</tr>
<tr>
<td>Medications</td>
<td>52 +/- 67 [0]</td>
<td>50 +/- 70 [0]</td>
<td>1 (-3 to 6)</td>
<td>0.50</td>
</tr>
<tr>
<td>Total</td>
<td>1900 +/- 2642 [552]</td>
<td>1438 +/- 2581 [86]</td>
<td>462 (303 to 621)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Outcomes of Anatomical versus Functional Testing for Coronary Artery Disease

Pamela S. Douglas, M.D., Udo Hoffmann, M.D., M.P.H., Manesh R. Patel, M.D., Daniel B. Mark, M.D., M.P.H., Hussein R. Al-Khalidi, Ph.D., Brendan Cavanaugh, M.D., Jason Cole, M.D., Rowena J. Dolor, M.D., Christopher B. Fordyce, M.D., Megan Huang, Ph.D., Muhammad Akram Khan, M.D., Andrzej S. Kosinski, Ph.D., Mitchell W. Krucoff, M.D., Vinay Malhotra, M.D., Michael H. Picard, M.D., James E. Udelson, M.D., Eric J. Velazquez, M.D., Eric Yow, M.S., Lawton S. Cooper, M.D., M.P.H., and Kerry L. Lee, Ph.D., for the PROMISE Investigators

Symptomatic, non-urgent non-invasive investigation necessary for suspected CAD

- age >54 y in men and >64 y in women
- ≥1 risk factors
- between 45 and 54 y in men
- between 55 and 64 y in women

Randomly assigned to CTCA or functional testing with exercise ECG, nuclear stress testing, or stress echocardiography
PROMISE

Douglas et al. NEJM. 2015
PROMISE

• CTA was associated with fewer invasive coronary angiography showing no obstructive CAD than functional testing
  – 3.4% vs. 4.3%, P=0.02
• More patients in the CTA group underwent invasive coronary angiography within 90 days after randomization
  – 12.2% vs. 8.1%
PROMISE – economic analysis

- Mean costs at 90 days
  - $2494 for CTA strategy
  - $2240 for the functional strategy
  - difference $254

- More revascularizations and catheterizations in the CTA group
  - 4.25 per 100 patients

- Similar out to 3 years

PROMISE – symptoms

• Symptoms and quality of life improved
  – Duke Activity Status Index and Seattle Angina Questionnaire frequency scale and quality of life scale improved in both groups over 6 months

• No difference between CTCA and functional testing
### Meta-analysis – stable chest pain

<table>
<thead>
<tr>
<th>Study</th>
<th>Inclusion</th>
<th>Exclusion</th>
<th>Total N</th>
<th>CTCA</th>
<th>Standard care</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROMISE</td>
<td>Symptomatic, non-urgent noninvasive CV testing necessary for suspected CAD indicated, age &gt;54 y in men and &gt;64 y in women or between 45 and 54 y plus ≥1 risk factors in men and between 55 and 64 y plus ≥1 risk factors in women</td>
<td>Previous CAD, previous evaluation for CAD in the last 12 month or other cardiac abnormality or contraindication to any test in any arm</td>
<td>10003</td>
<td>4996</td>
<td>507</td>
</tr>
<tr>
<td>SCOT-HEART</td>
<td>Symptomatic stable chest pain evaluation, age between 18 and 75 y for both sexes</td>
<td>Contraindication to coronary CTA</td>
<td>4146</td>
<td>2073</td>
<td>2073</td>
</tr>
<tr>
<td>CAPP</td>
<td>Symptomatic stable chest pain evaluation, no age range</td>
<td>Contraindication to coronary CTA or treadmill test</td>
<td>488</td>
<td>243</td>
<td>245</td>
</tr>
<tr>
<td>Min et al</td>
<td>Symptomatic stable chest pain evaluation, non urgent noninvasive CV testing necessary for suspected CAD indicated, age ≥ 40 y for both sexes</td>
<td>Previous CAD, contraindication to either arm or a class I indication for invasive angiography</td>
<td>180</td>
<td>91</td>
<td>89</td>
</tr>
</tbody>
</table>

Total: 14817, CTCA: 7403, Standard care: 7414
Meta-analysis – stable chest pain

**Myocardial infarction**

- **Study**
  - PROMISE: 0.75 (0.47, 1.21)
  - SCOT-HEART: 0.63 (0.37, 1.07)
  - CAPP: 0.50 (0.05, 5.56)
  - **Overall** (I-squared = 0.0%, p = 0.857): 0.69 (0.49, 0.98)

  - p = 0.038

**All cause death**

- **Study**
  - PROMISE: 0.99 (0.72, 1.36)
  - SCOT-HEART: 0.85 (0.45, 1.62)
  - CAPP: 1.01 (0.06, 16.12)
  - **Overall** (I-squared = 0.0%, p = 0.919): 0.96 (0.72, 1.28)

  - p = 0.78

**Significant reduction in the annual rate of myocardial infarction**

**No difference in all cause mortality**
Hot off the press – ESC 2016 Rome

The CONSERVE Trial

Randomised multicentre controlled trial
1530 patients with indications for invasive coronary angiography
Direct invasive coronary angiography vs selective CT driven

No difference in MACE at 12 months
Lower rates of invasive coronary angiography
Lower costs ($2,883 vs $6,031).

http://congress365.escardio.org
ACUTE CHEST PAIN
Acute Chest Pain
Acute Chest Pain

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Male Gender (%)</th>
<th>Hypertension (%)</th>
<th>Hyperlipidemia (%)</th>
<th>Diabetes (%)</th>
<th>Median TIMI risk score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldstein, JACC 07</td>
<td>50</td>
<td>45</td>
<td>39</td>
<td>34</td>
<td>11</td>
<td>1.27</td>
</tr>
<tr>
<td>Goldstein, JACC 11 CT-STAT</td>
<td>50</td>
<td>47</td>
<td>37</td>
<td>35</td>
<td>7</td>
<td>1.01</td>
</tr>
<tr>
<td>Hoffman 12, ROMICAT II</td>
<td>55</td>
<td>53</td>
<td>54</td>
<td>45</td>
<td>17</td>
<td>–</td>
</tr>
<tr>
<td>Litt, NEJM 12</td>
<td>49</td>
<td>49</td>
<td>51</td>
<td>27</td>
<td>14</td>
<td>0.98</td>
</tr>
</tbody>
</table>
Acute Chest Pain

Reduced time to diagnosis

Reduced time to cost
Acute Chest Pain

Increased revascularisation
Acute Chest Pain

No difference in death, MI or hospitalisation

Reduced length of hospital stay

Cost savings (3 out of 4 studies)

CT group had an increase in ICA (6.3 vs 8.4%)
revascularisation (4.6% vs 2.6%)

Table 2: Exclusion Criteria by Study

<table>
<thead>
<tr>
<th>Study</th>
<th>Exclusion Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goldstein et al. (18)</td>
<td>Age &lt;25 yrs, known CAD, + Trp, Ischemic ECG changes, BMI &gt;39 kg/m², unable to undergo contrast CT, LVEF &lt;45%, &gt;12 h without symptoms</td>
</tr>
<tr>
<td>CT-STAT (19)</td>
<td>Age &lt;25 yrs, known CAD, + Trp, Ischemic ECG changes, BMI &gt;39 kg/m², unable to undergo contrast CT, LVEF &lt;45%, &gt;12 h since arrival at ED, &gt;12 h from symptom onset to ED arrival</td>
</tr>
<tr>
<td>ACRIN-PA (21)</td>
<td>Age &lt;30 yrs, Ischemic ECG changes, TIMI risk score &gt;2, normal CCTA within 1 yr, unable to undergo contrast CT, other major comorbidity requiring admission</td>
</tr>
<tr>
<td>ROMICAT II (20)</td>
<td>Age &lt;40 or &gt;75 yrs, known CAD, + Trp, Ischemic ECG changes, BMI &gt;40, unable to undergo contrast CT, &gt;6 h since arrival at ED, cocaine, shock</td>
</tr>
</tbody>
</table>
Causes of Acute Chest Pain

- Gallstones, pancreas
- Oesophagus
- Indigestion
- Anxiety
- Pneumonia
- Pneumo-thorax
- PE
- Acute coronary syndrome
- ST elevation MI
- Pericarditis
- Non ST elevation MI
- Acute aortic syndrome
- Dissection
- Musculo-skeletal
- Trauma
- Fractured rib
- Chest pain
- Oesophagus
- Indigestion
- Anxiety
- Pneumonia
- Pneumo-thorax
- PE
- Acute coronary syndrome
- ST elevation MI
- Pericarditis
- Non ST elevation MI
- Acute aortic syndrome
- Dissection
- Musculo-skeletal
- Trauma
- Fractured rib
- Chest pain
Triple rule out
LIMITATIONS OF CT CORONARY ANGIOGRAPHY
The problem with calcium

- Beam hardening and photon starvation
- Partial volume averaging, “blooming”
The problem with calcium

Williams MC et al, Heart, 2011
“Stair-step” artifact
Motion artifact
• Radiation dose is a major health care concern

• Computed tomography is widely used
  – 70 million CT/year in US
  – 4 million CT/year in UK

• Cardiac imaging is responsible for up to 30% of radiation exposure due to diagnostic imaging
Radiation dose reduction in CTCA

- Tube current optimisation
- Tube voltage optimisation
- Patient tailored imaging
- Heart rate reduction
- Iterative reconstruction
- Prospective ECG gating
- Scan range optimisation
- Tube current modulation
Low dose CT coronary angiography

Average for all heart rates and all BMI 2.5 mSv

Submillisievert scanning for BMI <25 and HR <65
Vulnerable plaque

- Inflammation
- Thin Fibrous Cap
- Large Necrotic Core
- Micro-Calcification
- Positive Remodeling
- Low Attenuation Plaque

References:
Motoyama JACC 2009, Maurovitch-Horvat JACC Imaging 2010
Guiding therapy

Two Year Survival free of Death/MI

Days Since Randomization

Survival Free from Death and MI

- FFR-Guided
- Angio-Guided

360 Days
3.8%

720 Days
4.3%
Comprehensive cardiac CT

- Patient preparation
- CTCA & Rest images
- Adenosine infusion
- Stress perfusion & function
- 4 minutes
- Delayed enhancement
- Home

Structure
Function
Perfusion
Viability

Williams MC, Heart 2011
Chief Investigator: Prof David Newby. Trial Research Fellows: Dr Michelle Williams, Dr Amanda Hunter, Dr Tania Pawade, Dr Anoop Shah.
Grant Applicants: Prof David Newby (Principal Applicant), Dr Andrew Flapan, Prof John Forbes, Dr Allister Hargreaves, Prof Stephen Leslie, Dr Steff Lewis, Dr Graham McKillop, Dr Scott McLean, Dr John Reid, Dr James Spratt, Dr Neal Uren.
Trial Steering Committee: Prof Adam Timmis (Chair), Prof Colin Berry, Dr Nicholas Boon, Mrs Liz Clark, Dr Peter Craig, Dr Tom Barlow, Dr Marcus Flather, Prof John Forbes, Dr Steff Lewis, Dr Chiara McCormack, Dr Scott McLean, Prof David Newby, Dr Giles Roditi, Prof Edwin van Beek, Dr Michelle Williams, Dr Amanda Hunter, Mrs Susan Shepherd, Ms Marise Bucukoglu.
Edinburgh Clinical Trials Unit: Dr Steff Lewis, Dr Valentina Assi, Dr Richard Parker, Miss Ashma Krishan, Dr Chiara McCormack, Mrs Fiona Wee, Mr Anthony Wackett, Mr Allan Walker, Miss Lynsey Milne, Ms Kat Oatey.
Royal Infirmary of Edinburgh, Edinburgh: Ms Barbara Allen, Prof Edwin van Beek, Dr Miles Behan, Miss Danielle Bertram, Mr David Brian, Ms Amy Cowan, Dr Nicholas Cruden, Dr Martin Denvir, Dr Marc Dweck, Ms Laura Flint, Dr Andrew Flapan, Miss Samantha Fyfe, Dr Neil Grubb, Mrs Collette Keanie, Dr Chris Lang, Dr Tom MacGillivray, Dr David MacLachlan, Miss Margaret MacLeod, Dr Saeed Mirsadraee, Mrs Avril Morrison, Dr Nicholas Mills, Dr David Northridge, Mrs Alyson Phillips, Miss Laura Queripel, Dr John Reid, Dr Neal Uren, Dr Nicholas Weir.
St John’s Hospital, Livingston: Dr Ashok Jacob, Mrs Fiona Bett, Mrs Frances Divers, Ms Katie Fairley, Ms Edith Keegan, Ms Tricia White, Ms Julia Fowler.
University Hospital, Ayr: Dr John Gemmill, Dr James McGowan, Mrs Margo Henry.
Victoria Hospital, Kirkcaldy: Dr Mark Francis, Mr Dennis Sandeman Ms Lorraine Dinnel.
Western General Hospital, Edinburgh: Prof David Newby Dr Peter Bloomfield, Dr Martin Denvir, Dr Peter Henriksen, Dr Donald MacLeod, Mrs Avril Morrison.
Western Infirmary, Glasgow & Institute of Cardiovascular & Medical Sciences, University of Glasgow: Prof Colin Berry, Dr Kenneth Mangion, Dr Ify Mordi, Dr Giles Roditi, Dr Nikolaos Tzemos, Dr Eugene Connolly, Mrs Heather Boylan, Mrs Ammanni Brown, Ms Lesley Farrell, Mrs Alison Frood, Ms Caroline Glover, Mrs Janet Johnstone, Mrs Tracey Steedman, Mrs Kirsten Langahan, Mrs Deborah McGlynn, Ms Lorraine McGregor, Ms Evonne McLennan, Ms Laura Murdoch, Miss Victoria Paterson, Ms Fiona Teyhan, Ms Marion Teenan, Ms Rosie Woodward.
Borders General Hospital, Melrose: Dr Paul Neary Mrs Gillian Donaldson, Mr Terry Fairbairn, Mrs Marlene Fotheringham, Mrs Fiona Hall.
Forth Valley Royal Hospital, Larbert: Dr Allister Hargreaves, Dr James Spratt, Dr Stephen Glen, Ms Sarah Perkins, Ms Fiona Taylor Mrs Louisa Cram, Ms Catherine Beveridge, Ms Avril Cairns, Ms Frances Dougherty.
Glasgow Royal Infirmary: Dr Hany Eteiba, Dr Alan Rae, Ms Kate Robb, Ms Wenda Crawford, Ms Patricia Clarkin, Ms Elizabeth Lennon.
Ninewells Hospital, Dundee: Prof. Graeme Houston, Prof Stuart Pringle, Dr Prasad Guntur Ramkumar, Dr Thiru Sudarshan, Dr Yvonne Fogarty, Ms Dawn Barrie, Ms Kim Bisset, Dr Adelle Dawson, Mr Scott Dundas, Mrs Deborah Latham, Ms Linda O’Neill, Mrs Valerie Ritchie.
Perth Royal Infirmary, Perth: Dr Hamish Dougall.
Royal Alexandra Hospital, Paisley: Dr Faheem Ahmed, Dr Alistair Cormack, Dr Iain Findlay, Dr Stuart Hood, Dr Clare Murphy, Dr Eileen Peat, Ms Lynne McCabe, Ms Margaret McCubbin.
SCOT-HEART

• In patients presenting with suspected angina due to coronary heart disease, the addition of computed tomography coronary angiography

  – Clarifies the diagnosis: 1 in 4

  – Increases the diagnosis of CHD but reduce the diagnosis of angina due to CHD

  – Alters subsequent investigations: 1 in 6

  – Changes treatments: 1 in 4

  – Enables more appropriate targeted coronary revascularisation
Recruitment

- 42% of all patients recruited into the Trial
- 47% of eligible patients recruited into the trial
- Few patients crossed over to receive CTCA in Standard Arm (n=3)
- In the CTCA arm 14% did not undergo CTCA (n=295)
- 100% data for the primary end point
- Intention-to-treat analysis
### Results

<table>
<thead>
<tr>
<th></th>
<th>All Participants</th>
<th>Standard Care + CTCA</th>
<th>Standard Care</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anginal Symptoms</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical</td>
<td>1462 (35%)</td>
<td>737 (36%)</td>
<td>725 (35%)</td>
</tr>
<tr>
<td>Atypical</td>
<td>988 (24%)</td>
<td>502 (24%)</td>
<td>486 (23%)</td>
</tr>
<tr>
<td>Non-anginal</td>
<td>1692 (41%)</td>
<td>833 (40%)</td>
<td>859 (41%)</td>
</tr>
<tr>
<td><strong>Electrocardiogram</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>3492 (84%)</td>
<td>1757 (85%)</td>
<td>1735 (84%)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>608 (15%)</td>
<td>292 (14%)</td>
<td>316 (15%)</td>
</tr>
<tr>
<td><strong>Further Investigation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1315 (32%)</td>
<td>633 (31%)</td>
<td>682 (33%)</td>
</tr>
<tr>
<td><strong>Stress Imaging</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radionuclide</td>
<td>389 (9%)</td>
<td>176 (9%)</td>
<td>213 (10%)</td>
</tr>
<tr>
<td>Other</td>
<td>30 (1%)</td>
<td>16 (1%)</td>
<td>14 (1%)</td>
</tr>
<tr>
<td><strong>Invasive Coronary Angiography</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>515 (12%)</td>
<td>255 (12%)</td>
<td>260 (13%)</td>
</tr>
<tr>
<td><strong>Baseline Diagnosis</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHD</td>
<td>1938 (47%)</td>
<td>982 (47%)</td>
<td>956 (46%)</td>
</tr>
<tr>
<td>Angina due to CHD</td>
<td>1485 (36%)</td>
<td>742 (36%)</td>
<td>743 (36%)</td>
</tr>
</tbody>
</table>
Rapid access chest pain clinic

General Practitioner’s Default Management
- Open access electrocardiogram: 8%
- Hospitalized: 27%
- Medical out-patient review: 7%
- Observe in the community: 6%
- Cardiology out-patient review: 52%

Chest Pain Clinic Management
- Cardiac catheterization: 10%
- Hospitalized: 14%
- Cardiology out-patient review: 26%
- Discharged: 50%

Rapid access chest pain clinic

HR* 6.76 (5.69, 8.03), p<0.001
Adjusted HR¹ 3.98 (3.09, 5.14), p<0.001

Angina due to Coronary Heart Disease
Non-cardiac Chest Pain

Sekhri et al. Heart 2007;93:458–463
Conclusion

• Imaging modalities can tell us more than stenosis severity
• SPECT and PET can provide information on myocardial perfusion, myocardial function and viability
• Advances in hardware and software improve image resolution and reduce radiation dose
Computed tomography coronary angiography

BMI 23
Heart rate <65
0.86 mSv
(k=0.014)
Entry criteria

• **Inclusion Criteria**
  - Age 18-75 years
  - Suspected angina due to coronary heart disease

• **Exclusion Criteria**
  - Inability to undergo CT scanning
  - Renal failure (estimated GFR <30 mL/min)
  - Allergy to contrast media
  - Pregnancy
  - Acute coronary syndrome within 3 months
  - Previous recruitment to the trial

Newby et al, Trials, 2012:13; 184
Results

- Recruited 4146 patients
  - 2073 standard care, 2073 + CTCA
- 56% male
- Age 57 +/- 10 years
- BMI 30 +/- 6 kg/m²
## Results

<table>
<thead>
<tr>
<th></th>
<th>All Participants</th>
<th>Standard Care + CTCA</th>
<th>Standard Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial Fibrillation</td>
<td>84 (2%)</td>
<td>42 (2%)</td>
<td>42 (2%)</td>
</tr>
<tr>
<td>Prior CHD</td>
<td>372 (9%)</td>
<td>186 (9%)</td>
<td>186 (9%)</td>
</tr>
<tr>
<td>Current or Ex-smoker</td>
<td>2185 (53%)</td>
<td>1095 (53%)</td>
<td>1090 (53%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>1395 (34%)</td>
<td>712 (34%)</td>
<td>683 (33%)</td>
</tr>
<tr>
<td>Diabetes Mellitus</td>
<td>444 (11%)</td>
<td>223 (11%)</td>
<td>221 (11%)</td>
</tr>
<tr>
<td>Hypercholesterolaemia</td>
<td>2176 (53%)</td>
<td>1099 (53%)</td>
<td>1077 (52%)</td>
</tr>
<tr>
<td>Family History</td>
<td>1716 (41%)</td>
<td>887 (43%)</td>
<td>829 (40%)</td>
</tr>
<tr>
<td>Serum Cholesterol (mg/dL)</td>
<td>206±46</td>
<td>206±47</td>
<td>206±44</td>
</tr>
<tr>
<td>Predicted 10-year CHD Risk</td>
<td>17±12%</td>
<td>18±11%</td>
<td>17±12%</td>
</tr>
</tbody>
</table>
## CTCA Safety

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast Reactions</td>
<td>13 (0.7%)</td>
</tr>
<tr>
<td>Contrast Extravasation</td>
<td>7 (0.4%)</td>
</tr>
<tr>
<td>Vasovagal Reaction</td>
<td>4 (0.2%)</td>
</tr>
<tr>
<td>Headache</td>
<td>4 (0.2%)</td>
</tr>
<tr>
<td>Other</td>
<td>3 (0.2%)</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>31 (1.7%)</strong></td>
</tr>
</tbody>
</table>

Median Radiation Dose: 4.1 mSv (Interquartile Range 3.0-5.6)

Dose-length Product: 291 mGy.cm (Interquartile Range 216-397)

37% Radiation Dose Attributable to Coronary Artery Calcium Score

Newby et al, Lancet, 2015
CTCA Prevalence of Coronary Heart Disease

Newby et al, Lancet, 2015
Clinical outcome
1.7 year follow-up

CHD Death and Non-Fatal MI

CHD Death, Non-fatal MI, and Non-fatal stroke

Proportion of patients with an event (%)

HR 0.62 [0.38-1.01], P=0.053

HR 0.64 [0.41-1.01], P=0.056

Newby et al, Lancet, 2015
SCOT-HEART – symptoms

- Symptoms improved in CTCA and standard care groups at 6 months
- CTCA was associated with slightly less marked improvements in physical limitation, angina frequency and quality of life
- Baseline score was important - those with the lowest score made the most improvement

Williams et al, 2016
SCOT-HEART – symptoms

- Whilst clarifying the diagnosis for the attending clinician, CTCA was associated with reduced improvements in overall symptoms.
- Due to changes in diagnosis and the increased detection of non-obstructive coronary artery disease and initiation of preventative therapies.

Williams et al, 2016
PROMISE – men and women

- Women were older
- Women had more risk factors
- Women had different chest pain characteristics
- All risk scores characterized women as lower risk
- Women were more often referred to imaging than non-imaging tests
- Women were less likely to have a positive test (9.7% vs. 15.1%; p < 0.001).
Meta-analysis – stable chest pain

Trend toward more invasive coronary angiography
- OR 1.33
- 95% CI 0.95–1.84
- P=0.09

Trend towards higher use of coronary revascularization
- OR 1.77
- 95% CI 1.14–2.75
• Single centre - CT (99) vs standard care (98)

• CT
  ▫ reduced time to diagnosis (3.4 h vs. 15.0 h, p 0.001)
  ▫ lowered costs ($1,586 vs. $1,872, p 0.001)
  ▫ reduced repeat evaluations (2.0% vs 7%) patients, p 0.10
• Multi centre - CT (361) vs perfusion imaging (338)

• CT
  ▫ reduced time to diagnosis 54% (2.9h vs 6.3h, p <0.001)
  ▫ reduced cost 38% ($2137 vs $3458, p <0.001)
  ▫ No different in major adverse cardiac events
• Multi centre - 1370 CTCA vs 462 traditional care

• CT
  ▫ increased discharge - 49.6% vs. 22.7%
  ▫ decreased length of stay - 18.0 vs. 24.8 hours, P<0.001
  ▫ increased diagnosis of coronary disease - 9.0% vs. 3.5%
Multi centre - CTCA 501, standard care 499

CT
- reduced length of stay by 7.6h
- increased discharge from ED: 47% vs 12%, p 0.001
- No differences in major adverse events
- cost similar
Outcomes After Coronary Computed Tomography Angiography in the Emergency Department
A Systematic Review and Meta-Analysis of Randomized, Controlled Trials
Edward Hulten, MD, MPH,* Christopher Pickett, MD,† Marcio Sommer Bittencourt, MD,* Todd C. Villines, MD,† Sara Petrillo, MD,‡ Marcelo F. Di Carli, MD,* Ron Blankstein, MD*
Boston, Massachusetts; and Bethesda and Rockville, Maryland

- No difference in death, MI or rehospitalisation
- Reduced length of hospital stay
- Cost savings (3 out of 4 studies)
- CT group had an increase in ICA (6.3 vs 8.4%) and revascularisation (4.6% vs 2.6%)