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# Impact on stable chest pain pathways of CT fractional flow reserve

Rachel A O'Leary <sup>1</sup>, Julie Burn <sup>1</sup>, Samuel G Urwin,<sup>1</sup> Andrew J Sims <sup>1,2</sup>, Anna Beattie <sup>3</sup>, Alan Bagnall <sup>2,4</sup>

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<sup>1</sup>Northern Medical Physics and Clinical Engineering, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle Upon Tyne, UK

<sup>2</sup>Faculty of Medical Sciences, Newcastle University, Newcastle upon Tyne, UK

<sup>3</sup>Radiology, Royal Victoria Infirmary, Newcastle upon Tyne, UK

<sup>4</sup>Cardiology, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle Upon Tyne, UK

## Correspondence to

Dr Andrew J Sims, Northern Medical Physics and Clinical Engineering, Newcastle Upon Tyne Hospitals NHS Foundation Trust, Newcastle Upon Tyne NE7 7DN, UK; [andrew.sims5@nhs.net](mailto:andrew.sims5@nhs.net)

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## ABSTRACT

**Objectives** To evaluate the impact of introducing CT fractional flow reserve (FFR<sub>CT</sub>) on stable chest pain pathways, concordance with National Institute for Health and Care Excellence (NICE) chest pain guidelines, resource usage 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-FFR<sub>CT</sub> and post-FFR<sub>CT</sub>, respectively. First-line CTCA use per NICE Guideline CG95 increased (50.6% pre-FFR<sub>CT</sub> vs 75.7% post-FFR<sub>CT</sub>,  $p < 0.001$ ). More patients reached pathway endpoint (revascularisation or assumed medical management) after one investigation (74.9% pre-FFR<sub>CT</sub> vs 84.9% post-FFR<sub>CT</sub>,  $p = 0.005$ ). There were fewer stress (22.8% pre-FFR<sub>CT</sub> vs 7.7% post-FFR<sub>CT</sub>,  $p < 0.001$ ) and rest (10.4% pre-FFR<sub>CT</sub> vs 4.2% post-FFR<sub>CT</sub>,  $p = 0.007$ ) myocardial perfusion scans and diagnostic-only angiograms (25.5% vs 13.7%,  $p < 0.001$ ). Despite fewer invasive procedures (29.3% pre-FFR<sub>CT</sub> vs 17.6% post-FFR<sub>CT</sub>,  $p = 0.002$ ), revascularisation rates remained similar (10.4% pre-FFR<sub>CT</sub> vs 8.8% post-FFR<sub>CT</sub>,  $p = 0.561$ ). Avoiding invasive investigations reduced inpatient admissions (39.0% pre-FFR<sub>CT</sub> vs 24.3% post-FFR<sub>CT</sub>,  $p < 0.001$ ). Time to revascularisation was unchanged (153.5 days pre-FFR<sub>CT</sub> vs 142.0 post-FFR<sub>CT</sub>,  $p = 0.925$ ). Unplanned hospital attendances, emergency admissions and adverse events were similar.

**Conclusions** FFR<sub>CT</sub> 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<sub>CT</sub>). FFR is the reference standard measure of the functional impact of a coronary stenosis on blood flow.<sup>1</sup> FFR<sub>CT</sub> uses standard CT coronary angiography (CTCA)

## WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Fractional flow reserve CT (FFR<sub>CT</sub>) facilitates the anatomical and functional assessment of coronary artery disease (CAD) using a single, non-invasive radiation exposure, which can inform clinical management decisions.

## WHAT THIS STUDY ADDS

⇒ Implementation of FFR<sub>CT</sub> in diagnostic pathways for stable chest pain reduced the number of diagnostic-only invasive angiograms, planned hospital admissions and need for myocardial perfusion scans. Patients were more likely to need only one diagnostic test to reach a pathway endpoint, which was achieved with no increase in time to revascularisation or adverse events.

## HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study confirms the feasibility of National Institute for Health and Care Excellence CG95 in routine clinical practice and supports evidence that CT coronary angiography (CTCA) and FFR<sub>CT</sub> is a safe alternative for guiding revascularisation decisions in patients presenting with new-onset chest pain without known CAD. Guideline adoption will likely require additional CTCA capacity but may release capacity for revascularisation by reducing the number of diagnostic-only invasive procedures.

image data to create a three-dimensional model of the coronary arteries and associated stenoses to predict this impact. FFR<sub>CT</sub> 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.<sup>2–7</sup>

Prior to the 2016 update, the UK National Institute for Health and Care Excellence (NICE) Clinical guideline CG95 ('Recent-Onset Chest Pain of Suspected Cardiac Origin: Assessment and Diagnosis') recommended CTCA only for patients with low pretest probability of significant CAD.<sup>8</sup> The updated guidance recommends CTCA first line for all patients at any risk level to detect the presence of CAD if symptoms are suggestive of typical



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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,<sup>9</sup> which appraised the utility of FFR<sub>CT</sub> for anatomical and functional assessment of CAD. A guidance update in 2021 featured economic analysis estimating a cost saving of £391 per patient for FFR<sub>CT</sub>-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 FFR<sub>CT</sub> 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<sub>CT</sub> 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<sub>CT</sub>, 'pre-FFR<sub>CT</sub>' between 1 July 2017 and 31 December 2017, or after FFR<sub>CT</sub> adoption under the ITP programme, 'post-FFR<sub>CT</sub>' between 1 August 2018 and 31 January 2019, thus avoiding a cross-over period when FFR<sub>CT</sub> 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<sub>CT</sub> 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<sub>CT</sub> and post-FFR<sub>CT</sub> 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<sub>CT</sub>.

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

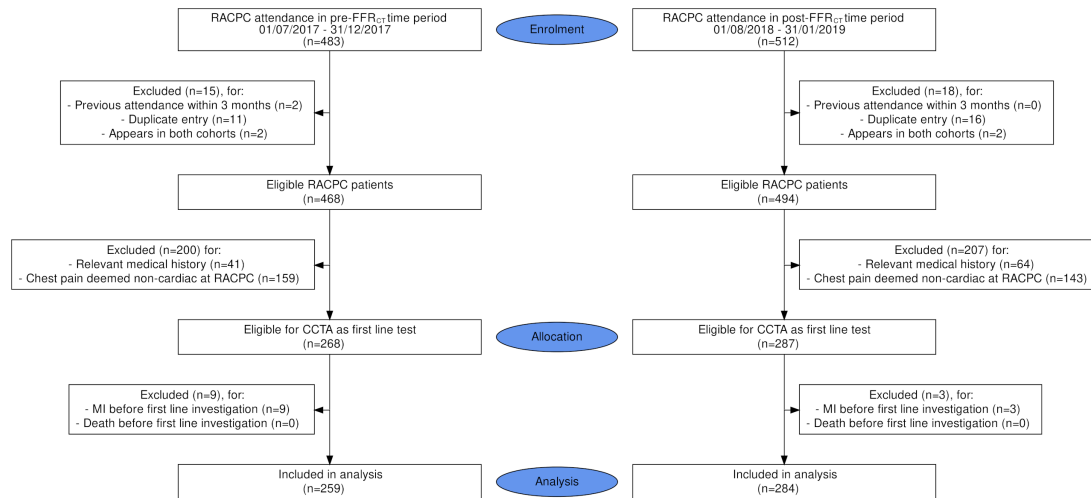
Records were excluded if duplicated, unrelated to an index appointment, or if patient identifiers were missing or invalid. Patients with known CAD were excluded if a previous inpatient episode contained relevant OPCS or ICD codes, or existing CAD was recorded at the RACPC (see online supplemental file). 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



**Figure 1** Recruitment flowchart for pre-FFR<sub>CT</sub> (left) and post-FFR<sub>CT</sub> (right) time periods. CCTA, CT coronary angiography; FFR<sub>CT</sub>, CT fractional flow reserve; MI, myocardial infarction; RACPC, rapid access chest pain clinic.

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

**Statistical analysis**

Analysis used ‘R’ statistical programming language<sup>10</sup> and a significance level of 0.05 using Bonferroni correction for related groups of observations. Comparisons of pre-FFR<sub>CT</sub> and post-FFR<sub>CT</sub> cohorts used Student’s t-test,  $\chi^2$  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-FFR<sub>CT</sub> and 512 post-FFR<sub>CT</sub>) attended the RACPC. After data cleaning and exclusion of patients with known CAD, or discharge without further investigation, 268 pre-FFR<sub>CT</sub> and 287 post-FFR<sub>CT</sub> patients were eligible for CTCA first line (figure 1). The proportions of patients discharged without additional investigation were similar (pre-FFR<sub>CT</sub> 37.2% (n=159) vs 33.3% (n=143) post-FFR<sub>CT</sub>, p=0.225). Of those discharged, two died and one suffered an MI in the pre-FFR<sub>CT</sub> cohort, and one died in the post-FFR<sub>CT</sub> cohort.

Patient characteristics and extent of missing data are summarised in table 1. Smoking was more prevalent in the post-FFR<sub>CT</sub> 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-FFR<sub>CT</sub> and 3 post-FFR<sub>CT</sub>) 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-FFR<sub>CT</sub> vs 3/287, 1.0% post-FFR<sub>CT</sub>; 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-FFR<sub>CT</sub> vs 53 days (IQR 46–59) post-FFR<sub>CT</sub>.

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

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

**Non-invasive cardiac investigations**

After introducing FFR<sub>CT</sub> 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.

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

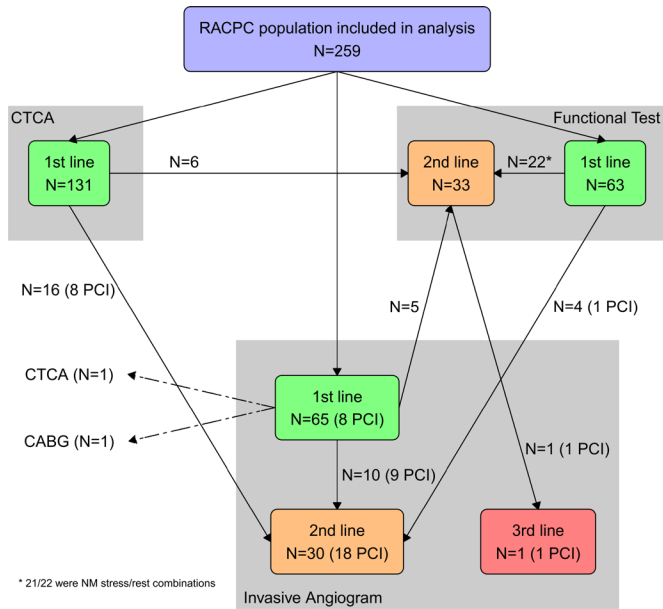
\*Value changes in subsequent rows due to unrecorded data or patient answering ‘Don’t know’ when asked.

†P value calculated using t-test; all others used  $\chi^2$  test.

‡Ever smoked includes current and ex-smokers.

§Significant with Bonferroni correction applied to the group of eight observations (p<0.00625).

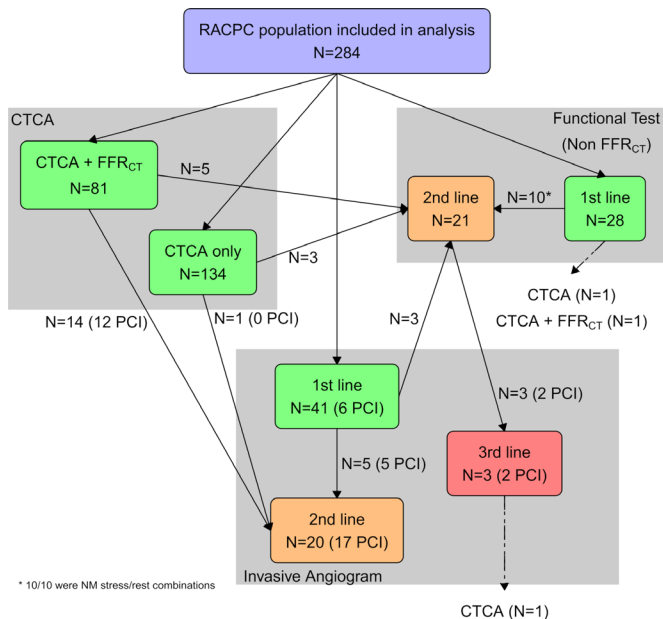
FFR<sub>CT</sub>, CT fractional flow reserve.



**Figure 2** Pre-FFR<sub>CT</sub>: sequence of testing between RACPC attendance and endpoint. CABG, coronary artery bypass grafting; CTCA, CT coronary angiography; FFR<sub>CT</sub>, CT fractional flow reserve; NM, nuclear medicine; PCI, percutaneous coronary intervention; RACPC, rapid access chest pain clinic.

decreased (10.4% pre-FFR<sub>CT</sub> vs 4.2% post-FFR<sub>CT</sub>), although with Bonferroni correction, this was not statistically significant (p=0.007). The use of stress cardiac MRI (cMRI) and stress echocardiography was unchanged.

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



**Figure 3** Post-FFR<sub>CT</sub>: sequence of testing between RACPC attendance and endpoint. CTCA, CT coronary angiography; FFR<sub>CT</sub>, CT fractional flow reserve; NM, nuclear medicine; PCI, percutaneous coronary intervention; RACPC, rapid access chest pain clinic.

**Table 2** Cardiac test usage within 8 months of attendance at the rapid access chest pain clinic, pre-FFR<sub>CT</sub>/post-FFR<sub>CT</sub> adoption

Investigation	Pre-FFR <sub>CT</sub> (n=259)	Post-FFR <sub>CT</sub> (n=284)	P value*
	Patients, n (%)	Patients, n (%)	
Invasive angiogram only	66 (25.5)	39 (13.7)	<0.001†
Invasive angiogram with pressure wire only	3 (1.2)	0 (0.0)	0.108
CTCA only	131 (50.6)	136 (47.9)	0.548
CTCA plus FFR <sub>CT</sub>	0 (0.0)	82 (28.9)	<0.001†
Rest NMPS	27 (10.4)	12 (4.2)	0.007
Stress NMPS	59 (22.8)	22 (7.7)	<0.001†
Stress MRI	3 (1.2)	8 (2.8)	0.227
Stress echo	13 (5.0)	9 (3.2)	0.286

\*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<sub>CT</sub>, CT fractional flow reserve; NMPS, nuclear myocardial perfusion scan.

**Invasive coronary angiography and revascularisation**

The overall proportion of patients undergoing diagnostic-only invasive angiography decreased significantly after introducing FFR<sub>CT</sub> (25.5% pre-FFR<sub>CT</sub> vs 13.7% post-FFR<sub>CT</sub>, 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<sub>CT</sub> vs 41/284, 14.4% post-FFR<sub>CT</sub>; 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<sub>CT</sub> vs 15/215, 7.0% post-FFR<sub>CT</sub>; p=0.12).

The proportion of patients revascularised remained similar between cohorts (27/259, 10.4% pre-FFR<sub>CT</sub> vs 25/284, 8.8% post-FFR<sub>CT</sub>; p=0.561).

Pre-FFR<sub>CT</sub> 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<sub>CT</sub> prior to cath lab attendance, the revascularisation rate was 12/14 (85.7%), although this was not statistically significant (p=0.058).

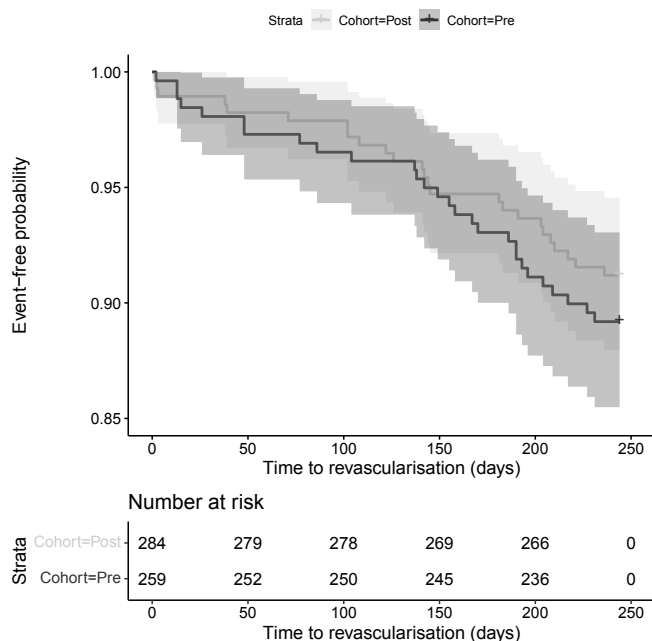
**Time to revascularisation**

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<sub>CT</sub> vs 142.0 days (maximum of 236 days) post-FFR<sub>CT</sub> (p=0.925).

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

Investigations required to reach endpoint	Pre-FFR <sub>CT</sub> (n=259)	Post-FFR <sub>CT</sub> (n=284)	P value
	Patients, n (%)	Patients, n (%)	
1	194 (74.9)	241 (84.9)	0.014*
2	58 (22.4)	39 (13.7)	
3	7 (2.7)	4 (1.4)	

\*Significant using Fisher's exact test with null hypothesis of no change in the number of investigations to reach endpoint.  
FFR<sub>CT</sub>, CT fractional flow reserve.



**Figure 4** Kaplan-Meier plot comparing time to revascularisation for pre-FFR<sub>CT</sub> and post-FFR<sub>CT</sub> cohorts. The Cox proportional hazards model found no significant difference in the risk of revascularisation between cohorts. The coloured bands are 95% CIs. FFR<sub>CT</sub>, CT fractional flow reserve.

**Hospitalisation and adverse events**

The proportion of patients with ≥1 planned inpatient admissions reduced from 39.0% pre-FFR<sub>CT</sub> to 24.3% post-FFR<sub>CT</sub> (p<0.001) due to fewer elective invasive angiography procedures. Unplanned hospital attendances did not differ with 5.8% of pre-FFR<sub>CT</sub> patients attending A&E at least once for cardiovascular reasons, compared with 4.9% of post-FFR<sub>CT</sub> patients (p=0.705). Both cohorts had similar rates of ≥1 emergency admissions (6.9% pre-FFR<sub>CT</sub> vs 7.7% post-FFR<sub>CT</sub>, p=0.745), table 4.

Of patients completing first-line investigations, there were no deaths and one MI in the pre-FFR<sub>CT</sub> cohort, and one death and

two MIs post-FFR<sub>CT</sub>. All MIs were treated with revascularisation, and the death in the post-FFR<sub>CT</sub> cohort occurred following revascularisation.

**DISCUSSION**

**Summary of findings**

We assessed RACPC diagnostic pathways and concordance with NICE Guideline CG95<sup>8</sup> before and after introducing FFR<sub>CT</sub> at a large NHS tertiary cardiac centre. FFR<sub>CT</sub> 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<sub>CT</sub> 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,<sup>9</sup> 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.<sup>7</sup> Of note, first-line CTCA use was higher (63%) in the standard care arm of FORECAST compared with our pre-FFR<sub>CT</sub> cohort (51%), which may reflect local differences in guideline adoption, service provision or the influence of trial participation.

In common with previous studies,<sup>2-7</sup> 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<sub>CT</sub>, while avoiding the associated risks of invasive angiography. Our data and those of other studies<sup>4,11</sup> support the concept that patients with prior positive FFR<sub>CT</sub> 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

**Table 4** Hospital attendance for cardiovascular emergency or elective treatment within 8 months of rapid access chest pain clinic attendance

Type of attendance	Post-FFR <sub>CT</sub>		P value*
	Pre-FFR <sub>CT</sub> (n=259)	Post-FFR <sub>CT</sub> (n=284)	
A&E attendance	15 (5.8)	14 (4.9)	0.705
Inpatient admission (elective)	101 (39.0)	69 (24.3)	<0.001†
Inpatient admission (for reasons other than angiography or revascularisation)	33 (12.7)	28 (9.9)	0.341
Inpatient admission (emergency)	18 (6.9)	22 (7.7)	0.745
Outpatient appointment	256 (98.8)	282 (99.3)	0.673

\*P values calculated using Fisher's exact test.

†Significant with Bonferroni correction applied to the group of five observations (p<0.01)

A&E, accident and emergency; FFR<sub>CT</sub>, CT fractional flow reserve.

separate visit. Therefore,  $\text{FFR}_{\text{CT}}$  reduces not only total patient visits but also patient exposure to ionising radiation. The potential reduction in radiation exposure associated with  $\text{FFR}_{\text{CT}}$  is quantified elsewhere.<sup>5 12</sup> Despite differences in study design, we found our decreased reliance on diagnostic cath lab procedures and non- $\text{FFR}_{\text{CT}}$  functional tests to be concordant with other studies<sup>7</sup> and NHS hospitals.<sup>13</sup> However, it is challenging to disaggregate the influence of increased CTCA use alone, compared with CTCA plus selective  $\text{FFR}_{\text{CT}}$ .

$\text{FFR}_{\text{CT}}$  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  $\text{FFR}_{\text{CT}}$ , 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- $\text{FFR}_{\text{CT}}$  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  $\text{FFR}_{\text{CT}}$  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<sup>14</sup> and from Bath Hospital.<sup>13</sup>

### CONCLUSIONS

Introduction of  $\text{FFR}_{\text{CT}}$  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

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**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.

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**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.

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#### ORCID iDs

Rachel A O'Leary <http://orcid.org/0000-0003-2544-9827>

Julie Burn <http://orcid.org/0000-0002-2300-2725>

Andrew J Sims <http://orcid.org/0000-0002-9553-7278>

Anna Beattie <http://orcid.org/0000-0001-7723-8760>

Alan Bagnall <http://orcid.org/0000-0003-0683-851X>

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