

openheart Research priorities in cardiovascular imaging

Guo Liang Yong ¹, Jonathan Weir-McCall ², Michael Wilson,³ Giles H Roditi,⁴ Russell Bull,⁵ Michelle Claire Williams,⁶ Matthias Schmitt⁷

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¹Clinical Radiology, Edinburgh Royal Infirmary, Edinburgh, UK

²University of Cambridge School of Clinical Medicine, UK, Cambridge, UK

³General Surgery, Forth Valley Royal Hospital, Larbert, UK

⁴Radiology, NHS Greater Glasgow and Clyde, Glasgow, UK

⁵Clinical Radiology Royal Bournemouth Hospital, Bournemouth, UK

⁶Centre for Cardiovascular Sciences, University of Edinburgh, Edinburgh, UK

⁷North West Heart Centre, Manchester University NHS Foundation Trust, Manchester, UK

Correspondence to

Dr Guo Liang Yong; d.yong@nhs.net

ABSTRACT

Aim A modified Delphi approach was used to develop consensus opinion among British Society for Cardiac Imaging/British Society of Cardiac CT (BSCI/BSCCT) members in order to prioritise research questions in cardiovascular imaging.

Methods All members of the BSCI/BSCCT were invited to submit research questions that they considered to be of the highest clinical and/or academic priority in the field of cardiovascular imaging (phase 1). Subsequently a steering committee removed duplicate questions and combined questions of a similar theme by consensus agreement where appropriate. BSCI/BSCCT members were invited to rank the resulting research questions in two further iterative rounds (phases 2 and 3) to determine a final list of high-priority research questions.

Results A total of 111 research questions were submitted in phase 1 by 30 BSCI/BSCCT members. While there was a broad range of topics, from determining the optimal features/markers of the vulnerable plaque to investigating how cardiac imaging can best be used to maximise clinical outcomes and economic costs, multimodality imaging-related (n=44, 40%) questions dominated the categories and coronary artery imaging (n=40, 36%) was the most common topic. Over two iterative rounds of prioritisation of these research questions, the original 111 were reduced to 75 questions in round 2, and 25 in round 3. From these 25 a final *Top 10 list* was distilled by consensus grouping.

Conclusion This study has identified and ranked the top research priorities in cardiovascular imaging, as identified by the BSCI/BSCCT membership. This is a first step towards identifying the cardiovascular imaging research priorities within the UK and may assist researchers and funding bodies alike in setting priorities.

INTRODUCTION

Cardiovascular imaging (CI) has significantly enhanced the diagnosis of all forms of heart disease and is now often centre stage to the patient care pathway. Following rapid technological advancement the cardiovascular (CV) physician has access to a wide armamentarium of invasive and non-invasive imaging modalities, including invasive coronary angiography, echocardiography, CT, nuclear imaging and MRI.¹ In the UK alone over 500 000 non-invasive cardiac imaging examinations are performed every year, with an annual growth

Key questions

What is already known about this subject?

► Cardiovascular imaging has revolutionised the diagnosis and treatment of heart disease. Research resources should be deployed in areas likely to have the greatest clinical impact. A modified Delphi process can be used to develop a list of priorities by consensus from a group of experts.

What does this study add?

► Our survey aims to develop a list of high-priority clinical research questions in cardiovascular imaging using a modified Delphi approach to help focus future research.

How might this impact on clinical practice?

► This list of 10 high-priority research questions in cardiovascular imaging will facilitate funding applications and design high-quality collaborative research over the coming years.

rate of 3%.² This is due to a growing body of evidence supporting its use as outlined in multiple national appropriateness and guideline documents covering a wide spectrum of heart diseases.³ Additionally, many research studies testing novel CV medicines and interventional therapies now use CI as either primary or secondary outcomes, or as surrogate markers. However, consensus opinion on the major research priorities for CI in the UK is currently unknown.

British CV research, and specifically cardiovascular imaging research (CIR) is world leading, yet is facing multiple challenges not least the potential loss of access to significant funding sources from European research funding bodies such as the Horizon programme. It is in this context that the British Heart Foundation (BHF) has engaged with multiple stakeholders including the British Cardiovascular Society (BCS) with all its affiliated Societies (of which the British Society for Cardiac Imaging/British Society of Cardiac CT (BSCI/BSCCT) is one member) and established the BHF-Clinical Research Collaborative (CRC). The

BHF-CRC aims to act as a catalyst for CV research collaborations by providing enabling infrastructure, simplifying and democratising CV research. It was in the context of the founding meeting of the BHF-CRC that the research subcommittee of the BSCI/BSCCT decided to formulate its own research priorities.

A modified Delphi process can be used to develop a list of priorities by consensus from a group of experts, specifically its own membership. This method has been extensively used by a number of surgical specialties⁴⁻⁷ to develop research priorities and importantly is also the method used to formulate the Royal College of Radiology iREFER guidelines.⁸ To date there has been no comprehensive undertaking to determine research priorities in the subspecialty of CI. Such information will be invaluable to centres involved in CIR and funding bodies alike. Specifically, if taken up by other BHF-CRC-affiliated and/or BCS-affiliated groups it could be the first step towards creating a comprehensive picture of CV research priorities. In addition, this information will facilitate multi-centre collaboration on important research topics.

This study, organised by the BSCI/BSCCT, aims to develop a *Top 10 list* of clinically focused CV research questions that are thought to have immediate translational potential to advance CV care.

METHODS

A three-phase modified Delphi process was undertaken (figure 1) using established methodology, as previously described.^{4-7,9,10} This included the submission of research questions by members of the BSCI/BSCCT followed by two distinct rounds of prioritisation and question ranking.

Phase 1

A steering committee (GLY, JWM, MCW, MW, MS) was formed from the research subcommittee of the BSCI/BSCCT executive committee. The steering committee was composed of cardiologists, radiologists and a lay representative with previous experience of the modified Delphi process.

All BSCI/BSCCT members were invited by email to submit research questions relating to CI via an online survey form (<http://surveymonkey.co.uk>). There was no limit on the number of research questions that an individual could submit. The survey remained open for 2 months with two reminder emails sent to the BSCI/BSCCT membership during this period.

Submitted questions were collated and classified by the steering committee based on modality and area of research. Modality classification was divided into the following subcategories: (1) CT, (2) MRI, (3) nuclear medicine, and (4) multimodality. Area of research classification included the following subcategories: (1) coronary, (2) myocardium, (3) structural, (4) valvular, (5) cardio-oncology, (6) vascular, (7) congenital, (8) harm/side effects, (9) outcomes, (10) research technique, (11) technological advancement, (12) economic impact,

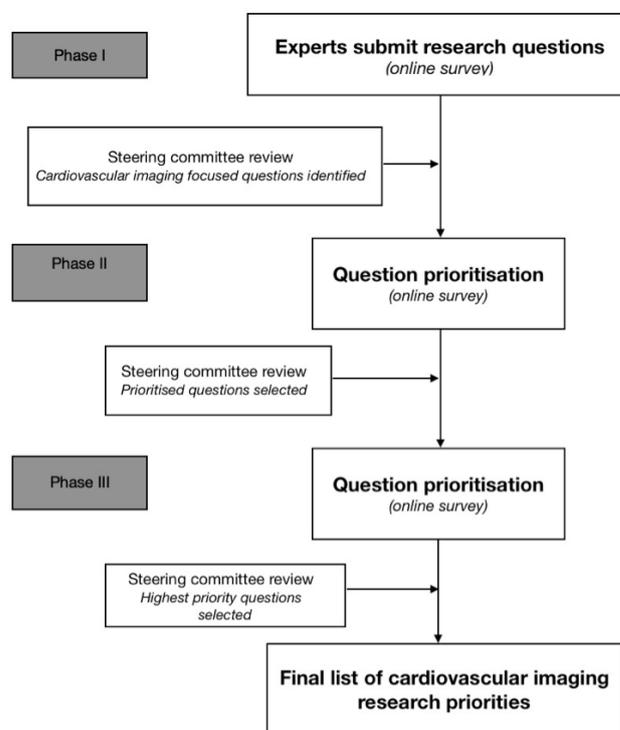


Figure 1 Modified Delphi process for cardiovascular imaging research prioritisation.

(13) artificial intelligence, and (14) other/general. Any disagreements regarding categorisation were resolved by consensus.

Duplicate questions were removed. Similar questions were combined following discussion by the steering group into a single question. Care was taken not to alter the meaning of the original questions when questions were combined or rephrased.

Phase 2

BSCI/BSCCT members were invited by email to prioritise the CIR questions identified during phase 1. Using an online survey form (<http://surveymonkey.co.uk>) research questions were presented in a random order for each respondent. Respondents were asked to score each question based on their own perception of the clinical importance using a 5-point Likert scale (1—lowest priority to 5—highest priority). The survey remained open for 2 months with two email reminders sent to all BSCI/BSCCT members.

The results of the round 2 prioritisation were reviewed by the steering committee and a ‘cut-off’ point agreed by consensus in order to identify the highest scoring 25 questions.

Phase 3

BSCI/BSCCT members were invited by email to perform a final round of prioritisation on the 25 questions identified in phase 2 using an online survey form (<http://surveymonkey.co.uk>). Research questions were provided

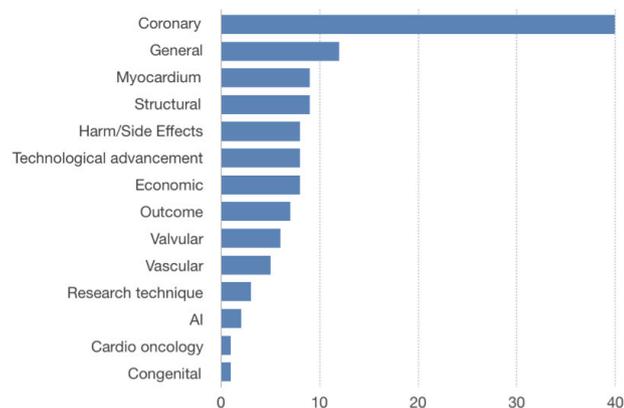


Figure 3 The range of topics referred to the submitted research questions. AI, artificial intelligence.

in a random order for each respondent. Using the same 5-point Likert scale respondents were asked to score each question on the perceived clinical importance. The survey remained open for 2 months with two reminder emails sent to all BSCI/BSCCT members. Results were reviewed by the steering committee to identify the final list of prioritised questions.

Statistical analysis

Weighted average scores were generated by SurveyMonkey for each question when each phase of the survey was closed. These weights were downloaded from the SurveyMonkey website in a Microsoft Excel spreadsheet format. The weighted averages were used to prioritise the research questions during each of the phases of the survey, with questions with the highest weighted average having the highest priority.

RESULTS

One hundred and eleven research questions were submitted by 30 BSCI/BSCCT members in phase 1, representing participation of ~7% of the BSCI/BSCCT membership. Research questions regarding multimodality imaging were the most frequent (n=44, 40%), followed by those regarding CT (n=33, 30%, [figure 2](#)). The most frequent research topic in the submitted questions was coronary artery disease (n=40, 36%, [figure 3](#)).

The submitted questions were reviewed by the steering committee and duplicate or similar questions were combined or amended, leaving 75 questions available for prioritisation in phase 2. Thirty-eight BSCI/BSCCT members (9%) participated in the phase 2 research question prioritisation. The mean weighted average question score was 3.19, with a range from 2.56 to 3.84. The complete question list in the order of priority is shown in online supplemental appendix 1.

A cut-off value for the weighted average was set as 3.31 in order to identify the top 25 research questions for prioritisation in phase 3. Forty BSCI/BSCCT members (10%) participated in phase 3 research question prioritisation.

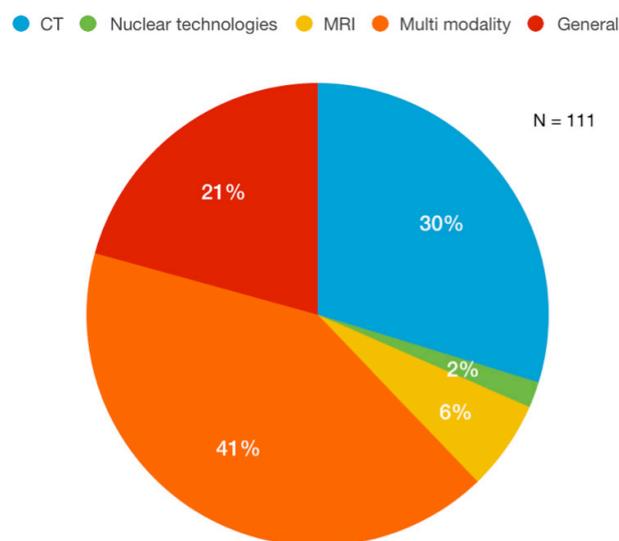


Figure 2 Imaging modalities referred to the submitted research questions.

The mean weighted average question score was 3.54, with a range from 3.13 to 3.93. The top 25 research questions ordered by priority are shown in [table 1](#).

A cut-off value for the weighted average was set as 3.60 in order to identify the final top 10 research questions in CI. Of these 10 questions, 6 (60%) related to stable coronary artery disease, 2 (20%) to acute coronary syndrome, 1 (10%) to arrhythmias and 1 (10%) to a wider question on the incorporation of multimodality imaging into clinical practice ([table 2](#)).

DISCUSSION

This study has produced and ranked high-priority research questions related to non-invasive CVI as defined by the BSCI/BSCCT expert membership. To our knowledge, this is the first time that such a project has been undertaken in the field of CI. It is hoped and anticipated that this undertaking will stimulate CV research collaboration within (but also beyond) the BSCI/BSCCT and inform researchers and research funding bodies alike.

The top 10 priority list has a strong emphasis on coronary artery disease (priorities 1, 2, 5, 6, 7, 8, 10). This was a consistent theme from the submitted questions in phase 1 through to the final prioritisation. This is unsurprising as the investigation of stable coronary artery disease and its acute presentation represents a significant clinical workload for both cardiologists and radiologists involved in CI in the UK.¹¹ The Top 10 list also includes questions regarding optimising of imaging protocols, choice of imaging strategies, improving patient outcomes and assessing economic impact (priorities 2, 5, 6, 8, 10).

It needs to be emphasised that participants were asked to rank questions in order of their clinical priority. The study therefore concentrated on translational research spectrum as opposed to the preclinical/bench spectrum.

Table 1 Top 25 BSCI/BSCCT research priorities in descending order

Priority	Research question
1	Is there a combination of stenosis/CTFFR/plaque features that identify a situation where the benefit of a stent outweighs its risks?
2	How can we best target cardiac imaging to optimise its yield in terms of outcomes and economic costs?
3	Is there a mortality/morbidity reduction through the wider use of CTCA?
4	What is the optimum imaging/investigative strategy in acute coronary syndromes?
5	What are the outcomes of CTCA use in low-risk ACS patients?
6	How can we limit increases in downstream costs and healthcare utilisation after CTCA?
7	What are the optimal features/markers of the vulnerable plaque?
8	What is the role of CTFFR in clinical practice?
9	Can we identify and characterise biomarkers of sudden cardiac death/arrhythmias in order to develop better risk stratification tools?
10	What is the economic impact of CTFFR in routine practice?
11	Can we standardise advanced MRI techniques (eg, late gadolinium enhancement quantification, mapping)?
12	How do different cardiac imaging strategies affect downstream testing?
13	How useful are TAVI (Transcatheter Aortic Valve Implantation) CTs in management decisions when many people who are worked up don't end up getting TAVI, is there a more cost-effective strategy to predict who needs TAVI CT?
14	Can cardiovascular imaging be used to predict/improve outcomes in cardiomyopathy imaging?
15	How can we reduce the impact of calcification on CTCA diagnostic accuracy, in a radiation and time-efficient manner?
16	Can we use artificial intelligence to enable decision support tools for the use of cardiovascular imaging?
17	What is the optimum follow-up interval for imaging of cardiovascular disease (eg, aneurysms, dissection)?
18	Can CTCA replace functional imaging for stable angina?
19	Can we develop methods to improve accuracy in CTCA assessment of in-stent disease?
20	What is the role of artificial intelligence in cardiovascular disease?
21	Is there a role for early use of cardiac CT in confirmed/high-risk ACS?
22	What are the barriers to the implementation of evidence-based imaging strategies in cardiovascular imaging?
23	Which patients do not need or derive no benefit from cardiovascular imaging?
24	Do any advanced imaging modalities improve outcome in dilated cardiomyopathy?
25	Has the change of the NICE guidance resulted in more inappropriate CTCA referrals?

BSCI/BSCCT, British Society for Cardiac Imaging/British Society of Cardiac CT; NICE, National Institute for Health and Care Excellence.

This is relevant and justified in so far as the BSCI/BSCCT membership is mainly composed of clinically active practitioners and several other BCS-affiliated groups exist (British Society for Cardiovascular Research, British Atherosclerosis Society, Society for Cardiological Science and Technology, to name just a few) dedicated to preclinical and/or bench side science.

Indeed, the BSCI/BSCCT membership is a diverse group of clinically focused radiologists and cardiologists from throughout the UK and Ireland. The BSCI/BSCCT is the specialist interest group for CI of the Royal College of Radiologists and is also a member of the Imaging Council of the BCS. Although the membership does include many practitioners who use multiple modalities it has a particular focus on CT as there are other UK imaging societies specifically dedicated to CV MRI and cardiac nuclear imaging—that is, the British Society of Cardiovascular Magnetic Resonance and British Nuclear Cardiology Society, respectively. Therefore, by definition this exercise has produced a focused and unquestionably biased result which was inherent to the study design.

As mentioned above it is hoped this study is the first piece of the wider puzzle. Furthermore, in addition to other affiliated groups and clinical stakeholders, future efforts should include members of the public given the increasing emphasis on patient and public involvement to determine where future CV research should be focused.¹²

A further limitation of the study is that only approximately 10%–15% of the BSCI/BSCCT membership participated in the various iterations of the study. Similar studies using the modified Delphi methodology have demonstrated a similar response rate.⁶ Therefore, although low, this is probably a fair reflection of the engagement such an exercise can deliver. Lastly, this study was conducted in the pre-COVID-19 era and it is acknowledged that research prioritise since they have significantly shifted to address the not inconsiderable acute and long-term CV aspects of this global pandemic.

This study has identified and ranked the top research priorities in the field of CI as defined by the BSCI/BSCCT membership in the pre-COVID-19 era. The emerging theme has a strong emphasis on coronary artery disease

Table 2 Top 10 BSCI/BSCCT research priorities in descending order

Priority	Research question
1	Is there a combination of stenosis/CTFFR/plaque features that identify a situation where the benefit of a stent outweighs its risks?
2	How can we best target cardiac imaging to optimise its yield in terms of outcomes and economic costs?
3	Is there a mortality/morbidity reduction through the wider use of CTCA?
4	What is the optimum imaging/investigative strategy in acute coronary syndromes?
5	What are the outcomes of CTCA use in low-risk ACS patients?
6	How can we limit increases in downstream costs and healthcare utilisation after CTCA?
7	What are the optimal features/markers of the vulnerable plaque?
8	What is the role of CTFFR in clinical practice?
9	Can we identify and characterise biomarkers of sudden cardiac death/arrhythmias in order to develop better risk stratification tools?
10	What is the economic impact of CTFFR in routine practice?

ACS, acute coronary syndrome; BSCI/BSCCT, British Society for Cardiac Imaging/British Society of Cardiac CT; CTCA, computed tomography coronary angiogram; CTCFFR, computed tomography fractional flow reserve.

research and identification of the vulnerable patient (and plaque). It is hoped that this although biased (through the lens of the BSCI/BSCCT membership) piece of work will stimulate sister societies and other BHF-CRC and BCS-affiliated groups to undertake similar if not identical exercises so that the funding researchers, funding and government bodies gain a comprehensive picture of the UK CV research priorities and needs.

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Wilson, Subramanya Upadhyaya, Sue Thomas, Sunil Nair, Thomas Semple, Victor Voon.

Contributors GLY, JWM, MCW, MW and MS formed the steering group, ran the study and analysed the results. GLY wrote the manuscript, which was revised and edited by JWM, MCW, MW, MS, GHR and RB. All authors provided advice, intellectual input and approved the final manuscript. MS provided a supervisory role, reviewed and finalised the manuscript.

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ORCID iDs

Guo Liang Yong <http://orcid.org/0000-0002-4080-3559>

Jonathan Weir-McCall <http://orcid.org/0000-0001-5842-842X>

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Supplementary information

Supplementary Appendix: The 75 research questions in Phase 2 in no particular order.

<i>Priority</i>	<i>Research Question</i>
1	<i>Can imaging identify those who benefit from PCI over optimal medical treatment?</i>
2	<i>Is there a mortality/morbidity reduction through the wider use of CTCA?</i>
3	<i>Can CTCA replace functional imaging for stable angina?</i>
4	<i>How can the reliability of CTCA in heavily calcified vessels be improved?</i>
5	<i>What is the economic impact of CTFFR in routine practice?</i>
6	<i>How can we limit increases in downstream costs and healthcare utilisation after CTCA?</i>
7	<i>Can cardiovascular imaging be used to predict/improve outcomes in cardiomyopathy imaging?</i>
8	<i>What are the optimal features/markers of the vulnerable plaque?</i>
9	<i>What is the role of CTFFR in clinical practice?</i>
10	<i>Has the change of the NICE guidance resulted in more inappropriate CTCA referrals?</i>
11	<i>How can we limit increases in downstream costs and healthcare utilisation after CTCA?</i>
12	<i>How can we reduce the impact of calcification on CTCA diagnostic accuracy, in a radiation and time efficient manner?</i>

13	<i>Can we use artificial intelligence to enable decision support tools for the use of cardiovascular imaging?</i>
14	<i>Which patients do not need or derive no benefit from cardiovascular imaging?</i>
15	<i>Is there a combination of stenosis/CTFFR/plaque features that identify a situation where the benefit of a stent outweighs its risks?</i>
16	<i>What is the optimum Imaging/investigative strategy in acute coronary syndromes?</i>
17	<i>Can we standardise advanced MRI techniques? (e.g. late gadolinium enhancement quantification, mapping)</i>
18	<i>What is the role of Artificial Intelligence in cardiovascular disease?</i>
19	<i>Can we develop methods to improve accuracy in CTCA assessment of in-stent disease?</i>
20	<i>What are the outcomes of CTCA use in low risk ACS patients?</i>
21	<i>How can we best target cardiac imaging to optimise its yield in terms of outcomes and economic costs?</i>
22	<i>How do different cardiac imaging strategies affect downstream testing?</i>
23	<i>Do any advanced imaging modalities improve outcome in dilated cardiomyopathy?</i>
24	<i>Is there a role for early use of cardiac CT in confirmed / high risk ACS?</i>
25	<i>How useful are TAVI CTs in management decisions when many people who are worked up don't end up getting TAVI, is there a more cost-effective strategy to predict who needs TAVI CT?</i>
26	<i>What is the optimum follow-up interval for imaging of cardiovascular</i>

	<i>disease (e.g aneurysms, dissection)?</i>
27	<i>Can we derive robust T1 mapping reference values for different vendors?</i>
28	<i>Can we Identify and characterise biomarkers of sudden cardiac death/arrhythmias in order to develop better risk stratification tools?</i>
29	<i>Can Cardiac CT be used as a screening tool for high risk patients (such as in diabetes) to predict long term outcome?</i>
30	<i>How do different cardiac imaging strategies affect resource utilization?</i>
31	<i>How can we enhance the role of machine learning across the spectrum of cardiovascular imaging and facilitate its application in clinical practice?</i>
32	<i>Can we enable the molecular phenotyping of cardiomyopathy with cardiovascular imaging through the quantification of fibrosis/scar?</i>
33	<i>How can the availability/accessibility of advanced imaging be improved?</i>
34	<i>Can total plaque quantification provide better prognostic assessment than calcium scoring?</i>
35	<i>What is the impact of CT on outcome in surgical/transcatheter valve insertion?</i>
36	<i>Does CTCA identification of non-obstructive coronary artery disease provide better stratification for the use of novel medical therapies for CAD? (PCSK9, canakinumab, SGLT2 inhibitor)</i>
37	<i>Is CACS superior/inferior/complementary to echo for the detection of severe AS and selecting for surgery/TAVR?</i>
38	<i>What is the value of baseline cross-sectional (MRI & CT) imaging for congenital heart disease?</i>
39	<i>Should CTCA or MRI be the baseline test in new onset dilated</i>

	<i>cardiomyopathy?</i>
40	<i>Is negative research in cardiovascular imaging being published in a useful way?</i>
41	<i>Does on site CTFFR facilitate improved work flow and patient outcome?</i>
42	<i>What imaging biomarkers can aid decision making in cardio-oncological patients?</i>
43	<i>Can we develop non-invasive methods for the evaluation of the haemodynamic significance of vascular disease (e.g. computational fluid dynamics) out with the coronary arteries?</i>
44	<i>What is the additional value of cardiac CT in structural heart disease compared with TOE?</i>
45	<i>Does standardized reporting improve communication of cardiac imaging findings?</i>
46	<i>What is the role of CTCA in established CAD?</i>
47	<i>Should cardiac CT be the first line test for aortic prosthetic valve dysfunction instead of TOE?</i>
48	<i>Is there a role for CTA/MRI in surgical valve replacement sizing/patient selection?</i>
49	<i>Can we identify barriers to MRI of all body systems for patients with implanted electronic cardiac devices?</i>
50	<i>How do different vendors/algorithms of FFRCT calculation compare in their impact on decision making and outcomes?</i>
51	<i>Can we examine the roles of CT and MRI in GUCH and develop more robust data for guiding intervention?</i>

52	<i>What is the optimum follow-up interval for imaging in congenital heart disease?</i>
53	<i>How can PET services be better expanded/centralized to optimally meet the needs/demands of the population?</i>
54	<i>Should advice regarding downstream investigation and management be provided in the report of cardiovascular imaging?</i>
55	<i>What are the best ways to decrease side effects/harms of current imaging modalities? (e.g. radiation exposure, contrast agents, pharmacological stressors)</i>
56	<i>What is the best way to explain cardiac imaging to patients?</i>
57	<i>Are research findings being supported by funding where new ideas are being proven or put into clinical practice?</i>
58	<i>What are contemporary radiation doses of all cardiac imaging modalities, including invasive and non-invasive imaging?</i>
59	<i>Can serial assessment of plaque be used as a surrogate marker of disease progression/treatment response?</i>
60	<i>What role does PET imaging have in the assessment of cardiovascular disease when many don't have access to it?</i>
61	<i>Can CTCA + \- MRI replace the need for ICA and biopsy in the follow-up of cardiac transplants?</i>
62	<i>Which biomarkers best aid clinical decision making for valvular heart disease?</i>
63	<i>Does onsite or remote reporting of cardiac CT impact quality/speed/access?</i>

64	<i>Comparison of image quality and radiation dose across all vendors in coronary, valve and functional imaging ?</i>
65	<i>How does exercise impact coronary plaque remodeling?</i>
66	<i>Is assessment of plaque morphology on CTCA improved using ultra high density scanners?</i>
67	<i>What is the role of functional cardiac CT imaging in clinical practice?</i>
68	<i>Can we develop accelerated 4D flow acquisitions and rapid evaluation workflows?</i>
69	<i>What is the impact of Radiomics with respect to imaging biomarkers that inform clinical decision making?</i>
70	<i>What coronary arterial/cardiovascular remodeling occur secondary to ageing?</i>
71	<i>What is the role for molecular cardiovascular imaging?</i>
72	<i>Does low dose radiation dose calcium scoring affect the results of calcium quantification?</i>
73	<i>What is the value of IPH (intraplaque haemorrhage) and other markers of risk in stratifying patients for CEA (carotid endarectomy)?</i>
74	<i>What is the role of CFD (computation fluid dynamics) in transcatheter valve planning, and can this become streamlined/standarised enough to enter clinical practice?</i>
75	<i>Can imaging identify those who benefit from PCI over optimal medical treatment?</i>