National Trends in Coronary Artery Disease Imaging: Associations With Health Care Outcomes and Costs

Jonathan R Weir-McCall, PhD, [1,2], Michelle C. Williams, PhD, [3], Anoop SV Shah, PHD, [4], Giles Roditi, MBChB, [5], James H.F. Rudd, PhD, [1], David E. Newby, PhD, [3], Edward D Nicol, MD, [6,7].

1. School of Clinical Medicine, University of Cambridge, Cambridge, UK.
2. Royal Papworth Hospital, Cambridge, UK.
3. University of Edinburgh/British Heart Foundation Centre for Cardiovascular Science, Edinburgh, UK.
4. London School of Hygiene and Tropical Medicine, London, UK.
5. Glasgow Royal Infirmary, NHS Greater Glasgow, Glasgow, UK
6. Royal Brompton and Harefield NHS Foundation Trust, Departments of Cardiology and Radiology, London, UK.
7. School of Biomedical Engineering and Imaging Sciences, Kings College London, UK

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DISCLOSURES

JRWM, MCW, GR and DEN were investigators in the SCOT-HEART trial. The remaining authors have nothing to disclose.

CORRESPONDING AUTHOR:

Dr. Ed Nicol

Honorary consultant cardiologist and senior clinical lecturer,

School of Biomedical Engineering and Imaging Sciences, Kings College London,

Department of Cardiology, Royal Brompton and Harefield NHS FT, London, SW3 6NP, UK

Email address: e.nicol@nhs.net

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ABSTRACT

Background: In 2016, CG95 recommended coronary computed tomography angiography (CCTA) as the first-line test for possible angina.

Objectives: To determine the impact of temporal trends in imaging use on outcomes for coronary artery disease (CAD) following the National Institute for Health and Care Excellence chest pain guidelines (CG95) recommendations.

Methods: Investigations from 2012-2018 were extracted from a national database and linked to hospital admission and mortality registries. Growth rates were adjusted for population size, and image modality use, cardiovascular hospital admissions and mortality compared using Kendall's rank correlation. The impact of CG95 was assessed using an interrupted time-series analysis.

Results: 1,909,314 investigations for CAD were performed, with an annualized per capita growth of 4.8%. Costs were £0.35 million/100,000 population/year with an increase of 2.8%/year mirroring inflation (2.5%/year). CG95 was associated with a rise in CCTA (exp(β) 1.10 [95% confidence interval 1.03 to 1.18]), no change in myocardial perfusion imaging and a potential modest fall (exp(β) 0.997 [0.993 to 1.00]) in invasive coronary angiography (ICA). There was an apparent trend between CTA growth and ICA reduction across regions (Kendall Tau -0.19, p=0.08). Coronary CTA growth was associated with a reduction in cardiovascular mortality (Kendall Tau -0.21, p=0.045), and ischemic heart disease deaths (Kendall Tau -0.22, p=0.042), with an apparent trend with reduced all-cause mortality (Kendall Tau -0.19, p=0.07).

Conclusions: Imaging investigations for CAD are increasing. Greater regional increases in CCTA were associated with fewer hospitalizations for myocardial infarction and a more rapid decline in CAD mortality.

Keywords: Coronary Artery Disease; Coronary Computed Tomography Angiography; Practice Guidelines as Topic; Health Care Economics; Interrupted Time Series Analysis

CONDENSED ABSTRACT

From 2012 to 2018, there was an increase in the use of imaging investigations for the diagnosis and management of coronary artery disease, with an increased use of coronary CTA, but no overall change in myocardial perfusion imaging. Regions with the greatest growth in the usage of coronary CTA demonstrated a fall in cardiovascular disease deaths. There was a rise in costs, but only in line with inflation. Our findings suggest that coronary CTA may improve clinical outcomes, at little additional cost. Our findings require prospective validation.

Abbreviations:

ARIMA = Auto Regressive Integrated Moving Average

CAD = Coronary artery disease

CCTA = Coronary Computed Tomographic Angiography

CG95 = Clinical Guideline Number 95 ("Chest pain of recent onset")

ICA = Invasive Catheter Angiography

MRI = Cardiac Magnetic Resonance Imaging

NICE = National Institute for Health and Care Excellence

PET = Positron Emission Tomography

SE = Stress Echocardiography

SPECT = Single Positron Emission Computed Tomography

STP = Sustainability and Transformation Partnerships

SNOMED-CT = Systematized Nomenclature of Medicine - Clinical Terms

INTRODUCTION

Non-invasive cardiac imaging has assumed a central role in both the diagnosis and management of coronary artery disease (1, 2). Following its introduction in 1999, single-photon emission computed tomography became the main imaging modality for the investigation of coronary artery disease (3). However technological advancements in stress echocardiography, positron emission tomography, coronary computed tomography angiography (CCTA) and cardiac magnetic resonance imaging have allowed for alternate strategies for the non-invasive investigation of chest pain, with comparable or superior diagnostic accuracy (4, 5).

In 2016, the UK National Institute for Health and Care Excellence (NICE) updated their guidelines for the investigation of stable chest pain (CG95) (6, 7). It selected CCTA as the first line test for those with possible angina and no known prior coronary artery disease due to its lower overall pathway costs and high sensitivity and negative predictive value (7). Subsequent individual patient data meta-analysis has also demonstrated that CCTA has a high specificity and positive predictive value for the detection of obstructive coronary artery disease, which is comparable or superior to other non-invasive imaging approaches (8). Despite these observations, the NICE CG95 is an outlier in international guidelines. Both the combined society guideline of the United States and the European Society of Cardiology recommend the use of either non-invasive imaging for ischemia or coronary CTA in patients with stable chest pain (1, 2). Preferential consideration for CCTA is only suggested for low-intermediate risk individuals.

The aim of the current study was to investigate contemporary trends in imaging for coronary artery disease and to assess the impact of the updated 2016 NICE CG95 guideline in England. Specifically, we wished to explore the relationship of increased CCTA use on rates of invasive coronary angiography, hospitalization for myocardial infarction, coronary artery disease mortality and health care costs.

METHODS

Study population

This was a retrospective observational nation-level study comprising all adults ≥18 years of age in England who underwent a cardiac imaging investigation within the National Health Service between 2012 and 2018 with individual follow-up through to the end of 2019. Ethical approval for the use of aggregate national data was provided by the University of Cambridge, Cambridge Psychology Research Ethics Committee.

Data sources

Imaging data were collected from the Digital Imaging Dataset held by National Health Service (NHS) Digital, who are responsible for the curation, maintenance and regulation of health-related information and technology for England. Since 2012, it has been mandatory for imaging departments funded within the English NHS to submit monthly data on all imaging tests. These data are extracted from the Radiology Informatics System at each center and uploaded to NHS Digital where they are stored and amalgamated with existing records. All imaging data submitted to NHS Digital are coded using Systematised Nomenclature of Medicine - Clinical Terms (SNOMED-CT). Where local clinical practices used alternate terminology, codes are provided to the nearest SNOMED-CT equivalent by the referring center. At the initial data extraction, all data on SNOMED-CT codes relating to cardiac anatomical and functional imaging were obtained (Supplementary Table 1).

Hospital admission data were collected from the Hospital Episode Statistics database. This is a database containing details of all admissions, Emergency Department attendances and outpatient appointments at NHS hospitals in England. Submission of these data is required for payment of care delivered by hospitals. Mortality data were collected from the Office for National Statistics which curates the information from the death certificate for all individuals registered in England and Wales. It consists of the cause, date, and place of death.

NHS Digital linked all cardiac imaging tests in the Digital Imaging Dataset with hospital admission and mortality data from Hospital Episode Statistics and Office for National Statistics at a patient level. Hospital admissions for cardiovascular disease, and all-cause, cardiovascular, and coronary artery disease deaths, were collected within 12 months of an imaging investigation based on International Classification of Diseases 10 codes (see Supplementary Table 2 for codes used to categorize admissions and mortality into circulatory, major cardiovascular disease, ischemic heart disease, myocardial infarct and cerebrovascular outcomes). Data were then provided at an aggregate regional level based on the 42 Sustainability and Transformation Partnerships (STPs) into which NHS England is geographically divided.

For health economic analysis, direct imaging costs were calculated using the NHS National Schedule of Reference Costs for each of the study years. This is compiled annually as reference for all NHS service providers and is based on the average unit cost of providing a service. As myocardial stress perfusion positron emission tomography is not nationally reimbursed, the cost of an oncological positron emission tomography scan was used. Costs were also calculated using those listed in the NICE guidelines adjusted for the Consumer Price Index (Supplementary Table 3). Clinic use and follow-up data were not available, so downstream costs related to these could not be calculated. This is in line with the NICE guidelines which looked at costs to diagnose rather than total healthcare system costs.

Statistical analysis

Continuous variables are reported as mean [95% confidence interval (CI)], and ordinal or nominal variables as number (percentage). Imaging usage and outcomes are reported on per hundred thousand population basis to account for inter-regional population differences and population growth over the study period. Population estimates for each year from 2012-2018 from the Office of National Statistics were used for this purpose (9).

To examine the impact of the NICE guidelines, an interrupted time-series analysis was performed (10). This was conducted at a national level considering all scans performed for coronary artery disease across the whole country. Monthly data were used to provide a greater number of time points allowing for a more robust interrupted time-series analysis. The 2016 update of the NICE CG95 guidelines document was released on 30 November 2016. For the purposes of our analysis, imaging performed from 1 January 2017 onwards was considered "post CG95" and imaging prior to this date was "pre CG95". Modelling assumed both an immediate step-change in CCTA usage and a change in the rate of growth following the introduction of the guidelines based on work of Asher and colleagues (11). Scans per capita per month were log-transformed to stabilize the variance across the time-series. Autocorrelation function analysis suggested non-stationary data with significant co-linearity at yearly intervals even after adjusting for seasonality. As a result, an Auto Regressive Integrated Moving Average (ARIMA) model was used. Analysis was performed using the *forecast* package (v8.14) in R (12). An automatic approach was used for model selection, with additional manual modeling based on autocorrelation function plots and Seasonal and Trend decomposition (12). The models with the lowest Akaike information criteria were chosen for the final model. Examination of the residual plots, autocorrelation function, partial autocorrelation function and testing with the Ljung-Box test confirmed no residual auto-correlation in these models. After selection of the best ARIMA model, a counterfactual ARIMA model was produced using the same model, but only the data from 2012 to 2016, a forecast was then generated for the 2017 and 2018 period to demonstrate the predicted growth in the absence of the intervention (CG95).

To assess the impact of changes in modality growth on healthcare outcomes, a quasi-experimental approach was applied using the natural differences in the growth of the use of coronary CTA across the 42 STPs. For this analysis, annual data for each of the regions were used to increase the event numbers per region. Regression models were used to examine the rates of changes in imaging usage, hospital admissions, and mortality per 100,000 population between 2012 and 2018 for each of the healthcare regions (STPs). Due to significant heteroscedasticity in the regression models with multiple outliers, the Siegel adaptation of Thiel Sen regression analysis was used in the *mblm* package (version 0.12.1) in R (13). The Theil Sen regression is robust to such effects, with the Siegel adaption allowing for 70% of data points to be outliers and still produce robust estimates. The relationship between regression estimates for each STP were examined using a Kendall rank correlation model, comparing the imaging growth regression coefficients and the corresponding hospital admissions and mortality regression coefficients.

All statistical analysis and plots were performed using R (version 3.6.3) within RStudio (Version 1.3.1093, RStudio, PBC). Two-sided p value of <0.05 was considered statistically significant.

RESULTS

Over the 8-year study period, records of 3,480,744 cardiac examinations were submitted to the Diagnostic Imaging Data Set. A clear and consistent growth in the usage of cardiac imaging was present during the study period, with 764 examinations per 100,000 of the population performed in 2012, increasing to 1129 examinations per 100,000 of the population in 2018. This represents an annualized growth rate in imaging usage of 6.6%. Of the submissions to the Diagnostic Imaging Data Set, 354,635 scans could not be attributed to an STP, and 44,467 had no patient identifier so could not be followed up and were excluded. Of the remaining 3,183,786 imaging investigations, 1,909,314 (60.0%) were for the investigation of coronary artery disease (Central Figure), with an annualized per capita growth rate of 4.8%.

Coronary artery disease imaging

Throughout the study period, invasive coronary angiography was the commonest modality performed, with an average of 214.5 angiograms/100,000 population/year, at an annual growth of 5.3 [95% CI 2.0 to 7.6] angiograms/100,000 population, or 2.5% (Table 1, Central Figure). Single-photon emission computed tomography was the second most frequent modality performed, with a fall in usage over the study period, at an average of 151.7 examinations/100,000 population/year, an annual decline of -4.9 [95% CI -7.1 to -2.5] scans/100,000 population, or -3.2%. CCTA was the third commonest, with the highest growth rate, at an average of 84.6 CTA/100,000 population/year, an annual growth of 15.7 [95% CI 14.9 to 17.1] CTA/100,000 population, or 18.5%.

Impact of NICE CG95 on imaging investigations

Prior to CG95, the use of invasive coronary angiography was rising, with an increase of 0.02 [95% CI 0.00 to 0.04] angiograms/100,000 population/month (Table 2, Figure 1). After CG95, this growth ceased and appeared to fall with -0.06 [95% CI -0.13 to 0.01] angiograms/100,000 population/month. There was no step change in invasive coronary angiography usage following the introduction of the guidelines (exp(β) 1.01 [95% CI 0.96 to 1.06], p=0.84) but there was an apparent decrease in the slope following CG95, although this failed to reach statistical significance (exp(β) 0.997 [95% CI 0.993 to 1.00], p=0.06). Single-photon emission computed tomography showed a fall in usage both before and after CG95, with no apparent step change or change in slope. CCTA usage was increasing prior to CG95 (0.09 [95% CI 0.08 to 0.10] angiograms/100,000 population/month), but growth in activity became more rapid after CG95 (0.19 [95% CI 0.14 to 0.24] angiograms/100,000 population/month). Over the study period there was an upward drift in the utilization of CCTA (drift exp(β) 1.015 [95% CI 1.001 to 1.03], p=0.03) as well as an estimated step change in CCTA usage following CG95 (exp(β) 1.099 [95% CI 1.03 to 1.18], p=0.006), but there was no change in slope (exp(β) 1.00 [95% CI 0.99 to 1.02], p=0.89) beyond the background growth rate. Cardiac magnetic resonance imaging showed sustained growth irrespective of CG95 (drift exp(β) 1.013 [95% CI 1.007 to 1.019], p<0.001), with no step change or change in slope following CG95. Overall, CG95 resulted in a step change in the total number of all investigations performed (exp(β) 1.04 [95% CI 1.003 to 1.08], p=0.03), but no change in slope (exp(β) 1.00 [95% CI 0.99 to 1.01], p=0.5; Table 2). Full ARIMA model details, testing and outputs are contained within the Supplemental Material.

Impact of CCTA on other imaging modalities.

Annual growth in imaging modalities was compared between healthcare regions. There was an apparent inverse association between CTA growth and ICA growth across regions but this was not statistically significant (Kendall Tau -0.19, p=0.08). There was no association between a region's CTA growth and SPECT growth (Kendall Tau = 0.01, p=0.92). There was no association between the fall in use of SPECT and the increasing use of MRI (Kendall Tau 0.10, p=0.35).

Clinical Outcomes

Over the study period, hospital admissions for cardiovascular causes within 12 months of a cardiac test rose by 12.3 [95% CI 10.3 to 14.4] admissions/100,000 population/year ($p<0.0001$), while admissions for myocardial infarction rose by 0.55 [95% CI 0.27 to 1.41] admissions/100,000 population/year ($p<0.0001$). In contrast, cardiovascular deaths within 12 months of an imaging investigation fell by -2.95 [95% CI -3.11 to -2.72] deaths/100,000 population/year ($p<0.0001$), and coronary artery disease deaths fell by -1.66 [95% CI -1.79 to -1.51] deaths/100,000 population/year ($p<0.0001$).

There was no association between a regions rate of growth of CCTA, and change in hospital admissions (Figure 2, Supplemental Table 5). There was a positive association between regional growth in SPECT and growth in hospital admissions for circulatory (Kendall Tau = 0.25, p=0.022), cardiovascular (Kendall Tau = 0.25, p=0.021), and non-fatal myocardial infarction (Kendall Tau = 0.22, p=0.038) (Supplemental Table 6). No relationship was present between a region's growth of cardiac MRI and growth in hospital admissions ($p>0.4$ for all, Supplementary Table 7).
CCTA growth was associated with a reduction in cardiovascular deaths (Kendall Tau = -0.21, p=0.045), ischemic heart disease deaths (Kendall Tau = -0.22, p=0.042), and an apparent trend in all-cause mortality which did not reach significance (Kendall Tau = -0.19, p=0.07) (Figure 3, Supplemental Table 8).

The opposite pattern was seen for single-photon emission computed tomography with a positive correlation between regional growth in SPECT and circulatory deaths (Kendall Tau = 0.23, p=0.029), cardiovascular deaths (Kendall Tau = 0.22, p=0.043), and all-cause mortality (Kendall Tau = 0.30, p=0.006), (Figure 3 and Supplemental Table 9).

There was no relationship between cardiac MRI growth and change in cardiovascular or all-cause mortality ($p>0.6$ for all, Supplementary Table 10).

Health economics

The average annual healthcare spending for coronary imaging was £214 million and this remained largely stable across the study period (Table 3). On a per 100,000 population level, spending was £0.35 million/100,000 population/year with an average change of -1.6% per year. These changes were largely driven by a reduction in the tariff for invasive coronary angiography between 2012 and 2013 (Supplementary Table 3). When only 2013 to 2018 were examined, the average costs were £0.34 million/100,000 population/year with an average increase of 1.6% per year. Using the modality costs used in the NICE cost analysis, adjusted for the consumer price index, the average cost was £0.34 million/100,000 population/year with an average change of 4.6% per year (Supplementary Table 4). These values reflect the rate of inflation over this timeframe which was an average of 2.5% per year over the study period based on the consumer price index.

DISCUSSION

The current study reveals several major novel and impactful findings. First, there is a sustained and consistent increase in use of imaging investigations for the diagnosis and management of coronary artery disease, with substantial shifts in the use of specific individual imaging modalities. In particular, there was an increased use of CCTA, with modest reductions in invasive coronary angiography. Importantly, regions with the greatest growth in the usage of CCTA were also those that saw the greatest decline in cardiovascular mortality, with a trend toward a greater fall in all-cause mortality. These changing imaging trends were associated with a rise in costs, but only in line with inflation.

The increase in total imaging procedures performed is consistent with countrywide trends in all diagnostic imaging usage. The 3.7% annual growth in cardiac imaging is conservative when compared to other clinical areas. A recent UK report over the same time period demonstrated an almost 10% per year growth in total cross-sectional imaging covering all body areas (14). These trends likely reflect an increasing reliance on imaging to both rule in and rule out disease irrespective of body area or disease process (15). The increased use of imaging for the investigation and management of coronary artery disease is also a downstream consequence of the original 2010

NICE CG95 guideline which removed its recommendation for the use of exercise electrocardiogram, based on its poor sensitivity and specificity for significant coronary artery disease (4, 16). Thus, it was inevitable that a steady increase in imaging would follow even if all other factors were to remain unchanged. These findings will be further accentuated by the combined effects of an aging population with an increasing burden of co-morbidities (9).

Despite the 4.8% increase in imaging usage, we only observed a 1.6% per annum rise in the per capita costs of providing this imaging which is in line with the level of inflation across the study period (2.5%). This is consistent with an increased demand of imaging services being offset by a transition from the more expensive modalities (invasive coronary angiography and single-photon emission computed tomography) to a cheaper option (CCTA). This confirms the underpinning rationale of the 2016 NICE CG95 which sought to provide the most accurate diagnosis of coronary artery disease at the lowest healthcare cost (17). Such cost-effective approaches are essential if we are to continue providing effective healthcare in the face of a growing need and growing demand. Health regions with the greatest growth in CCTA provision showed a trend towards a greater fall in ICA use, with no difference in the rate of decline for SPECT. This is contrary to population studies and trials in the United States where CCTA has been associated with increased invasive and non-invasive downstream testing (18, 19). Such differences likely reflect systematic differences in physician practices between the United Kingdom and the United States. Further work is required to ensure optimal management after CCTA and the appropriate selection of downstream testing, to ensure that those who require it, are not deprived of it, and equally that those who are unlikely to benefit, are not subjected to it (20).

Over the study period we observed increasing rates of hospital admissions and falling rates of cardiovascular mortality. These observations within this subset of the population (patients undergoing cardiac imaging) are representative of the wider population where the same trends have been reported nationally (21). Our study showed significant heterogeneity across regions in relation to both changes in cardiovascular admissions and mortality. Regions with the highest growth of

CCTA saw the greatest decline in cardiovascular and ischemic heart disease mortality. Our observational data cannot of course establish causality, and the association may be confounded by shifts in health system and population factors which were unaccounted for. For example, greater adherence to guidelines could also indicate a greater adherence to other guidelines and implementation of cardiovascular disease prevention. Future studies which collect prescription data and downstream intervention will be of great benefit to understand these relationships. The direction and magnitude of the changes in our study are congruent with the expected changes from the use of CCTA in the investigation of stable chest pain (22, 23). A study performed in the Danish registry of 86,705 patients also established a reduction in rates of myocardial infarction in those investigated with coronary CTA compared with functional testing (24). However, such associations are likely to be confounded by indication, because CCTA may have been selectively applied in patients at lower risk of myocardial infarction, and SPECT in those with highest risk. One could argue that regions with greatest increase in imaging may also have had better provision of overall healthcare delivery and thereby better outcomes. However, across the study period, we did not observe this trend in cardiac MRI with no changes in mortality with increasing growth, suggesting this effect is specific to CCTA.

Limitations

There are several limitations of our study. The data available for analysis were prospectively collected from Radiological Information Systems across England. While central provision of RIS data to NHSX is compulsory, if there are additional local departmental information systems not linked to the central RIS, data on these may be overlooked in this process. The clinical indication for the scan is unknown and both initial diagnostic and subsequent follow-up scans will be included within the dataset. Current international guidelines continue to recommend functional and invasive testing for chest pain in those with established coronary artery disease (1, 2, 7), thus there may be persistent issues of confounding by indication when comparing CCTA with other imaging modalities. We also do not have data on patient comorbidities, or treatment differences which could provide the potential mechanisms for these beneficial associations. However, based on prior data, we would anticipate greater use of preventative therapies in those undergoing CCTA (23, 25). Finally, we have only examined the early impact of CG95 in the first two years since its implementation. Further long-term follow-up would be desirable, but the impact of the COVID-19 pandemic will have a major effect on all imaging use and clinical outcomes, and this may take many years before a true reflection of this change can be established.

CONCLUSIONS

There is a sustained and consistent increase in the usage of imaging for the diagnosis and management of coronary artery disease with the greatest growth seen in CCTA. Albeit our findings were derived from medical utilization and outcome statistics, greater use of CCTA was associated with a decline in cardiovascular mortality. Despite this significant increase in imaging, healthcare cost increases remained in line with inflation.

CLINICAL PERSPECTIVES:

COMPETENCY IN MEDICAL KNOWLEDGE: Cardiac imaging is being increasingly used in the work-up of coronary artery disease. Growth in use of imaging is greatest for CCTA and MRI, with falling use of SPECT. Due to the low cost of CT, this growing use of imaging has had only a small impact on cost of provision of diagnostic imaging in this population.

TRANSLATIONAL OUTLOOK: Healthcare regions with the greatest growth in the usage of CCTA demonstrated the greatest decline in cardiovascular disease deaths. Our findings suggest that coronary CTA may improve clinical outcomes, at little additional cost, with this requiring prospective validation.

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Figure 1: Month by month imaging data usage at a country level for the investigation of coronary artery disease from 2012 to 2018, with an Auto Regressive Integrated Moving Average (ARIMA) analysis of projected growth had trends remained stable versus the actual growth observed.

In all images the broken vertical grey line represents the update of the national chest pain guidelines CG95. The four images show the modality specific (log transferred) monthly scans performed per capita. The solid coloured lines and dots showing observed scans. The solid grey lines and dots represent the growth that would have been expected in the four modalities had the chest pain guidelines not been released based on forecast modelling from the preceding 5 years of data. In CCTA there is a clear divergence of the expected growth (solid grey) with the actual growth post CG95, consistent with an accelerated usage in the wake of CG95. In ICA, MRI and SPECT the solid coloured lines show a close match with expected growth trends consistent with no significant impact of NICE on the use of these imaging modalities.

CG95 = NICE clinical care guideline 95; CCTA = Coronary Computed Tomographic Angiography; ICA = Invasive Catheter Angiography; MRI = Magnetic Resonance Imaging; SPECT = Single Positron Emission Computed Tomography, STP = Sustainability and Transformation Partnerships.

Figure 2: Comparison of changes in mortality from cardiovascular causes with changes in Coronary computed tomography angiography use.

The x-axis represents the Thiel Sen regression co-efficient of the change in mortality per 100,000 population within 12 months of an imaging investigation within each of the STPs from 2012 to 2018. The y-axis represents the Thiel Sen regression co-efficient of the change in use of CCTA within each of the STPs from 2012 to 2018. The Kendall Tau rank correlation then compares the rank difference of each of these changes across each of the 42 STPs, showing a consistent trend across outcomes with mortality falling faster in regions with faster growth in CCTA performance.

CCTA = Coronary Computed Tomographic Angiography; STP = Sustainability and Transformation Partnerships.

Figure 3: Map of the healthcare regions in England demonstrating the regional changes in usage of CCTA and SPECT and the regional changes in cardiovascular mortality from 2012 to 2018.

CCTA = Coronary Computed Tomographic Angiography; STP = Sustainability and Transformation Partnerships.

Central Figure: England-wide examinations performed per month per 100,000 population for the investigation of coronary artery disease from 2012 to 2018. The broken vertical grey line represents the update of the national chest pain guidelines CG95. The top right shows the histogram of the change in cardiovascular mortality across the same time period in the healthcare regions. The bottom right shows the relationship between the change in coronary computed tomography angiography and cardiovascular mortality.

In the left plot a clear nationwide temporal trend of falling monthly performance of SPECT is seen with a growith in CTA, MRI, and SE, with stable ICA usage. In the top right we see the range of variation in temporal improvements in mortality across the 42 STPs, ranging from stable mortality across the study period in 17%, to a fall of 7.5 cardiovascular deaths per 100,000 population per year in 2.3%. In the bottom right the x-axis represents the Thiel Sen regression co-efficient of the change in mortality per 100,000 population within 12 months of an imaging investigation within each of the STPs from 2012 to 2018. The y-axis represents the Thiel Sen regression co-efficient of the change in use of CTA within each of the STPs from 2012 to 2018. The Kendall Tau rank correlation then compares the rank difference of each of these changes across each of the 42 STPs, showing a clear trend (Kendall Tau -0.21, p=0.045) between regions with faster growth in CTA performance and greater falls in cardiovascular mortality.

CCTA = Coronary Computed Tomographic Angiography; ICA = Invasive Catheter Angiography; MRI = Cardiac Magnetic Resonance Imaging; PET = Positron Emission Tomography; SE = Stress Echocardiography; SPECT = Single Positron Emission Computed Tomography; STP = Sustainability and Transformation Partnerships.

TABLES

Table 1: Annual imaging for coronary artery disease across healthcare regions in England from 2012 to 2018.

	2012	2013	2014	2015	2016	2017	2018
Invasive Coronary Angiography	203.32 (164.5 to 242.1)	203.51 (161.9 to 245.1)	208.90 (165.7 to 252.1)	214.19 (171.3 to 257.1)	224.36 (181.7 to 267.1)	225.29 (183.2 to 267.4)	221.95 (179.1 to 264.8)
Single-photon Emission Computed Tomography	174.75 (141.6 to 207.9)	163.14 (132.0 to 194.3)	156.28 (126.2 to 186.4)	140.94 (114.1 to 167.8)	138.80 (111.7 to 165.9)	145.92 (118.8 to 173.1)	141.86 (114.8 to 168.9)
Positron Emission Tomography	1.54 (0.7 to 2.4)	0.93 (0.3 to 1.6)	1.25 (0.4 to 2.1)	2.29 (1.0 to 3.6)	1.19 (0.5 to 1.9)	1.23 (0.5 to 2.0)	2.80 (0.7 to 4.9)
Stress Echocardiography	2.87 (0.3 to 5.5)	1.99 (-0.3 to 4.3)	4.36 (0.4 to 8.3)	5.17 (0.5 to 9.9)	5.18 (0.9 to 9.5)	7.13 (2.5 to 11.7)	6.70 (2.6 to 10.8)

Coronary Computed Tomography Angiography	41.94 (30.8 to 53.1)	51.44 (39.8 to 63.1)	63.04 (50.3 to 75.8)	70.36 (57.8 to 82.9)	87.21 (72.2 to 102.2)	126.04 (107.6 to 144.5)	152.43 (131.6 to 173.2)
Magnetic Resonance Imaging	31.59 (22.6 to 40.6)	33.92 (23.7 to 44.1)	40.29 (28.7 to 51.9)	47.16 (36.1 to 58.2)	53.32 (42.0 to 64.6)	60.94 (48.6 to 73.2)	65.61 (52.2 to 79.0)
Total	453.6 (395.8 to 511.5)	454.0 (391.9 to 516.1)	472.7 (413.1 to 532.3)	477.1 (419.9 to 534.3)	508.8 (451.1 to 566.6)	565.1 (507.0 to 623.1)	589.0 (529.2 to 648.7)

Data are provided as mean (95% CI) usage at a regional sustainability and transformation partnership healthcare level. Numbers are per 100,000 population.

Table 2: Change in utilization of imaging for coronary artery disease in England from 2012 to 2018 comparing before and after the update of the national chest pain guidelines.

Modality	Monthly growth		Before versus after CG95			
	Before CG95*	After CG95*	Step change+	P-value	Ramp change+	P-value
Invasive Coronary Angiography	0.02 (0.00 to 0.04)	-0.06 (-0.13 to 0.01)	1.01 (0.96 to 1.06)	0.84	0.997 (0.993 to 1.00)	0.06
Single-photon Emission Computed Tomography	-0.08 (-0.10 to -0.06)	-0.07 (-0.14 to 0.00)	1.02 (0.95 to 1.10)	0.56	1.00 (0.98 to 1.01)	0.48
Coronary Computed Tomography Angiography	0.09 (0.08 to 0.10)	0.19 (0.14 to 0.24)	1.10 (1.03 to 1.18)	0.006	1.00 (0.99 to 1.02)	0.89
Magnetic Resonance Imaging	0.04 (0.04 to 0.05)	0.03 (0.01 to 0.06)	0.98 (0.90 to 1.06)	0.54	0.99 (0.99 to 1.001)	0.08
Total	0.08 (0.04 to 0.12)	0.09 (-0.11 to 0.29)	1.04 (1.003 to 1.08)	0.033	1.00 (0.99 to 1.01)	0.50

* Descriptive values for trends are the linear regression estimates of the change in number of studies per 100,000 population per month.

+ Values are exp(β) (95% CI) from the ARIMA model.

Table 3: Cost of provision (£ million) of imaging for the investigation for chest pain at a national and regional (STP) level.

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Total cost (England, £million)	258.5	200.8	207.1	195.5	202.9	206.9	195.5
Mean Cost **(STP level, £million)**	5.74 (4.24 to 7.24)	4.46 (3.19 to 5.73)	4.60 (3.37 to 5.83)	4.34 (3.30 to 5.39)	4.51 (3.60 to 5.41)	4.60 (3.84 to 5.35)	4.34 (3.67 to 5.02)
Mean Cost per 100,000 population **(STP level, £million)**	0.43 (0.37 to 0.50)	0.32 (0.27 to 0.38)	0.34 (0.28 to 0.39)	0.32 (0.27 to 0.37)	0.34 (0.29 to 0.39)	0.36 (0.31 to 0.41)	0.34 (0.29 to 0.39)

Data is provided as mean (95% CI). Costs calculated using the annual NHS reference costs (detailed in supplemental table 3). For CG95 costings with CPI adjustment see supplemental Table 4.

STP = Sustainability and transformation partnership