Impact on stable chest pain pathways of CT fractional flow reserve

Rachel A O’Leary, Julie Burn, Samuel G Urwin, Andrew J Sims, Anna Beattie, Alan Bagnall

ABSTRACT

Objectives To evaluate the impact of introducing CT fractional flow reserve (FFR\textsubscript{CT}) on stable chest pain pathways, concordance with National Institute for Health and Care Excellence (NICE) chest pain guidelines, resource use and revascularisation of patients from a tertiary UK cardiac centre rapid access chest pain clinic (RACPC).

Methods Single-centre before and after study comparing data from electronic records and Strategic Tracing Service of all RACPC patients attending between 1 July 2017 and 31 December 2017, and 1 August 2018 and 31 January 2019.

Results Two hundred and sixty-eight and 287 patients (overall mean age 62 years, range 26–89 years, 48.3% male), were eligible for first-line CT coronary angiography (CTCA) pre-FFRCT, and post-FFRCT, respectively. First-line CTCA use per NICE Guideline CG95 increased (50.6% pre-FFRCT vs 75.7% post-FFRCT, p<0.001). More patients reached pathway endpoint (revascularisation or assumed medical management) after one investigation (74.9% pre-FFRCT vs 84.9% post-FFRCT, p<0.001). There were fewer stress (22.8% pre-FFRCT vs 7.7% post-FFRCT, p<0.001) and rest (10.4% pre-FFRCT vs 4.2% post-FFRCT, p=0.007) myocardial perfusion scans and diagnostic-only angiograms (25.5% vs 13.7%, p<0.001). Despite fewer invasive procedures (29.3% pre-FFRCT vs 17.6% post-FFRCT, p=0.002), revascularisation rates remained similar (10.4% pre-FFRCT vs 8.8% post-FFRCT, p=0.561). Avoiding invasive investigations reduced inpatient admissions (39.0% pre-FFRCT vs 24.3% post-FFRCT, p<0.001). Time to revascularisation was unchanged (153.5 days pre-FFRCT vs 142.0 post-FFRCT, p=0.925). Unplanned hospital attendances, emergency admissions and adverse events were similar.

Conclusions FFR\textsubscript{CT} adoption was associated with greater compliance with NICE guidelines, reduced invasive diagnostic angiography, planned admissions and needing more than one test to reach a pathway endpoint.

INTRODUCTION

Patients presenting with chest pain commonly require investigation to determine if they have coronary artery disease (CAD) and to plan revascularisation. Simulation software is now available to non-invasively estimate coronary fractional flow reserve from CT angiography (FFR\textsubscript{CT}). FFR is the reference standard measure of the functional impact of a coronary stenosis on blood flow. FFR\textsubscript{CT} uses standard CT coronary angiography (CTCA) image data to create a three-dimensional model of the coronary arteries and associated stenoses to predict this impact. FFR\textsubscript{CT} analysis therefore facilitates the anatomical and functional assessment of CAD within a single, non-invasive radiation exposure and reduces the requirement for invasive angiography when employed in diagnostic pathways for stable chest pain.
Coronary artery disease

or atypical angina, or in patients with non-anginal chest pain if ECG abnormalities are present. If CTCA shows CAD of uncertain significance or is non-diagnostic, a second-line functional investigation is recommended, such as nuclear myocardial perfusion scan (NMPS), stress echocardiography or stress MRI perfusion imaging. If results remain inconclusive, invasive coronary angiography is then offered.

In 2017, NICE published MTG32,9 which appraised the utility of FFRCT for anatomical and functional assessment of CAD. A guidance update in 2021 featured economic analysis estimating a cost saving of £391 per patient for FFRCT-based assessment pathways, potentially saving the National Health Service (NHS) >£9 million annually. In August 2018, the Newcastle on Tyne Hospitals NHS Foundation Trust (NuTH) was designated a pilot site for FFRCT adoption under the Innovation and Technology Payment (ITP) programme funded by NHS England. The service was made available to patients presenting to the rapid access chest pain clinic (RACPC).

This retrospective service evaluation aimed to assess the effect of introducing FFR_{CT} on (1) uptake of CTCA for first-line investigation of stable chest pain, (2) requirement for other non-invasive functional tests and (3) efficiency of use of the cardiac ‘cath lab’ (defined by the proportion of patients undergoing invasive investigation having immediate follow-on revascularisation). The study also assessed the impact on pathway times, hospital attendances and adverse events.

METHODS

Approval

The study was registered as a service evaluation on the NuTH Clinical Effectiveness Register and jointly undertaken by the Directorates of Northern Medical Physics and Clinical Engineering, Radiology and Cardiothoracic Services.

Setting

NuTH is an NHS Trust with >2250 beds providing tertiary cardiac services to the region, performing >1600 CTCA scans and around 2800 percutaneous coronary interventions (PCIs) per year.

The RACPC assesses patients with suspected angina within 14 days of referral with capacity for approximately 1000 patients annually. Nine consultant cardiologists and one chest pain specialist nurse managed patients attending the RACPC during the study.

Inclusion and exclusion criteria

Eligible patients were ≥18 years with stable chest pain with an appointment at the RACPC in one of two recruitment periods: before the introduction of FFR_{CT}, ‘pre-FFR_{CT}’ between 1 July 2017 and 31 December 2017, or after FFR_{CT} adoption under the ITP programme, ‘post-FFR_{CT}’, between 1 August 2018 and 31 January 2019, thus avoiding a cross-over period when FFR_{CT} was used infrequently. The index appointment for each patient was the earliest appointment or earliest appointment within any 3-month period where multiple referrals were made.

Patients with previously confirmed CAD (eg, previous myocardial infarction (MI), revascularisation or angiography) were excluded from analysis as CG95 recommends first-line non-invasive functional testing in this group. Because our study was designed to examine the influence of FFR_{CT} on radiological investigation pathways, patients discharged from the RACPC without radiological tests were excluded from analysis. It was assumed such patients had non-cardiac chest pain diagnosed clinically by the attending cardiologist.

Data sources

Data were obtained retrospectively from the RACPC database for the pre-FFR_{CT} and post-FFR_{CT} time periods, plus 3 months prior to each, to exclude patients with index appointments before the recruitment periods. Patient-level identifiers (NHS number and local medical record number) were used to quantify healthcare encounters from local administrative data, including accident and emergency (A&E), outpatient attendances and inpatient admissions. Clinical events identified from inpatient data included acute MI, revascularisation with coronary artery bypass grafting (CABG) and invasive cath lab procedures including diagnostic angiography with or without pressure wire functional testing, and revascularisation with PCI. Patient-level identifiers were used to extract records from the radiology information system to ensure all relevant investigations were identified, including CTCA, MRI and NMPS (stress and rest) scans, intravascular ultrasound and optical coherence tomography. Investigations and events were identified using International Classification of Diseases, 10th Revision, and Office of Population Censuses and Surveys (OPCS) Classification of Interventions and Procedures codes, and standardised exam descriptions used locally (see online supplemental file). An in-house database was checked for stress echocardiography investigations. Additional data sources included the Strategic Tracing Service to identify patient deaths and the software provider’s web application for FFR_{CT}.

All healthcare encounters and clinical event data between 1 July 2017 and 30 September 2019 were extracted. This allowed 8 months of follow-up for all patients, which was deemed appropriate for completion of related investigations.

Data cleaning

Records were excluded if duplicated, unrelated to an index appointment, or if patient identifiers were missing or invalid. Patients with known CAD were excluded if a previous inpatient episode contained relevant OPCS or ICD codes, or existing CAD was recorded at the RACPC (see online supplemental file). As the latter used a text-matching algorithm, the authors manually verified exclusions.

Definitions and outcomes

Pathway start point was defined as the date of RACPC attendance when a decision was made to refer for additional radiological investigation. Pathway endpoint was defined as either revascularisation (PCI or CABG), death or MI without revascularisation, or an assumed decision to manage medically (ie, no further investigations, procedures or adverse events recorded during follow-up).

Investigations were ordered chronologically and only the earliest instance of each considered. Times between RACPC attendance and investigations, and the pathway endpoint were calculated for each patient. Overall numbers and types (emergency/non-emergency, cardiac/non-cardiac) of inpatient and outpatient attendances, number of cardiac radiological investigations and invasive procedures were determined. Safety outcomes were frequencies of MI, death and unplanned hospital attendance.

For analysis, related investigations and procedures were grouped into ‘other’ non-invasive functional tests (NMPS, stress echo and stress MRI); diagnostic-only cath lab procedures
Coronary artery disease

(angioangiography or angiography plus pressure wire); and invasive revascularisation (PCI or CABB).

Statistical analysis
Analysis used ’R’ statistical programming language and a significance level of 0.05 using Bonferroni correction for related groups of observations. Comparisons of pre-FFRCT and post-FFRCT cohorts used Student’s t-test, χ² test, Mann-Whitney U test or Fisher’s exact test, as appropriate. Tests were two-sided. Kaplan-Meier analysis and Cox proportional hazards test were used to compare time to revascularisation events.

Patient and public involvement
This was a retrospective evaluation of standard care pathways and routinely collected data. Therefore, no patients or members of the public were directly involved.

RESULTS
Study population
In total, 995 patients (483 pre-FFRCT and 512 post-FFRCT) attended the RACPC. After data cleaning and exclusion of patients with known CAD, or discharge without further investigation, 268 pre-FFRCT and 287 post-FFRCT patients were eligible for CTCA first line (figure 1). The proportions of patients discharged without additional investigation were similar (pre-FFRCT 37.2% (n=159) vs 33.3% (n=143) post-FFRCT, p=0.225). Of those discharged, two died and one suffered an MI in the pre-FFRCT cohort, and one died in the post-FFRCT cohort.

Patient characteristics and extent of missing data are summarised in table 1. Smoking was more prevalent in the post-FFRCT cohort (p=0.003). Hyperlipidaemia and hypertension were also more prevalent (p=0.0063 and 0.035, respectively), although not significantly following Bonferroni correction (Bonferroni threshold 0.0063). After referral for investigation, 12 eligible patients (9 pre-FFRCT and 3 post-FFRCT) experienced an MI before planned first-line investigations and were excluded from the main analysis. The risk of event prior to first-line investigation did not differ (9/268, 3.4% pre-FFRCT vs 3/287, 1.0% post-FFRCT; p=0.08).

Investigations and pathways
The sequence and number of tests between RACPC attendance and pathway endpoint are shown in figures 2 and 3. Flow diagrams detailing a chronological breakdown of investigations and times between them are shown in online supplemental file 1.

Time from RACPC attendance to first-line investigation did not differ between cohorts (p=0.98). Median time was 52 days (IQR 35–74) pre-FFRCT vs 53 days (IQR 46–59) post-FFRCT.

The proportion of patients offered CTCA as a first-line investigation increased (131/259, 50.6% pre-FFRCT vs 215/284, 75.7% post-FFRCT; p<0.001).

The impact of FFRCT on cardiac test referral within 8 months of attendance at the RACPC is shown in table 2. After introduction of FFRCT, more patients reached their pathway endpoint (revascularisation or assumed decision to manage medically) following one investigation (74.9% pre-FFRCT vs 84.9% post-FFRCT, p=0.005; table 3).

Non-invasive cardiac investigations
After introducing FFRCT, use of stress NMPS decreased from 22.8% to 7.7% of patients (p<0.001). Use of rest NMPS also

Table 1 Clinical characteristics of patients included in the analysis.

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Pre-FFRCT</th>
<th>Post-FFRCT</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients, n</td>
<td>268*</td>
<td>287*</td>
<td>–</td>
</tr>
<tr>
<td>Male (%)</td>
<td>137/268 (51.1)</td>
<td>131/287 (45.6)</td>
<td>0.228</td>
</tr>
<tr>
<td>Mean age (range)</td>
<td>62 (35–89)</td>
<td>62 (26–89)</td>
<td>0.764†</td>
</tr>
<tr>
<td>Ever smoked (%)</td>
<td>116/261 (44.4)</td>
<td>167/283 (59.0)</td>
<td>0.003§</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>112/259 (43.2)</td>
<td>149/283 (52.7)</td>
<td>0.035</td>
</tr>
<tr>
<td>Hyperlipidaemia (%)</td>
<td>139/252 (55.2)</td>
<td>184/274 (67.2)</td>
<td>0.006</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>44/260 (16.9)</td>
<td>48/282 (17.0)</td>
<td>1</td>
</tr>
<tr>
<td>Family history (%)</td>
<td>123/252 (48.8)</td>
<td>127/270 (47.0)</td>
<td>0.751</td>
</tr>
<tr>
<td>Body mass index ≥30 (%)</td>
<td>66/159 (41.5)</td>
<td>95/229 (41.5)</td>
<td>1</td>
</tr>
</tbody>
</table>

*Value changes in subsequent rows due to unrecorded data or patient answering ‘Don’t know’ when asked.
†P value calculated using t-test; all others used χ² test.
§Significant with Bonferroni correction applied to the group of eight observations (p<0.00625).
FFRCT, CT fractional flow reserve.
Coronary artery disease

Invasive coronary angiography and revascularisation

The overall proportion of patients undergoing diagnostic-only invasive angiography decreased significantly after introducing FFR_{CT} (25.5% pre-FFR_{CT} vs 13.7% post-FFR_{CT}, p<0.001). This reduced the overall proportion of patients requiring cath lab procedures from 86/259 (33.2%) to 59/284 (20.8%) (p=0.001).

The proportion of patients undergoing invasive coronary angiography as a first-line investigation was reduced (65/259, 25.1% pre-FFR_{CT} vs 41/284, 14.4% post-FFR_{CT}, p=0.002), as was, non-significantly, the use of invasive coronary angiography as a second-line investigation following initial CTCA (16/131, 12.2% pre-FFR_{CT} vs 15/215, 7.0% post-FFR_{CT}, p=0.12).

The proportion of patients revascularised remained similar between cohorts (27/259, 10.4% pre-FFR_{CT} vs 25/284, 8.8% post-FFR_{CT}, p=0.561).

Pre-FFR_{CT}, the revascularisation rate was 8/16 (50.0%) among patients with first-line CTCA only before cath lab attendance. After first-line CTCA plus FFR_{CT} prior to cath lab attendance, the revascularisation rate was 12/14 (85.7%), although this was not statistically significant (p=0.058).

Time to revascularisation

The time taken to reach an endpoint of revascularisation was unchanged between cohorts (figure 4), with a median time of 153.5 days (maximum of 231 days) pre-FFR_{CT}, vs 142.0 days (maximum of 236 days) post-FFR_{CT} (p=0.925).

Table 2 Cardiac test usage within 8 months of attendance at the rapid access chest pain clinic, pre-FFR_{CT}/post-FFR_{CT} adoption

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Pre-FFR_{CT} (n=259)</th>
<th>Post-FFR_{CT} (n=284)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive angiogram only</td>
<td>66 (25.5)</td>
<td>39 (13.7)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Invasive angiogram with pressure wire only</td>
<td>3 (1.2)</td>
<td>0 (0.0)</td>
<td>0.108</td>
</tr>
<tr>
<td>CTCA only</td>
<td>131 (50.6)</td>
<td>136 (47.9)</td>
<td>0.548</td>
</tr>
<tr>
<td>CTCA plus FFR_{CT}</td>
<td>0 (0.0)</td>
<td>82 (28.9)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Rest NMPS</td>
<td>27 (10.4)</td>
<td>12 (4.2)</td>
<td>0.007</td>
</tr>
<tr>
<td>Stress NMPS</td>
<td>59 (22.8)</td>
<td>22 (7.7)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Stress MRI</td>
<td>3 (1.2)</td>
<td>8 (2.8)</td>
<td>0.227</td>
</tr>
<tr>
<td>Stress echo</td>
<td>13 (5.0)</td>
<td>9 (3.2)</td>
<td>0.286</td>
</tr>
</tbody>
</table>

*P values calculated using Fisher’s exact test.
†Significant with Bonferroni correction applied to the group of eight observations (p<0.00625).

CTCA, CT coronary angiography; FFR_{CT}, CT fractional flow reserve ; NMPS, nuclear myocardial perfusion scan.

Table 3 Number of investigations after rapid access chest pain clinic visit required to reach pathway endpoint

<table>
<thead>
<tr>
<th>Investigations required to reach endpoint</th>
<th>Pre-FFR_{CT} (n=259)</th>
<th>Post-FFR_{CT} (n=284)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>194 (74.9)</td>
<td>241 (84.9)</td>
<td>0.014*</td>
</tr>
<tr>
<td>2</td>
<td>58 (22.4)</td>
<td>39 (13.7)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>7 (2.7)</td>
<td>4 (1.4)</td>
<td></td>
</tr>
</tbody>
</table>

*Significant using Fisher’s exact test with null hypothesis of no change in the number of investigations to reach endpoint.

FFR_{CT}, CT fractional flow reserve .

Figure 2 Pre-FFR_{CT}, sequence of testing between RACPC attendance and endpoint. CABG, coronary artery bypass grafting; CTCA, CT coronary angiography; FFR_{CT}, CT fractional flow reserve; NM, nuclear medicine; PCI, percutaneous coronary intervention; RACPC, rapid access chest pain clinic.

The proportion of patients with any functional investigation (including FFR_{CT}) before cath lab attendance increased from 5/86 (5.8%) pre-FFR_{CT}, to 17/59 (28.8%) post-FFR_{CT} (p<0.001).

Table 2 Cardiac test usage within 8 months of attendance at the rapid access chest pain clinic, pre-FFR_{CT}/post-FFR_{CT} adoption

<table>
<thead>
<tr>
<th>Investigation</th>
<th>Pre-FFR_{CT} (n=259)</th>
<th>Post-FFR_{CT} (n=284)</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invasive angiogram only</td>
<td>66 (25.5)</td>
<td>39 (13.7)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Invasive angiogram with pressure wire only</td>
<td>3 (1.2)</td>
<td>0 (0.0)</td>
<td>0.108</td>
</tr>
<tr>
<td>CTCA only</td>
<td>131 (50.6)</td>
<td>136 (47.9)</td>
<td>0.548</td>
</tr>
<tr>
<td>CTCA plus FFR_{CT}</td>
<td>0 (0.0)</td>
<td>82 (28.9)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Rest NMPS</td>
<td>27 (10.4)</td>
<td>12 (4.2)</td>
<td>0.007</td>
</tr>
<tr>
<td>Stress NMPS</td>
<td>59 (22.8)</td>
<td>22 (7.7)</td>
<td>&lt;0.001†</td>
</tr>
<tr>
<td>Stress MRI</td>
<td>3 (1.2)</td>
<td>8 (2.8)</td>
<td>0.227</td>
</tr>
<tr>
<td>Stress echo</td>
<td>13 (5.0)</td>
<td>9 (3.2)</td>
<td>0.286</td>
</tr>
</tbody>
</table>

*P values calculated using Fisher’s exact test.
†Significant with Bonferroni correction applied to the group of eight observations (p<0.00625).

CTCA, CT coronary angiography; FFR_{CT}, CT fractional flow reserve ; NMPS, nuclear myocardial perfusion scan.

Figure 3 Post-FFR_{CT}, sequence of testing between RACPC attendance and endpoint. CTCA, CT coronary angiography; FFR_{CT}, CT fractional flow reserve; NM, nuclear medicine; PCI, percutaneous coronary intervention; RACPC, rapid access chest pain clinic.

Invasive coronary angiography and revascularisation

The overall proportion of patients undergoing diagnostic-only invasive angiography decreased significantly after introducing FFR_{CT} (25.5% pre-FFR_{CT} vs 13.7% post-FFR_{CT}, p<0.001). This reduced the overall proportion of patients requiring cath lab procedures from 86/259 (33.2%) to 59/284 (20.8%) (p=0.001).

The proportion of patients undergoing invasive coronary angiography as a first-line investigation was reduced (65/259, 25.1% pre-FFR_{CT} vs 41/284, 14.4% post-FFR_{CT}, p=0.002), as was, non-significantly, the use of invasive coronary angiography as a second-line investigation following initial CTCA (16/131, 12.2% pre-FFR_{CT} vs 15/215, 7.0% post-FFR_{CT}, p=0.12).

The proportion of patients revascularised remained similar between cohorts (27/259, 10.4% pre-FFR_{CT} vs 25/284, 8.8% post-FFR_{CT}, p=0.561).

Pre-FFR_{CT}, the revascularisation rate was 8/16 (50.0%) among patients with first-line CTCA only before cath lab attendance. After first-line CTCA plus FFR_{CT} prior to cath lab attendance, the revascularisation rate was 12/14 (85.7%), although this was not statistically significant (p=0.058).

Time to revascularisation

The time taken to reach an endpoint of revascularisation was unchanged between cohorts (figure 4), with a median time of 153.5 days (maximum of 231 days) pre-FFR_{CT}, vs 142.0 days (maximum of 236 days) post-FFR_{CT} (p=0.925).
two MIs post-FFR\textsubscript{CT}. All MIs were treated with revascularisation, and the death in the post-FFR\textsubscript{CT} cohort occurred following revascularisation.

**DISCUSSION**

**Summary of findings**

We assessed RACPC diagnostic pathways and concordance with NICE Guideline CG95\textsuperscript{3} before and after introducing FFR\textsubscript{CT} at a large NHS tertiary cardiac centre. FFR\textsubscript{CT} adoption was associated with improved compliance through increased CTCA as a first-line investigation and reduced use of some alternative functional tests. Elective inpatient admissions were reduced, as were the number of diagnostic-only invasive angiography procedures. The proportion of patients having percutaneous revascularisation after an invasive angiogram increased. The overall proportion of patients with stable chest pain requiring revascularisation was unchanged. Unplanned hospital admissions were not increased.

Within a single non-invasive test, FFR\textsubscript{CT} provides anatomical and functional information based on the modelled impact of epicardial stenoses. It does not identify patients with chest pain and evidence of ischaemia in the absence of fixed epicardial stenosis, such as those with microvascular dysfunction or vasospastic angina who may require alternative invasive or non-invasive assessment.

NICE economic modelling estimates potential cost savings of £391 per patient compared with alternative stable chest pain pathways,\textsuperscript{4} though this saving may only be achieved in those otherwise undergoing invasive angiography. Despite reduced use of invasive coronary angiography and other diagnostic modalities, similar to that observed in our own study, cost savings were not substantiated in the large UK randomised Fractional Flow Reserve Derived From Computed Tomography Coronary Angiography in the Assessment and Management of Stable Chest Pain (FORECAST) trial.\textsuperscript{5} Of note, first-line CTCA use was higher (63%) in the standard care arm of FORECAST compared with our pre-FFR\textsubscript{CT} cohort (51%), which may reflect local differences in guideline adoption, service provision or the influence of trial participation.

In common with previous studies,\textsuperscript{6,7} we observed fewer patients undergoing invasive, diagnostic-only angiography. Despite performing fewer invasive angiograms, revascularisation rates were similar between cohorts, with no increase in adverse events. This suggests that patients received the interventions they needed when triaged using FFR\textsubscript{CT}, while avoiding the associated risks of invasive angiography. Our data and those of other studies\textsuperscript{4,18} support the concept that patients with prior positive FFR\textsubscript{CT} results are more likely to undergo immediate follow-on PCI if referred for invasive assessment. Prioritising cath lab use for revascularisation (rather than diagnosis) is important to minimise revascularisation waiting times for those with proven stable CAD with symptoms inadequately controlled with medical therapy. This may release capacity for urgent or emergency angiography in patients with unstable coronary syndromes. Shifting towards cath lab usage for revascularisation will be particularly important to manage the backlog of patients awaiting PCI following the COVID-19 pandemic.

We observed reduced use of nuclear stress tests, previously our most used functional test. With resource constraints, this has important implications for service planning and may alleviate waiting times for nuclear investigations for other conditions. Reduced use of nuclear stress tests may particularly benefit patients as an abnormal scan requires a second resting test on a
Coronary artery disease

Separate visit. Therefore, FFR_{CT} reduces not only total patient visits but also patient exposure to ionising radiation. The potential reduction in radiation exposure associated with FFR_{CT} is quantified elsewhere.\(^5\) \(^12\) Despite differences in study design, we found our decreased reliance on diagnostic cath lab procedures and non-FFR_{CT} functional tests to be concordant with other studies\(^7\) and NHS hospitals.\(^11\) However, it is challenging to disaggregate the influence of increased CTCA use alone, compared with CTCA plus selective FFR_{CT}.

FFR_{CT} analysis is available within 12 hours, potentially enabling communication of diagnostic and treatment decisions to patients within a day of their CTCA. Conversely, pathways that ‘layer’ diagnostic tests (eg, CTCA followed by functional testing with stress cMRI, stress echocardiography or NMPS) typically have additive waiting times, potentially taking longer to reach diagnosis. Although we saw no difference in adverse events while patients awaited investigation, longer waiting times may prolong anxiety for patients and may delay return to work, travel or investigation of alternative causes of symptoms.

There was no significant difference in either the overall time patients spent on pathways or the median number of hospital attendances and procedures. However, this disguised changes in how attendances and investigation types were distributed. There was greater reliance on invasive testing earlier in the pathway before adopting FFR_{CT} with more patients undergoing first-line invasive coronary angiography. Changes in pathway time may also have been masked because waiting times for clinic review or elective revascularisation procedures did not change. We found a greater proportion of patients reached pathway endpoint after one test, which may be important for patient satisfaction and planning new ‘one-stop-shop’ services for diagnosis and management of new-onset stable chest pain.

Strengths and limitations

Our study is from a large UK NHS Trust and provides a comprehensive picture of all cardiac investigation modalities and hospital settings used to assess and diagnose stable chest pain. The work was retrospective and therefore reflects a ‘real-world’ change in pathways, without the influence of trial participation, although as an uncontrolled study, there were potential confounders.

Using NHS numbers and national datasets permitted identification of all patient deaths, although cause of death information was not available. RACPC patients undergo subsequent investigations at our hospital, and our records, combined with manual review of coded events, enabled identification of all encounters. We could not, however, identify additional investigations or emergency admissions at other hospitals. Exclusion of patients ineligible for CTCA under CG95 was achieved using local data and clinical history, although CAD events recorded outside of NuTH would rely on patient recall. However, it is likely that missed exclusions would occur proportionally across both cohorts and would not, therefore, alter our results.

The two cohorts differed significantly in certain clinical characteristics, with higher proportions of hyperlipidaemia, hypertension and smoking in the post-FFR_{CT} cohort. There were no changes in RACPC referral criteria during the study, and it is unlikely that these factors would have affected investigation choices. However, we could not determine the factors influencing first-line or second-line investigation choices. Patients with persistent symptoms and non-obstructive CAD on CTCA or FFR_{CT} may have undergone functional assessment for identification of ischaemia in the context of normal coronary arteries (eg, due to microvascular dysfunction) or because the physician suspected a false-negative result. Increased awareness of non-obstructive causes of ischaemic chest pain may have influenced second-line referral patterns.

Data relating to symptoms in the RACPC dataset were recorded as a free-text summary rather than a standardised scale and so were unsuitable for analysis, and no information on quality of life was available.

Similar results may not be realised in smaller hospitals or those without the necessary high-quality cardiac CT service capacity or compliance with information governance standards. The implications of the latter were presented in NICE shared learning from Liverpool Heart & Chest Hospital NHS Foundation Trust\(^18\) and from Bath Hospital.\(^15\)

CONCLUSIONS

Introduction of FFR_{CT} was associated with greater compliance with NICE CG95, reduction in invasive diagnostic coronary angiography, planned hospital admissions and need for more than one diagnostic test to reach a stable CAD pathway endpoint.

Twitter Anna Beattie @doctorradiology

Acknowledgements The authors thank David Astorph for providing radiology information system data, Susan Hollands for providing commissioning data and Tim Irvine for providing stress echo data.

Contributors ABe, JB, RO and SU were responsible for the design of the study. JB, RO and SU were responsible for the protocol and data management. JB, RO, SU and AJs were responsible for the analysis of the data. ABe, ABa, JB, RO and AJs were responsible for data review and interpretation of the analysis. ABe, ABa, JB, RO, SU and AJs drafted, revised and approved the final version of the manuscript. AJs is the guarantor.

Funding The study was facilitated by the Academic Health Science Network for the North East and North Cumbria. JB, RO and AJs are employed by the Northern Medical Physics and Clinical Engineering Directorate of The Newcastle upon Tyne Hospitals NHS Foundation Trust, which hosts an External Assessment Group funded by the National Institute for Health and Care Excellence.

Competing interests ABe has received honoraria for travel and speaker engagements from HeartFlow. ABa is UK chief investigator of the P4 trial that is part-funded by HeartFlow.

Patient and public involvement Patients and/or the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants. The study was a retrospective service evaluation of standard care pathways and routinely collected data. It took place in our own organisation that delivered the patient care, was carried out in accordance with clinical governance guidelines and was approved by the NHS Trust’s Caldicott Guardian. It was not intended to generate new, generalisable knowledge, was therefore not research and did not require ethical review. The study was a retrospective service evaluation of standard care pathways and routinely collected data within our own organisation. Approval was granted by the NHS Trust’s Caldicott Guardian for the use of patient data in this way.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. This study used identifiable data sets collected for the purpose of service evaluation within the same care organisation.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those of the author(s) and are not endorsed by BMJ. BMJ disclaims all liability and responsibility arising from any reliance placed on the content. Where the content includes any translated material, BMJ does not warrant the accuracy and reliability of the translations (including but not limited to local regulations, clinical guidelines, terminology, drug names and drug dosages), and is not responsible for any error and/or omissions arising from translation and adaptation or otherwise.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is
REFERENCES


