

NICE OBSERVATIONAL DATA UNIT (ODU)

Commissioning through Evaluation (CtE)
Percutaneous Closure of Patent Foramen
Ovale (PFOC) to prevent recurrent cerebral
embolic events

FINAL REPORT

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Executive summary

Around 80% of strokes in the UK are of ischaemic origin, with most being due to blockage of arteries in the brain caused by thromboembolism. In around 25% of cases, the putative source of the thromboembolism cannot be found, and these are known as cryptogenic strokes (or strokes of undetermined origin). In patients with cryptogenic stroke who are found to have a patent foramen ovale (PFO), which is present in around 25% of the general population, the stroke may be due to paradoxical embolism. The rationale for PFO closure (a percutaneous procedure which blocks the PFO) is to reduce the reoccurrence of stroke in patients with a prior event caused by presumed paradoxical embolism. Typically, this is a young, relatively healthy population.

In order to evaluate the PFO closure procedure, NHS England has set up a multi-centre observational registry using the process of Commissioning through Evaluation (CtE). The registry was designed to include patients who had had a confirmed ischaemic stroke presumed to be due to paradoxical embolism. The registry recorded a range of clinical outcomes with a maximum follow up of 2 years. The aims of the CtE registry were to provide data on the safety, efficacy and costs of PFO closure in a real-world setting, and specifically to answer 11 pragmatic questions concerning these issues. As the registry was single-armed, a parallel literature search was undertaken in order to present the registry findings in the context of published studies in other populations, and to assess whether procedural outcomes were consistent with previously reported studies. Information gained from the registry will be used to inform future commissioning.

The PFOC analysis included 940 patients of which 901 underwent device implantation. The median age of the patients was 45 years and the large majority did not experience cardiac symptoms from the PFO. Nearly all patients had a device successfully fitted (99.3% [95% CI 98.6 to 99.8%]), with a procedural success rate of 95.1% (95% CI 93.5 to 96.4%). The registry reported a major complication rate of 5.2% (95% CI 3.8 to 7.0%) following discharge, including 3.5% (95% CI 2.3 to 5.0%) of patients who experienced new onset atrial fibrillation. These results were consistent with those reported in RCTs and observational studies from the literature, and emphasise that PFO is a relatively safe procedure. The registry also reported that PFO closure may be associated with a reduction in anxiety and depression.

In the medium term, there was a neurological event rate of 3.4 (95% CI 2.1 to 5.0) per 100 person years (PY) and an ischaemic event rate of 1.3 (95% CI 0.6 to 2.5) per 100 PY over a total aggregated follow-up period of almost 700 PY. These results were similar to the control arms reported in the RCTs, but were numerically inferior to the primary efficacy outcomes reported in the intervention arms of these trials, particularly results reported from two new and one extended clinical trials published in September 2017. However, the validity of indirect comparisons with published data is problematic for several reasons: firstly because of differences in the methodology used between studies (e.g. different definitions used for outcomes); secondly because of issues with generalisability (e.g. diagnostic work up of patients in the included population); and thirdly because of issues with late data entry and quality assurance of registry results in the allotted timeframe [**described in [Addendum](#)**]. Revised data that had been manually corrected reported a lower neurological event rate of 2.2 (95% CI 1.2 to 3.6) per 100 PY, with the number of ischaemic events and deaths unchanged.

In conclusion, the CtE registry has reported data that show that PFO closure has a high technical success rate and is relatively safe in the short and long-term. In terms of clinical efficacy, although neurological and ischaemic event rates, including those from manually corrected data, appeared ostensibly higher than some published RCTs, the validity of such comparisons is questionable. It is noted that the natural history of this population of patients outside of tightly controlled experimental studies is not well described.

Clinical benefits of PFOC should be considered in the context of the procedural costs, which the EAC has calculated at £8,230 (range of £6,940 to £9,251). The literature review identified no economic evaluations which generalised to the NHS setting. Hence, a cost consequences analysis was undertaken. A *de novo* model compared lifetime costs for a cohort of 1,000 patients receiving PFOC plus medical therapy with medical therapy only. Patients entered the model aged 45 years, the median age in the registry. They flowed through the model for 45 years, to aged 90 years and could be in a stroke free state, experience a neurological event (ischaemic or haemorrhagic stroke or transient ischaemic attack), atrial fibrillation, bleeds or die. PFOC operative success and operative complications were informed by the CtE registry data to discharge. Thereafter the rates for these events were extracted from the RESPECT randomised controlled trial up to 5.9 years. Clinical events thereafter were extrapolated from 5.9 years to lifetime in the model (90 years).

Patients in the comparator arm received medical therapy consistent with that recorded in the CtE registry at baseline. Their modelled clinical event rates were taken from those of the comparator arm of the RESPECT RCT. The clinical event rates recorded in the trial were also extrapolated from 5.9 years to lifetime in the model. In the absence of published evidence to indicate that event rates diverge over time between the two arms, the EAC assumed that the event rates from 5.9 years in each arm continued for the rest of the patient's life.

The estimated cost of the PFOC procedure was calculated using resource use data from the registry and a costing template completed by participating sites. Stroke costs were taken from a cost study conducted by the Sentinel Stroke National Audit Programme. Other costs were from national databases.

From an NHS perspective, over the 45-year time horizon, the total discounted cost per patient receiving a PFOC procedure was estimated at £12,956 of which procedure-related costs were £8,233 (64%). For patients managed by medical therapy, the total discounted cost was estimated at £7,596 per patient, with stroke management accounting for £5,003 (66%) of these costs. Hence PFOC was estimated to cost an additional £5,360 per patient. Under the wider NHS and social care perspective, the discounted costs per patient were £3,733 higher for patients undergoing a PFOC procedure compared with medical therapy only.

The model predicted that over 45 years the total number of strokes per 1,000 patients (ischaemic, haemorrhagic and subsequent strokes) may reduce by about 40% from 456 when patients are managed only on medical therapy to 274 following a PFOC procedure. Associated with this reduction were 54 forecast fewer deaths in the cohort receiving the PFOC procedure.

The key uncertainties related to the clinical values used, particularly for ischaemic stroke rates and the relative benefit of PFOC as patients age in each arm.

A key limitation is that the form of analysis does not value the quality of life benefit associated with fewer strokes. Such a valuation would be essential to inform a cost utility analysis where results are expressed as an incremental cost per quality adjusted life year. However, NICE advised the EAC that this form of analysis was not requested by NHS England. With cost consequences analysis, the decision makers do not have a threshold-based decision rule to inform their decisions on cost effectiveness. Hence it is not possible for the EAC to advise from an NHS perspective, whether the additional cost to the NHS of £5,360 is cost-effective, given the forecast savings in strokes and deaths.

Abbreviations

| | |
|--------|--|
| AF | Atrial fibrillation |
| ASD | Atrial septal defect |
| CG | Clinical guideline |
| CI | Confidence interval |
| CT | Computed tomography |
| CtE | Commissioning through Evaluation |
| CVA | Cerebrovascular accident |
| DSA | Data Sharing Agreement |
| EAC | External Assessment Centre |
| ECG | Electrocardiograph |
| ESC | European Society of Cardiology |
| FU | Follow up |
| HR | Hazard ratio |
| ICE | Intracardiac echocardiogram |
| ICER | Incremental cost-effectiveness ratio |
| INR | International Normalized Ratio |
| IPG | Interventional procedures guidance |
| IQR | Inter-quartile range |
| ITT | Intention to treat |
| MDS | Minimum data standard |
| MDT | Multi-disciplinary team |
| MRI | Magnetic resonance imaging |
| LAO | Left atrial appendage occlusion |
| NHS | National Health Service |
| NICE | National Institute for Health and Care Excellence |
| NICOR | National Institute for Cardiovascular Outcomes Research |
| NYHA | New York Heart Association |
| OR | Odds ratio |
| PFO | Patent foramen ovale |
| PFOC | Patent foramen ovale closure |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| PY | Person years |
| QALY | Quality adjusted life year |
| QoL | Quality of life |
| RCT | Randomised controlled trial |
| RIND | Reversible ischaemic neurological deficit |
| RR | Relative risk |
| SD | Standard deviation |
| SE | Systemic embolism |
| TIA | Transient ischaemic attack |
| TOE | Transoesophageal echocardiogram |
| TTE | Transthoracic echocardiogram |

Section 1: Introduction

1.1 NHS ENGLAND COMMISSIONING THROUGH EVALUATION – PATENT FORAMEN OVALE CLOSURE (PFOC)

NICE provides support to NHS England in [Commissioning through Evaluation \(CtE\)](#):

“NHS England’s Commissioning through Evaluation (CtE) programme enables a limited number of patients to access treatments that are not funded by the NHS, but nonetheless show significant promise for the future, while new clinical and patient experience data are collected within a formal evaluation programme.”

The work commissioned by NICE (‘Project RX085’) from Newcastle and York (NY) EAC comprises evaluation of three percutaneous cardiac procedures:

- Percutaneous occlusion of the left atrial appendage in non-valvular atrial fibrillation for the prevention of thromboembolism ([NICE IPG349](#), June 2010). Shortened term used is ‘LAAO’.
- Percutaneous Closure of Patent Foramen Ovale to prevent recurrent cerebral embolic events ([NICE IPG472](#), December 2013). Shortened term used is ‘PFO Closure’.
- Percutaneous mitral valve leaflet repair for mitral regurgitation (MitraClip) ([NICE IPG309](#), August 2009). Shortened term used is ‘MitraClip’.

A Cardiology CtE Steering Group is established as a subgroup of the NHS England [Cardiothoracic Services Clinical Reference Group \(CRG\)](#). It reports to the [Programme of Care Board for Internal Medicine](#) for NHS England. Three Individual Technology Groups report to the CtE Steering Group on the progress of the above three specialised cardiological interventions which form the cardiac CtE programme.

The National Institute for Cardiovascular Outcomes Research (NICOR) was contracted by NY EAC to design and host an on-line registry for PFOC procedures, to provide a project management function to promote data entry quality and completeness by commissioned CtE provider sites and to link registry data with Hospital Episode Statistics (HES) and Office of National Statistics (ONS) mortality datasets. NICOR and the EAC consulted the PFOC Individual Technology Group in the design of the PFOC registry. NICOR were the formal data owner of the registry, and were the applicant to NHS Digital for data linkage with HES and ONS.

NY EAC’s objectives in Project RX085 from NICE were to:

- review existing register data fields in each dataset and advise on their suitability for updating and developing NICE guidance;
- advise on the appropriateness of register data fields for each dataset being proposed or considered in relation to clinical and cost effectiveness outcomes to enable NICE to provide NHS England with further data to help inform future commissioning decisions for the procedures;
- establish processes to a) ensure on-going review of the PFOC dataset quality, completeness and coverage, with action plans for improvements where needed and b) deliver regular evaluative reports that are useful for decision making;

- update the literature searches since publication of each NICE interventional procedures guidance (IPG) in order to identify publications of relevance;
- manage the contract with NICOR and participate in the CtE Steering Group for cardiovascular procedures;
- develop a protocol for analysis of data and consult with key partners (listed above) to gather views on the proposed methodology and proposed outputs;
- produce a final report (not intended for publication) answering the CtE evaluation questions set by NHS England (tabulated below);
- present findings in the form of a publishable paper (to be submitted for peer review for a high impact journal). This should be of a standard to be included as an input in the evidence base of the NICE technology appraisals programme (<http://www.nice.org.uk/article/PMG9/chapter/Foreword>);
- advise on further research that might be needed to generate clinical and cost effectiveness evidence in line with methods used in NICE evaluation programmes, including suitable study designs for such research.

Outputs required by NICE from NY EAC and delivered prior to this final report were:

- Output One [1] - a report for presentation to the CtE Steering Group on all three procedures, analysing the coverage, quality and completeness of the register to date, and making preliminary recommendations about the definitive dataset to inform NHS England's contracts for the procedures with the specialist centres, and to meet NICE's needs in relation to updating guidance. **Completed 28/11/2014.**
- Output Two [2] - a report for submission to the CtE Steering Group for cardiovascular procedures and collaborating partners proposing: a) a process to ensure on-going review of the database quality, completeness and coverage, with action plans for improvements where needed and b) the format of evaluative reports designed to be useful in informing decision making for guidance development. **Completed 04/02/2015.**
- Output Three [3] - a report for submission to NICE and the CtE Steering Group proposing a draft protocol for analysis of data that describes the methods that will be used to compare effectiveness of each of the procedures between propensity-matched cohorts of patients undergoing the range of treatment options (including cost analysis). This will have been circulated for consultation with key partners (listed above) and adjusted as appropriate prior to presentation to NICE. **Completed 31/03/2015.**

The above three outputs from the project, all of which were shared with the CtE Steering Group and approved by them, are used as source material for the general background and [methods](#) sections of this final report from NY EAC to NICE.

The NHS England questions for CtE of PFOC were originally presented to NICE, discussed with NY EAC, and edited to the final form presented in the [Table 1](#) below.

Table 1. Patent Foramen Ovale (PFO) Closure to Prevent Stroke

| Questions from NHS England | Final version of question, as amended by NICE following discussion with EAC |
|--|--|
| 1. Does patent foramen ovale closure offer these patients a lower risk of stroke or other embolic clinical events compared to those predicted by natural history studies? From modelling, how many strokes would likely have been avoided? | Does patent foramen ovale closure lower the risk of stroke or other embolic clinical events compared to no intervention (as predicted by natural history studies or from modelling)? |
| 2. Can UK clinical teams re-produce the success rates for patent foramen ovale closure reported in existing clinical trials, with equivalent or lower complication rates? | NICE agrees the question is appropriate |
| 3. Is patent foramen ovale closure associated with an improved quality of life for these patients? | Is patent foramen ovale closure associated with an improvement in quality of life? |
| 4. Are there any longer-term cardiac complications associated with the use of these devices (e.g. erosion with penetration through the wall of the atrium/aorta)? | N/A unless an extended time period for the project is agreed. |
| 5. Do the commercially available current devices perform equivalently? | Which devices are used to undertake PFO? What are the device-specific efficacy and safety outcomes in CtE funded patients undergoing the procedure? In particular, is there any published or register evidence of complications in the long term from percutaneous PFO closure (e.g. erosion with penetration through the wall of the atrium/myocardium/pericardium)? |
| 6. Is the frequency of complications sufficiently low to provide a positive risk-benefit ratio? | What are the short and medium term risks of percutaneous PFO closure? (If the CtE project indicated that this procedure has a more risky safety profile than appears in the current NICE interventional procedures guidance, it could potentially lead to NICE updating the guidance, in line with normal processes.) |
| 7. How many patients with a stroke believed to be due to paradoxical embolism in association with a patent foramen ovale might benefit from PFO closure? i.e. what is the likely clinical need if this procedure becomes routinely commissioned? | What proportion of patients referred to an MDT for possible percutaneous PFO closure against Commissioning through Evaluation criteria were considered suitable for the intervention? |
| 8. What are the characteristics of patients who are successfully treated compared to those in whom treatment is unsuccessful? Are there subsets of patients who get a particularly advantageous result? Conversely, are there subsets of patients for whom this treatment is not effective? Do patients of different gender or from different ethnic origins respond equivalently? | Are favourable clinical outcomes with patent foramen ovale closure associated with particular patient characteristics (clinical or demographic)? |
| 9. What is the true procedural cost of patent foramen ovale closure in the NHS? | What are the average full procedural costs of percutaneous patent foramen ovale closure to the NHS? |
| 10. What costs savings might occur in the NHS as a result of patent foramen ovale closure? | What are the potential cost savings for the NHS in patients receiving percutaneous patent foramen ovale closure? |

| Questions from NHS England | Final version of question, as amended by NICE following discussion with EAC |
|--|--|
| 11. What is the cost-effectiveness of patent foramen ovale closure based on UK procedural and follow-up costs? | What is the likely cost-effectiveness of percutaneous PFO closure in the NHS, based on UK costs? |

1.2 DESCRIPTION OF THE PROCEDURE

The PFOC procedure is described in [NICE IPG472](#):

“Percutaneous closure is performed using local anaesthesia and intravenous sedation, or with the patient under general anaesthesia. A closure device is introduced using a guide wire and delivery sheath through a small incision in the groin into the femoral vein. It is then passed into the heart and across the patent foramen ovale. The closure device is released to close the defect using image guidance such as echocardiography. Devices of differing design and mechanism are available.”

Three manufacturers’ CE marked devices that are eligible for the CtE programme were available and used in the UK. Each manufacturer had model variants in the PFOC register datasets, as stated. Each device also came in a range of sizes, to suit anatomical differences:

- the ‘AMPLATZER’ range, manufactured by St. Jude Medical (now owned by Abbott). Three variants listed in the CtE dataset were the AMPLATZER PFO Occluder, the AMPLATZER Septal Occluder and the AMPLATZER Cribriform;
- the ‘GORE CARDIOFORM Septal Occluder’, manufactured by W. L. Gore and Associates Inc. The V1.6 CtE launch version of the PFOC dataset, (December 2014) specified the ‘GORE HELEX Septal Occluder’. However, this had been discontinued by the manufacturer in 2011 and replaced by the GORE CARDIOFORM Septal Occluder. The live version of the CtE dataset was therefore updated in June 2015 and the only variant listed in the dataset was the GORE ‘GSO’, which is understood to mean the GORE CARDIOFORM Septal Occluder;
- the ‘Figulla Flex’, manufactured by Occlutech. Three variants listed in the CtE dataset were the Figulla Flex II ASD Occlutech Closure Device, the Figulla Flex II PFO Occlutech Closure Device and the Figulla Flex UNI Occlutech Closure Device.

Percutaneous PFOC received a positive recommendation with normal arrangements from NICE ([IPG472](#)). The guidance recommended that the procedure should only be performed in units with appropriate arrangements for urgent cardiac surgical support in the event of complications. NICE IPG472 does not clearly define which patients should be eligible for PFOC, but states: “The optimal treatment for patent foramen ovale in patients who have had a thromboembolic event remains undefined. Medical management with anticoagulation (usually warfarin) or antiplatelet therapy (for example aspirin) is commonly used to reduce the risk of further paradoxical thrombus emboli. Surgical closure of patent foramen ovale is sometimes performed as an adjunct to other open-heart surgery, but is rarely done on its own because of associated morbidity.”

Section 2: Methods

2.1 CTE PFOC PROVIDERS AND PROGRAMME GOVERNANCE

Hospitals providing the CtE procedures in the 20 centres participating in the PFOC scheme are:

- Barts Health NHS Trust and The Heart Hospital, University College London Hospitals
- Brighton & Sussex University Hospitals NHS Trust
- Central Manchester Hospitals NHS Foundation Trust/University Hospitals of South Manchester NHS Foundation Trust
- Guy's and St Thomas' NHS Foundation Trust
- King's College Hospital NHS Foundation Trust
- Leeds Teaching Hospitals NHS Trust
- Liverpool Heart & Chest Hospital NHS Foundation Trust
- Nottingham University Hospitals NHS Trust
- Oxford University Hospitals NHS Trust
- Papworth Hospital, in partnership with Essex Cardiothoracic Centre
- Royal Brompton & Harefield NHS Foundation Trust
- Royal Wolverhampton NHS Trust
- Sheffield Teaching Hospitals NHS Foundation Trust
- St George's Healthcare NHS Trust
- The Newcastle upon Tyne Hospitals NHS Foundation Trust
- University Hospital Birmingham NHS Foundation Trust
- University Hospitals Bristol NHS Foundation Trust
- University Hospitals Leicester NHS Trust
- University Hospital of North Staffordshire NHS Trust
- University Hospital Southampton NHS Foundation Trust

The criteria used to select the hospitals for the CtE work considered a number of competing factors and are described in the NHS England Specialised Services Circular (SSC) 1452 for PFOC. An advisory panel made recommendations to NHS England as to which providers should be selected to be CtE centres. The final selection of centres was undertaken by the regional Medical Directors.

The NHS England Cardiac CtE Clinical Lead for PFOC is Dr. Robert Henderson, Consultant Cardiologist, Nottingham University Hospitals NHS Trust. Dr. Henderson is Chair of the NHS England PFOC Individual Technology Group. The role of the Group, set out in its Terms of Reference (ToR), is to:

- Work with the EAC and the National Institute for Cardiovascular Outcomes Research (NICOR) on the development of the relevant dataset.
- Define and clarify patient access criteria, where required, within the terms of the published policy statements / specification.
- Ensure that all participating centres are collecting, verifying and uploading data in a timely manner.
- Ensure that all participating centres are collecting follow-up data appropriately.
- Monitor performance of all centres performing procedures as part of CtE and report any concerns to the Steering Group.

- Monitor referrals, patient pathways and waiting times for the relevant procedure at all participating centres (including pathways for patients who do not receive the CtE treatment).

2.2 CTE PFOC COMMISSIONING DETAILS

NHS England commissioned a total of 600 PFOC procedures in each full financial year of the cardiac CtE scheme. Each of the 20 centres was required to do no more than 30 procedures per year. As CtE commenced on 01/10/2014, each centre could do no more than 15 PFOC procedures in 2014/15. Funding was made available by NHS England for each centre to do 30 procedures in 2015/16, making 45 procedures per centre in total.

Owing to slower than anticipated roll-out of the programme, some centres were permitted, by NHS England Specialised Services Circular SSC 1669 (November 2016), to carry on with their 2015/16 activity plans in financial year 2016/17, up to the contracted number of 900 procedures in total for the PFOC CtE programme.

2.3 INCLUSION AND EXCLUSION PATIENT SELECTION CRITERIA

According to the NHS England Specialised Services Circular (SSC) 1452 for PFOC:

“The decision to perform PFO closure in cryptogenic stroke will be made by an MDT which must include a neurologist or stroke physician and a cardiologist. Patients should be considered for PFO closure if they fulfil the following criteria:

- clinical syndrome comprising one or more neurovascular event(s) confirmed by brain imaging demonstrating changes consistent with ischaemia.
- clinical syndrome believed by the MDT to be highly likely to be due to right-to-left intra-cardiac shunting.
- thorough investigation has demonstrated no other likely source of the clinical syndrome.
- demonstration of a PFO with significant right to left shunting either spontaneously or during Valsalva.
- the patient has been fully informed and consent obtained.

Patients can be referred by cardiologists, stroke physicians or other specialists to a service in a specialist cardiac centre. This must be in line with the specialised service specifications for cardiology and cardiac surgery. Direct referral to cardiac centres from primary care and general practice requesting consideration for PFO closure will not be accepted.”

2.4 PRIMARY DATA COLLECTION

2.4.1 Database details and information governance arrangements

NICOR worked with the CtE PFOC Individual Technology Group and NY EAC to produce the final dataset for PFOC.

NY EAC produced ‘RX085 Output One - Recommendations on three NHS England Commissioning through Evaluation (CtE) registry draft datasets for MitraClip, LAAO and PFO Closure cardiovascular procedures’ [1] (November 2014). This identified and appraised new evidence added to the literature base and public domain since the original [NICE IP237/2](#) overview [4] was published and compared findings against the data fields contained in the draft PFOC CtE dataset.

The final PFOC dataset was developed into the online database by NICOR and the latest version may be downloaded as a Microsoft Excel® spread sheet ([last updated 13/05/2016](#)).

Regarding information governance arrangements, as Data Controller, NICOR's responsibilities were:

- To ensure that a dataset being proposed or used for national data collection has appropriate independent oversight, and that all relevant data will be made available to NICE for use in developing guidance.
- To provide NY EAC with a monthly download of episode level full raw data sets from each registry (out with normal NICOR data sharing policy and following the 'Use of Data' principles agreed with NY EAC). Data cleansing will happen to usual NICOR schedule. Monthly downloads may be aggregated or incremental. The EAC will provide feedback to NICOR on any data quality / completeness issues observed in the monthly raw data downloads.
- To arrange and undertake data linkage with Hospital Episode Statistics (HES) and Office of National Statistics (ONS) mortality data and provide complete data extract(s) to NY EAC in order to check for extra safety and efficacy, clinical effectiveness or resource utilisation information.
- To arrange and maintain appropriate EQ-5D-5L licensing arrangements to cover all projected patient volumes commissioned by NHS England in its CtE programme. This should include all commissioned follow up visits.
- To provide a telephone helpdesk service for answering technical enquiries / requests and for individual registration and access to each registry web portal. Clinical enquiries will need to go to the NICOR project manager and NY EAC may be co-opted to help NICOR respond to clinical or scientific queries.
- To operate within the general principles of Good Clinical Practice (GCP) in research, as outlined in the Research Governance Framework for Health and Social Care 2005.
- To make all necessary applications to comply with information governance requirements. These include but are not restricted to:
 - i complete the Information Governance Statement of Compliance process to the satisfaction of the NHS Health and Social Care Information Centre
 - ii demonstrate compliance with the Data Protection Act 1998. This is also particularly relevant when data will leave or enter the EU. Appropriate regard needs to be paid to international regulations
 - iii complete the Confidentiality Advisory Group application process to comply with the NHS Health Research Authority requirements for Section 251 approval

2.4.2 Active surveillance

NICOR provided NY EAC with their Minimum Data Standard (MDS) Summary Document for Cardiac CtE (**Confidential**). Some of the background detail is extracted in the below summary:

“While NICOR undertakes a number of manual and automated data quality control processes, the responsibility for data quality is shared with clinicians and organisations undertaking procedures in the NHS. It is particularly important that data are collected for patients who experience adverse outcomes (such as death, stroke, bleeding) and harm.

NICOR aims to further assist organisations in their data submissions by defining a minimum data standard (an acceptable standard for data submissions to be measured against), to provide feedback to the provider organisations on the data quality of their quarterly submissions and to give organisations the opportunity to improve and resubmit the data should improvements be required.”

The final NICOR MDS for PFOC CtE baseline data completeness monitoring contained 19 key fields. Six additional fields were monitored for patient completion of EQ-5D questionnaires and EuroQol data entry (NICOR field identifiers 3.19 to 3.24). These are summarised in [Table 2](#):

Table 2. Fields in registry used for monitoring of data completeness.

| NICOR Field identifier | Data Field |
|------------------------|--|
| 1.03 | NHS Number |
| 1.06 | Birth date |
| 1.10 | Postcode |
| 2.03 | Reason for treatment |
| 3.08 | Hypertension |
| 3.18 | Date EuroQol form filled |
| 3.19 | EuroQol Mobility |
| 3.20 | EuroQol Self-care |
| 3.21 | EuroQol Usual activities |
| 3.22 | EuroQol Pain / discomfort |
| 3.23 | EuroQol Anxiety / depression |
| 3.24 | EuroQol Health state today |
| 5.01 | Brain scan |
| 5.04 | Echo shunt grade |
| 7.01 | Medications |
| 8.01 | Date of admission |
| 8.03 | Date/time of procedure |
| 8.06 | Consultant responsible |
| 8.27 | Number of devices implanted |
| 8.29 | 1st Device used |
| 9.01 | Device-specific complications |
| 9.04 | Neuro/embolic problems |
| 9.10 | Status at discharge |
| 9.11 | Discharge date |
| 9.13 | Successful procedure, no complications |

The seven follow-up MDS fields for PFOC data completeness monitoring at 6 weeks were:

- 10.02 Device still in situ
- 10.03 Embolisation/retrieval
- 10.06 Further intervention
- 10.08 Death
- 10.13 Neurological event
- 10.18 Atrial fibrillation
- 10.27 6 week EQ-5D-5L form filled

The equivalent variables were also monitored for follow up data at 6 months, 1 year, and 2 years.

Summary reports were submitted to NICE by NY EAC on a quarterly basis, to a standard reporting template agreed with NHS England for all CtE projects. Key parameters for each CtE provider were:

- Contracted activity to date: the amount of CtE activity the centre should have performed by this point, according to their contract with NHS England.
- Actual activity to date, as identified through both register entries and active surveillance by NICOR collating a [‘SurveyMonkey’](#) questionnaire from the CtE providers.
- Number of cases submitted to the NICOR registry to date. This number could be lower than the above actual activity to date, since active surveillance could identify cases that had not yet been registered.
- Number of cases identified through active surveillance but for which data were not yet submitted to the registry (i.e. the difference between the two previous figures).
- Data completeness (%) was calculated for the subset of all PFOC records where the CtE provider had selected the ‘CtE=Yes’ check box when submitting the case to the NICOR dataset (this is the ‘Number of cases’ denominator, below):

$$\text{Data completeness (\%)} = \frac{\text{Number of completed entries in MDS data fields}}{\text{Number of cases}} \times 100$$

- Later, queries from the CtE providers on this denominator led to refined definitions for Activity, Coverage, Completeness and Follow up (FU) reported. The final defined measures were:
 - Activity: The number of CtE procedures recorded with a procedure date between 01/10/2014 and the date of raw data extract that had an eligible reason for treatment.
 - Coverage: The percentage of patient follow ups reported out of the number of patients reaching the follow up time point in question. A ‘reported’ follow up had data in any of the MDS follow up fields for the time point in question.
 - Completeness: The percentage of fields with any data out of the number of MDS fields for the time point in question.
 - FU reported: This number included patients reported to have died since the previous follow up visit.

2.4.3 Case eligibility criteria

Inclusion criteria: All pseudonymised NHS procedures recorded in the PFOC CtE registry conducted between 1st October 2014 to 10th August 2017 with recorded reasons for treatment including previous stroke or TIA.

Exclusion criteria: Procedures meeting the inclusion criteria, but with missing procedure date.

2.4.4 Data cleaning

Detailed methods of variable cleaning are described in *Supplementary Material - Table 1*. Data completeness and summary statistics, in terms of distribution of responses, were conducted for each of the data fields available and used to inform variables used and definition of outcomes during the statistical analysis.

2.4.5 Outcomes indicators

a. Clinical

Primary outcome measures (detailed in *Supplementary Material - Table 2*) included: successful device implantation, in-hospital major complications (defined as death, neurological event of ischaemic, haemorrhagic or undetermined origin, device embolization, cardiac structural complications, major vascular problems, endocarditis, oesophageal

rupture, major bleed, and additional surgery), in-hospital minor complications, post-discharge major complications, post-discharge minor complications and confirmed PFO closure on contrast echocardiography (only captured from 6 months post-discharge onwards).

Secondary outcome measures included: death, neurological event, device embolization, major cardiac structural complications, myocardial infarction (MI), major vascular complications, endocarditis, oesophageal rupture, major bleed, additional surgery/intervention, device malfunction, device malposition, rhythm complications, minor cardiac structural complication, transient ST-elevation (no MI), minor embolic events, minor vascular complications, migraine/worsening migraine, oesophageal trauma, nickel allergy and minor bleeds. Detailed definitions of included outcome measures are described in *Supplementary Material – Table 2*.

b. Cost / resource

A bottom-up costing study of each stage in the pathway to insert PFOC devices was conducted to calculate the full procedure-related costs to the NHS. NY EAC firstly reviewed the draft Excel® costing template provided by the NHS England PFOC Individual Technology Group. Amendments were agreed with the Chair of the Group and the final template provided the 10 centres with detailed instructions on inputting the resources required to conduct each of the three stages in the relevant pathway being:

- Pre-operative assessment;
- Peri-operative procedure;
- Post-operative management.

The findings from the completed templates on resource use were reviewed by all authors and compared with existing clinical pathways. Where possible, outcomes reported in the PFOC dataset such as number and type of device implanted, type of imaging conducted at each stage in the pathway, procedure duration, primary and secondary operator and length of stay were used. Where such information was not available the three clinicians reached a consensus view on the appropriate resources required. Unit costs from NHS national datasets and other English national cost sources were applied to the resources and aggregated to give a total procedural cost. Sensitivity analyses were conducted to provide a high and low range of estimated costs. Full details are provided at [Appendix 9](#), with a summary of results in [Tables 7](#) and [8](#).

c. Patient experience

From the outset of the cardiac CtE project, it was intended that EQ-5D-5L questionnaires would be issued to all patients at baseline procedure and all subsequent follow-up visits. This should allow pairwise analysis of results over the follow up period. However, as PFO closure is a preventative procedure rather than a therapeutic one, it is unclear whether any symptoms of the condition would be improved, other than the possibility of reduced anxiety and reduced adverse effects of drugs, or less commonly reduced quality of life following stroke or embolism. It is not expected any historical symptoms from the previous cryptogenic stroke will be improved by the intervention, although there may be potentially measureable differences in the non-physical domains, such as reduced anxiety about the possibility of stroke.

2.4.6 Statistical analysis

All scripts for case ascertainment, cleaning, processing and statistical analysis were written in the statistical programming language R [5].

Patient demographics, pre-operative clinical scores and procedural details were compared between the whole cohort and the subgroup of patients with any information recorded from follow-up appointments (at 6 weeks, 6 months, 1 year or 2 years). Fisher's exact tests or Mann Whitney U-tests were used as appropriate. Bonferroni correction was used to adjust the level of significance to take into account multiple comparisons.

Exploratory univariate and exploratory multivariate analyses were conducted for the defined outcome measures. Univariate analyses were conducted for each outcome measure and up to 42 covariates. Bonferroni correction was used to adjust the level of significance to take into account multiple comparisons (between outcome measure and each covariate of interest). Multivariate analyses used generalised linear modelling with binomial error distribution in order to estimate the effect size of covariates. Numeric covariates were centred on their median before inclusion in the multivariate analyses, if appropriate. Binary outcome measures that were anticipated to have a suitable number of observations to allow multivariate analysis included device implanted (Yes/No), major complications in-hospital (Yes/No), and minor complications in-hospital (Yes/No). The resulting binary logistic regression analyses of these outcome measures were checked for convergence and over-fitting, and either modified (e.g. by combining multiple factor levels within covariates and/or reducing the number of covariates) or reported as not valid.

Crude incidence rates for death, neurological events, device embolization, myocardial infarction, additional surgery and peripheral embolic event recorded during the study period were calculated as the number of events per 100 person-years of follow-up. Kaplan-Meier analysis was applied to the time from procedure to the time of the death or first neurological event. Patients who suffered no events and were alive at the end of the study were considered censored.

Confirmed PFO closure at 6 months, 1 year and 2 year follow-up was determined from contrast echocardiography results at rest and with provocative manoeuvre ([Appendix 8](#)).

Paired quality of life scores from individual EQ-5D components, visual analogue scores (VAS) and overall utility were compared at each time interval (6 weeks, 6 months, 1 year, 2 years) against pre-operative scores using Fisher's tests or t-tests where appropriate.

2.5 SECONDARY DATA COLLECTION (LITERATURE REVIEW)

The aim of the final PFOC literature review for CtE was to identify key published studies in patients who have had a cryptogenic ischaemic event and summarise results so they align with the requirements of the outputs of NY EAC project RX085, including the 11 questions set by NHS England. A brief summary of the review methods is presented here. A standalone literature review document is available for further information [3].

Firstly, a literature search was performed from July 2013, which was the search date of the original [NICE IP237/2](#) which informed [NICE IPG472](#). The NICE search strategies for replication were sourced through documents supplied by NICE and through communication with the Senior Information Manager at NICE Guidance Information Services. The EAC team and NICE agreed that no quality assessment would be made of the NICE strategies and the intention was to use the NICE-designed strategies as supplied. Some minor edits were

made (for example, the correction of a line-combination error identified in an original strategy, the addition of device trade names not included in the original searches, the deletion of the trade name for a device which never became commercially available / CE marked, and edits to index terms due to changes in MeSH / Emtree indexing). Apart from these minor changes, the terms used in the update strategies reflected those used in the original strategies of [NICE IPG472](#).

The scope of the literature review was intended to broadly reflect the population and intervention covered in the CtE registry. The scope, described in PICO (Population, Intervention, Comparator, Outcomes) format, is summarised in [Table 3](#).

Table 3. Scope of literature review.

| Domain | Terms identified from title or abstract | Comment |
|---|---|---|
| Population | Patients with PFO at risk of a recurrent neurological event where no other likely cause has been demonstrated | Term is patients with “cryptogenic” stroke |
| Intervention | Percutaneous closure of PFO | All CE marked devices to be included. Known device models identified in the PFOC CtE dataset are the AMPLATZER range (St. Jude Medical), the GORE CARDIOFORM Septal Occluder (W L Gore and Associates Inc.) and the Figulla Flex range (Occlutech). The earlier V1.6 of the PFOC dataset (used by NICOR at launch of the cardiac CtE programme in December 2014) included the GORE HELEX Septal Occluder (discontinued in 2011). Three other manufacturers were also originally listed as options for selection in the CtE dataset: Ultrasept PFO (Cardia Inc.), FlatStent EF (Coherex Medical) and Nit-Occlude (PFM Medical). These were therefore included in the literature search terms. |
| Comparator | Any or none | Single arm observational studies will be considered (e.g. registries) |
| Outcomes | Clinical outcomes Utility and resource use outcomes* | Surrogate and non-clinical outcomes will be excluded. |
| Study type | All primary studies Secondary studies (systematic reviews and meta-analyses) Economic studies* | Non-systematic reviews, editorials and opinion pieces excluded. Abstracts excluded. |
| *Economic studies and associated outcomes to be identified for possible future reference. | | |

Given the timelines of the project and the purpose of the update search, the EAC team and NICE agreed that only the bibliographic databases listed in [Table 4](#) below would be searched. In addition, it was agreed that strategies would be limited to results published in English language only, and that conference-related publication types would be excluded from the Embase search.

Where database functionality allowed, results were limited to records added to the database since the date of the last search, using appropriate fields such as the entry date field in MEDLINE. Where database functionality did not allow this, results were limited by publication date, reflecting the pragmatic context of the search.

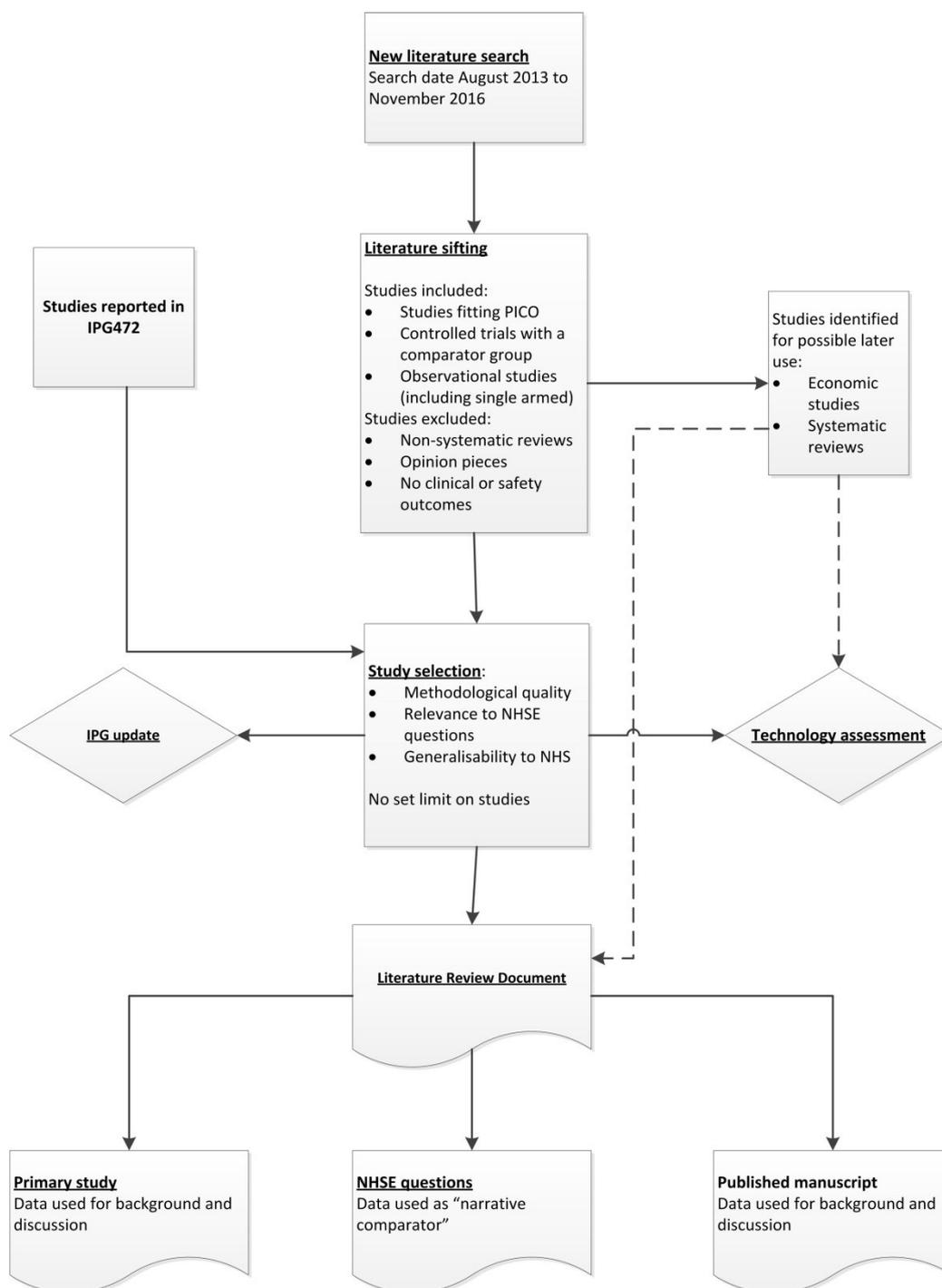
Table 4. Bibliographic databases searched.

| Database / information source | Interface / URL |
|--|---|
| MEDLINE and MEDLINE In-Process | OvidSP |
| EMBASE | OvidSP |
| Cochrane Database of Systematic Reviews (CDSR) | Cochrane Library/Wiley Interscience |
| Cochrane Central Register of Controlled Trials (CENTRAL) | Cochrane Library/Wiley Interscience |
| Database of Abstracts of Reviews of Effects (DARE) | http://www.crd.york.ac.uk/CRDWeb/ |
| Health Technology Assessment Database (HTA) | http://www.crd.york.ac.uk/CRDWeb/ |
| NHS Economic Evaluation Database (EED) | http://www.crd.york.ac.uk/CRDWeb/ |

Relevant studies were sifted by two reviewers according to the predefined scope, and these studies were then combined with those reported in IPG472. As this approach identified an unmanageable number of studies, a further selection process was employed to identify studies on the basis of methodological quality and size, with randomised controlled trials (RCTs) and observational studies with 500 or more participants selected for full review, with studies with 100 or more participants being flagged for *ad hoc* inclusion [3]. Systematic reviews and economic studies were also identified.

[Figure 1](#) is a flow diagram of this pragmatic literature review strategy, including the inclusion and exclusion criteria applied to sifting.

Figure 1. Flow chart illustrating the literature review strategy for PFOC.



A brief summary of the results of the literature review is presented in the [results](#) section of this final CtE report on PFOC, with full details available in the standalone literature review document [3].

2.6 RESEARCH DESIGN

The study was a procedural registry designed with a maximum 2 years of follow up. The registry was single armed with no comparator or control arm. Data were collected prospectively in accordance with best practice [6, 7].

As discussed in [Section 3.2](#), the current evidence base for the use of PFOC for the preventative treatment of patients with ischaemic stroke thought likely to be caused by a

paradoxical embolism is equivocal (although more recent studies have reported positive benefits, see [Section 3.3](#)). Although trial evidence reports a trend towards reduced incidence of recurrent stroke associated with PFOC, statistical significance has not been reported in any single RCT. Additionally, as recurrent strokes in this population are still relatively rare events, the absolute benefit of PFOC may be comparatively small and difficult to accurately gauge. Observational studies that have been performed are mainly single-armed. Comparisons with historical controls, where made, introduce further uncertainty. There is only limited information on how PFOC performs in NHS pathway settings, and the relative efficacy and safety of competing technologies is also poorly understood.

To help clarify this uncertainty, NHS England has requested that the answers to 11 clinical and economic questions should be addressed, using data reported by the CtE registry, and supported by published studies in the literature. These questions have been revised and adjudicated by NICE (see Table 5). [Table 5](#) summarises the *a priori* intended methods for answering each question [8]. However, due to issues with data quality and reporting of published literature, the original methods were not always possible. These limitations have subsequently been annotated in the table.

The EAC performed a pragmatic literature review, which identified the key experimental and observational studies performed to date on PFOC (see [Section 3.2](#)). As the CtE register was non-comparative, data from the literature has been used as a proxy control for the register. The relationship between the registry and published literature in answering the NHS England questions is illustrated in [Figure 2](#). Inference has been made by comparing point estimates and confidence intervals where available. Additionally, in some instances where the registry was not sufficiently robust to answer the questions, published evidence was used to directly answer questions.

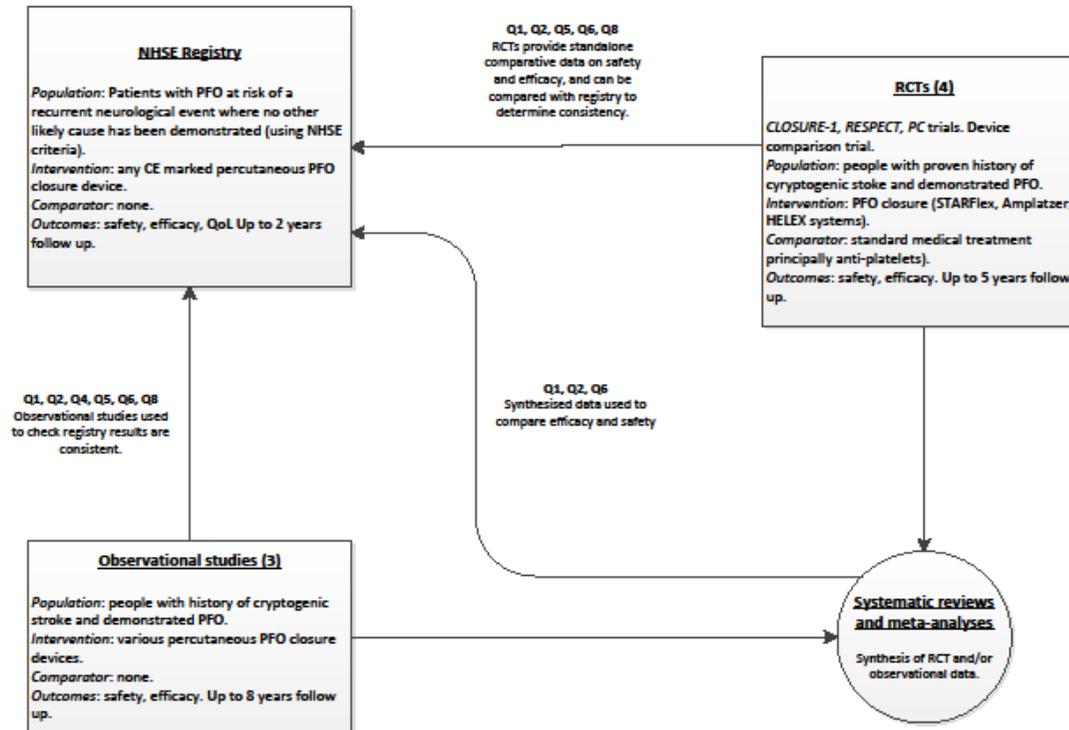
Table 5. Methods used to analyse and report CtE registry data.

| Question (NICE modified where applicable) | Can it be answered using registry data? | Key registry data required | Type of analysis | Comment |
|---|---|---|--|--|
| 1) Does patent foramen ovale closure lower the risk of stroke or other embolic clinical events compared to no intervention (as predicted by natural history studies or from modelling)? | No. | Neurological event (type) Rankin score | Survival analysis. Comparison with published RCTs and observational studies. | Incidence of endpoint (stroke and associated events) likely to be too low to be meaningfully compared with data published in the literature. |
| 2) Can UK clinical teams reproduce the success rates for patent foramen ovale closure reported in existing clinical trials, with equivalent or lower complication rates? | Yes, partly. | Successful procedure, no complications Neurological event (type) Device specific complication Rhythm complication Cardiac structural complication Neurological/other embolic complication Vascular complications Other complications Bleeding complication Life status | Proportion of people having event with confidence intervals. Comparison with expected rate from published RCTs. | Some outcome events expected to be low, statistical significance unlikely to be reported. |
| 3) Is patent foramen ovale closure associated with an improvement in quality of life? | Yes, partly. | Successful procedure, no complications Quality of life (EQ-5D-5L) | Pairwise ('before and after') analysis of registry data. Correlation and regression analysis. | Significant aggregate changes in quality of life unlikely. [Update: paired analysis limited by relatively poor follow up]. |
| 4) Are there any longer-term | No, probably not. | Device embolization | Proportion of people having | Longer-term data collection |

| Question (NICE modified where applicable) | Can it be answered using registry data? | Key registry data required | Type of analysis | Comment |
|---|---|--|--|--|
| cardiac complications associated with the use of these devices [for PFO closure] (e.g. erosion with penetration through the wall of the atrium/aorta)? | | Cardiac structural complications Rhythm complications Thrombus formation | event with confidence intervals. Survival analysis (Kaplan-Meier). | would be dependent on extension of contracted follow up. [Update: follow up not extended, could feasibly be addressed in future using HES analysis]. |
| 5) Which devices are used to undertake PFO? What are the device-specific efficacy and safety outcomes in CtE funded patients undergoing the procedure? In particular, is there any published or register evidence of complications in the long term from percutaneous PFO closure (e.g. erosion with penetration through the wall of the atrium /myocardium/pericardium)? | Yes, partly. | Device manufacturer Efficacy and safety outcomes | Subgroup analysis. Comparative survival curves. | Some subgroups may be low in number (real differences may not be statistically observable). |
| 6) What are the short and medium term risks of percutaneous PFO closure? | Yes, partly. | Key safety and complications outcomes Efficacy outcomes | Descriptive statistics on efficacy and complication data. Narrative comparison with published data. | Expert opinion will be sought on acceptability of risks. This question could lead to an update of IPG472. |
| 7) What proportion of patients referred to an MDT for possible percutaneous PFO closure against Commissioning Through Evaluation criteria were considered suitable for the intervention? | Yes, partly. | Decision to treat | Proportion of patients considered by MDT/patients received PFO closure. | Unknown how many potential candidates do not make the registry at all. [Update: descriptive analysis of indication reported]. |
| 8) Are favourable clinical outcomes with patent foramen ovale closure associated with particular patient characteristics (clinical or demographic)? | Yes, partly. | Patient characteristics Efficacy outcomes Complication outcomes Mortality | Subgroup analysis. Bonferroni correction if hypotheses not pre-specified. | Limitations with patient enrolment (power), patient selection and confounding variables (generalisability issues). [Update: low follow up and |

| Question (NICE modified where applicable) | Can it be answered using registry data? | Key registry data required | Type of analysis | Comment |
|--|---|---|---|---|
| | | | | primary event rate did not allow for subgroup analysis]. |
| 9) What are the average full procedural costs of percutaneous patent foramen ovale closure to the NHS? | Provides inputs. | Devices used, primary and secondary operator, investigations, length of stay initial admission and procedure duration. | Process costing with separate costs for each stage of the clinical pathway. | Procedural costs will be estimated by combining information from the registry and data from sites, collected using a pro forma. |
| 10) What are the potential cost savings for the NHS in patients receiving percutaneous patent foramen ovale closure? | Provides inputs. | Patient characteristics. Resource use data for procedure, initial admission and re-admissions. Efficacy outcomes. Complication outcomes. | Mean and SD for each key event on pathway. | This question will be answered by a cost consequences analysis to be provided in a separate report to NICE. |
| 11) What is the likely cost-effectiveness of percutaneous PFO closure in the NHS, based on UK costs? | Provides inputs. | Patient characteristics. Resource use data for procedure, initial admission and re-admissions. Efficacy outcomes. Complication outcomes. Mortality. | Mean and SD for each parameter. | This question will be answered by a cost consequences analysis to be provided in a separate report to NICE. |

Figure 2. Relationship between NHS England registry clinical data and published evidence identified in the literature review (questions 1 to 8 [Q1 to Q8]).



Section 3: Results

3.1 PRIMARY DATA COLLECTION (CTE DATABASE)

3.1.1 Numbers of patients treated at each centre

A total of 1126 PFOC procedure records were extracted by NICOR on 10th August 2017. One hundred and thirty one patients did not meet the eligibility criteria, [Appendix 1](#), 119 of which did *not* include eligible reasons for PFOC treatment (multiple reasons permitted): 44 decompression illness (diver), 25 MI (presumed embolic), 13 migraine (with or without aura), 12 peripheral embolus, 11 orthodeoxia-platypnoea or other desaturation syndrome, 8 primary stroke prevention, 1 high-altitude pulmonary oedema, 1 prior to neurosurgical procedure, 15 other, 3 none, and 12 not providing a reason for treatment. A total of 940 PFOC procedures were eligible for analysis, which included 111 (11.8%) non-CtE commissioned procedures i.e. private procedure or those conducted by non-CtE commissioned centres.

Of all procedures concluding with PFOC device implantation, with a discharge status of alive at last hospital visit, follow-up information for CtE commissioned procedures was recorded in 81.9% of cases at 6 weeks, 70.5% at 6 months, 60.8% at 1 year and 39.1% at 2 years (*Supplementary Material – Table 3*).

3.1.2 Summary statistics of patient and procedural characteristics

Patient demographics and procedural characteristics for the cohort are summarised in [Appendix 2](#) and [Appendix 3](#) respectively. No statistical differences were identified between the whole cohort and those with reported follow-up information for any variables. A total of 663 procedures were conducted with planned intra-operative TOE or TTE imaging, 627 of which were recorded under general anaesthesia (94.6%). A total of 206 procedures were conducted with planned intra-operative ICE imaging, 185 of which were recorded under local anaesthesia (89.8%).

3.1.3 Active surveillance (evaluation of coverage)

The data coverage and completeness results, for CtE commissioned procedures only, for the 25 PFOC MDS baseline fields and the 7 specified follow-up fields (to 10/08/2017) are reported in [Table 6](#).

Table 6. Data completeness by provider.

| CtE provider | Baseline MDS completeness | Coverage [†] & completeness [‡] at 6 weeks FU | Coverage [†] & completeness [‡] at 6 months FU | Coverage [†] & completeness [‡] at 1 Year FU | Coverage [†] & completeness [‡] at 2 years FU |
|--|---------------------------|---|--|--|---|
| The Newcastle upon Tyne Hospitals NHS Foundation Trust (FRE)* | 98% | 92.0% (23/25) coverage 87.6% FU data completeness | 50.0% (12/24) coverage 85.7% FU data completeness | 42.1% (8/19) coverage 83.9% FU data completeness | 14.3% (1/7) coverage 71.4% FU data completeness |
| Central Manchester Hospitals / University of South Manchester NHS Foundation Trust (MRI/WYT)* | 72% | 54.2% (13/24) coverage 76.2% FU data completeness | 18.8% (3/16) coverage 76.2% FU data completeness | 41.7% (5/12) coverage 74.3% FU data completeness | 12.5% (1/8) coverage 57.1% FU data completeness |
| Leeds Teaching Hospitals NHS Trust (LGI) | 81% | 96.8% (30/31) coverage 82.4% FU data completeness | 96.8% (30/31) coverage 80.0% FU data completeness | 85.2% (23/27) coverage 78.9% FU data completeness | 16.7 (1/6) coverage 14.3 FU data completeness |
| Liverpool Heart & Chest Hospital NHS Foundation Trust (BHL) | 74% | 61.5% (32/52) coverage 70.1% FU data completeness | 86.5% (45/52) coverage 83.8% FU data completeness | 54.0% (27/50) coverage 69.3% FU data completeness | 35.5% (11/31) coverage 79.2% FU data completeness |
| Oxford University Hospitals NHS Trust (RAD) | 94% | 91.1% (41/45) coverage 96.2% FU data completeness | 65.9% (29/44) coverage 96.6% FU data completeness | 78.4% (29/37) coverage 97.1% FU data completeness | 18.8% (3/16) coverage 95.2% FU data completeness |
| Brighton & Sussex University Hospitals NHS Trust (RSC) | 89% | 97.9% (46/47) coverage 71.1% FU data completeness | 97.9% (46/47) coverage 69.9% FU data completeness | 97.7% (42/43) coverage 69.4% FU data completeness | 83.3 (15/18) coverage 67.6 FU data completeness |
| University Hospitals Bristol NHS Foundation Trust (BRI) | 99% | 89.2% (58/65) coverage 98.0% FU data completeness | 80.3% (49/61) coverage 98.8% FU data completeness | 0% (0/51) coverage 0% FU data completeness | 0% (0/25) coverage 0% FU data completeness |
| University Hospital Southampton, NHS Foundation Trust (SGH) | 65% | 89.2% (33/37) coverage 81.8% FU data completeness | 89.2% (33/37) coverage 86.1% FU data completeness | 93.3% (28/30) coverage 78.5% FU data completeness | 100% (13/13) coverage 79.1% FU data completeness |
| University Hospital of North Staffordshire NHS Trust (now Royal Stoke University Hospital) (STO) | 84% | 61.2% (41/67) coverage 43.5% FU data completeness | 98.5% (66/67) coverage 59.1% FU data completeness | 93.2% (41/44) coverage 43.2% FU data completeness | 61.5% (8/13) coverage 48.2% FU data completeness |
| University Hospitals Leicester NHS Trust (GRL) | 95% | 92.0% (46/50) coverage 90.1% FU data completeness | 68.0% (34/50) coverage 93.3% FU data completeness | 57.5% (23/40) coverage 92.5% FU data completeness | 54.5% (12/22) coverage 94.0% FU data completeness |
| Nottingham University Hospitals NHS Trust (CHN) | 94% | 97.7% (43/44) coverage 94.0% FU data completeness | 97.7% (42/43) coverage 94.2% FU data completeness | 96.9% (31/32) coverage 94.0% FU data completeness | 100% (16/16) coverage 87.5% FU data completeness |
| University Hospital Birmingham NHS Foundation Trust (QEB) | 90% | 100.0% (30/30) coverage 85.7% FU data completeness | 10% (3/30) coverage 85.7% FU data completeness | 43.3% (13/30) coverage 87.9% FU data completeness | 63.6 (7/11) coverage 100.0% FU data completeness |
| Royal Wolverhampton NHS Trust (NCR) | 82% | 100.0% (26/26) coverage 72.0% FU data completeness | 100.0% (26/26) coverage 70.3% FU data completeness | 0% (0/24) coverage 0% FU data completeness | 7.7% (1/13) coverage 14.3% FU data completeness |
| Papworth Hospital in partnership with Essex Cardiothoracic Centre (PAP/BAS)* | 85% | 80.0% (32/40) coverage 79.2% FU data completeness | 81.6% (31/38) coverage 74.6% FU data completeness | 87.5% (28/32) coverage 63.7% FU data completeness | 58.8% (10/17) coverage 50.0% FU data completeness |
| Guy's and St Thomas' NHS Foundation Trust (STH) | 98% | 87.0% (47/54) coverage 84.8% FU data completeness | 28.3% (15/53) coverage 88.6% FU data completeness | 74.4% (32/43) coverage 90.2% FU data completeness | 6.7% (1/15) coverage 100.0% FU data completeness |

| CtE provider | Baseline MDS completeness | Coverage† & completeness‡ at 6 weeks FU | Coverage† & completeness‡ at 6 months FU | Coverage† & completeness‡ at 1 Year FU | Coverage† & completeness‡ at 2 years FU |
|---|---------------------------|--|--|--|--|
| Barts Health NHS Trust & The Heart Hospital, (SBH/UCLH)* | 71% | 83.3% (35/42) coverage 66.5% FU data completeness | 22.0% (9/41) coverage 60.3% FU data completeness | 42.9% (12/28) coverage 67.9% FU data completeness | 20.0% (1/5) coverage 71.4% FU data completeness |
| Kings College Hospital NHS Foundation Trust (KCH) | 80% | 33.9% (20/59) coverage 66.4% FU data completeness | 64.3% (36/56) coverage 73.8% FU data completeness | 63.8% (30/47) coverage 72.9% FU data completeness | 10% (2/20) coverage 71.4% FU data completeness |
| Royal Brompton & Harefield NHS Foundation Trust (NHB/HH)* | 66% | 89.2% (58/65) coverage 73.9% FU data completeness | 59.3% (35/59) coverage 74.7% FU data completeness | 39.6% (19/48) coverage 72.5% FU data completeness | 12.5% (2/16) coverage 57.1% FU data completeness |
| St. George's Healthcare NHS Trust (GEO) | 87% | 70.6% (12/17) coverage 71.4% FU data completeness | 62.5% (10/16) coverage 72.9% FU data completeness | 0% (0/15) coverage 0% FU data completeness | 0% (0/4) coverage 0% FU data completeness |
| Total | 84% | 820/848 (96.7%) with device implanted, discharged alive and reaching 6 weeks since procedure date. 666/820 (81.2%) with some degree of FU data Completeness of FU MDS (versus expected) = 79.6% | 792/820 (96.6%) with device implanted, still alive at 6 weeks FU and reaching 6 months since procedure date. 554/792 (69.9%) with some degree of FU data Completeness of FU MDS (versus expected) = 80.1% | 652/820 (79.5%) with device implanted, still alive at 6 months FU and reaching 12 months since procedure date. 391/652 (60.0%) with some degree of FU data Completeness of FU MDS (versus expected) = 75.6% | 276/820 (33.7%) with device implanted, still alive at 1 year FU and reaching 2 years since procedure date. 105/276 (38.0%) with some degree of FU data Completeness of FU MDS (versus expected) = 75.2% |
| <p>FU Coverage† = Actual no. of PFOC procedures with some degree of FU data entered / No. of PFOC procedures eligible for FU for the stated period (%)</p> <p>NB FU Coverage can only be calculated for cases with a procedure date entered. This is the case for 848/860 (98.6%) of PFOC cases in the registry, to 10/08/2017</p> <p>FU Completeness‡ = Average completeness of the 7 specified PFOC MDS-FU data fields (%)</p> <p>*CtE providers named in bold font in the table are separate NHS Trusts operating in partnership as a single contracted CtE provider with NHS England for cardiac CtE.</p> | | | | | |

3.1.4 Outcomes

a. Clinical

Of the 940 procedures eligible for analysis ([Appendix 1](#)), 929 (98.8%) recorded both admission and discharge dates, showing a median length of stay of 1 overnight stay (inter-quartile range 0 to 1, range 0 to 34 days). Device implantation was recorded in 907/940 (96.5%) of eligible procedures, with 901/907 procedures resulting in an implanted device and 6/907 resulting in failure to implant, for reasons categorised as: 3 unable to position device correctly, 1 incorrect size, 1 complication and 1 reporting “other” reason. Exploratory analysis indicated that excess body mass index (BMI) and older age were associated with lower implantation rates. 33/940 procedures (3.5%) did not record whether a device was implanted or not (missing data).

In-hospital major complications (1.0%) were reported in 9 patients, including: 1 death, 3 neurological events (2 ischaemic and 1 other categorised as a CVA/RIND), 3 device embolization events, 1 myocardial infarction (MI), 1 major bleed and 1 requiring additional surgery (surgical retrieval of embolised device). Twenty four patients (2.6%) experienced minor complications, including: 9 new or worsening atrial fibrillation, 5 minor vascular complications, 4 device malposition, 5 minor bleeds, 3 new or worsening migraine and 1 minor cardiac structural complication. Frequencies of in-hospital outcomes for all eligible PFOC patients, and post-discharge outcomes for all eligible PFOC patients with a device implanted are described in [Appendix 4](#). Procedural success (device implanted and no major complications) was achieved in 894 PFOC procedures (95.1%).

The only covariate which was significantly associated with an in-hospital major complication outcome during univariate analysis was right-to-left shunt (without provocation). Therefore, those with weaker evidence of shunts were more likely to experience a major in-hospital complication. No significant associations were found for the device implanted or in-hospital minor complication outcomes (*Supplementary Material – Tables 4-6*).

For those with a PFOC device implanted, follow-up was reported in 808 patients (89.7%). Major complications occurring post-PFOC procedure discharge were recorded in 42 patients, including: 2 deaths, 23 neurological events, 13 major bleeds, 1 MI, 1 major cardiac structural complication, 1 major vascular complication and 4 requiring additional surgery (device removed/retrieved further intervention with other device or surgical closure) ([Appendix 4](#)). One hundred and eighteen patients reported minor complications, including: 61 minor cardiac structural complications, 28 new or worsening atrial fibrillation, 21 new or worsening migraine, 7 minor bleeds, 5 minor vascular complications and 2 air embolisms.

Total crude incidence rates of adverse events are described in [Appendix 4](#). One in-hospital and 2 out-of-hospital deaths have been reported. Recorded causes of death were 1 fungal endocarditis and multi organ failure with auto-immune sclerosing cholangitis (recorded in-hospital); 1 unknown cause (recorded at 1 year follow up) and 1 multi-organ failure complicated by septicaemia (recorded at 2 year follow up). Neurological events were reported for 26 patients in-hospital or post-discharge (with potential for multiple events per patient). Due to internal inconsistencies in completion and interpretation of registry data field combinations (the combination of mechanism and type of neurological event), the EAC sought narrative confirmation of the recorded events from participating centres. For further information, see [Addendum](#). Kaplan-Meier curves for time to death, ischaemic neurological event and death or any neurological event are shown in [Appendix 6](#). The rate of neurological events was not significantly different between types of device implanted ($p=0.26$) ([Appendix 7](#)).

Echo contrast results over time are shown in [Appendix 8](#).

Use of antiplatelet and anticoagulant medications over time is described in *Supplementary Material – Table 7*. The difference in medication use on discharge compared with pre-procedure was statistically significant. Other medications recorded via free-text fields at pre-procedure, at discharge and during follow-up were available for only 4% of patients, so are not analysed any further.

In reporting changes in quality of life, one can only include individuals who provided data pre-procedure and at specified later time periods. This is to ensure one is comparing the EQ-5D scores of the same individuals over time. The mean utility value pre-procedure was 0.87, which changed to:

- 0.91 at 6 weeks (n= 241, p = 0.02);
- 0.91 at 6 months (n = 207, p =0.008)
- 0.90 at 1 year (n = 125, p = 0.55)
- 0.90 at 2 years (n = 36, p= 0.66)

Hence there was a 0.03 point improvement in quality of life at 12 months from the procedure. Whilst not statistically significant this is a material benefit for the individuals concerned.

The domain registering the greatest benefit from the procedure was reduction in anxiety and depression. A statistically significant improvement was seen in this domain in 241 paired results at 6 weeks post-procedure and in 207 paired results at 6 months post-procedure (*Supplementary Material – Table 8*).

b. Cost / resources

The overall quality of responses to the PFOC CtE Excel[®] costing template was poor, but there was one well-completed response. NY EAC synthesised the responses to create a list of the resources required at each stage of pathway. In February 2107, Dr Mark de Belder reviewed this list. Following subsequent changes in light of his comments and informed by several more responses from centres, NY EAC updated the template and included cost information. Unit costs were taken from published national datasets (primarily NHS Reference Costs [31] and PSSRU [32]). The NHS Supply Chain provided costs for the device as 'Commercial in confidence' and hence must not be disclosed beyond NICE staff and clinical leads in first instance. Such data are identified in yellow in this report and [Appendix 9](#). NHS Supply Chain price includes overheads of 3% for its internal costs. A further 15% has been added to the NHS Supply Chain price for NHS procurement and stores related costs plus property related overheads.

At this stage we also included results from the analyses of the CtE registry data for as many parameters as possible. These included number and type of device implanted, type of imaging conducted at each stage in the pathway, procedure duration, primary and secondary operator and length of stay. The updated templates were presented at a meeting of the three clinical leads in May 2017. Comments from that meeting informed the final pathway and costings.

The two rounds of clinical validation were judged essential to ensure the resulting costs have good internal and external validity and thus should generalise to settings across NHS England.

The resultant estimated central cost and high and low cost scenarios for a PFOC procedure conducted in NHS England are shown in [Table 7](#).

Table 7. Central cost and range of cost for a PFO closure procedure.

| Pathway stage | Central cost | Low cost | High cost |
|---------------------------|---------------|---------------|---------------|
| Pre-operative assessment | £286 | £229 | £343 |
| Peri-operative procedure | £6,379 | £5,798 | £6,960 |
| Post-operative management | £1,564 | £913 | £1,947 |
| Total | £8,229 | £6,939 | £9,251 |

Note figures are rounded so may not sum to last digit precisely.

[Table 8](#) analyses the estimated costs by component by stage for the central case. The device accounts for █% of the cost of a PFOC procedure. Investigations form the second largest cost component (32%), with consumables accounting for █%, staff and length of stay 6% and 3% respectively, theatre use █% and an outpatient follow-up appointment 2% to the cost base.

Table 8. Estimated costs by component by stage for central case.

| | Pre-op | Peri-op | Post-op | Total | % of Total |
|----------------|-------------|---------------|---------------|---------------|-------------|
| Device | | £█ | | £█ | █% |
| Investigation | £128 | £1,388 | £1,135 | £2,651 | 32% |
| Consumables | £16 | £█ | | £█ | █% |
| Staff | £142 | £339 | | £481 | 6% |
| Length of stay | | | £239 | £239 | 3% |
| Theatre | | £█ | | £█ | █% |
| Out-patient | | | £191 | £191 | 2% |
| Total | £286 | £6,379 | £1,564 | £8,229 | 100% |

Note figures are rounded so may not sum to last digit precisely.

A full summary of all resources and unit costs is provided in [Appendix 9](#). This also describes the assumptions underpinning the sensitivity analyses.

c. Patient experience

Pre-procedure, EQ-5D values were available for 432 patients. At 6 weeks, 241 paired scores were available and these showed a mean gain in utility of 0.03, with 34% of patients reporting improved quality of life, 50% no change and 17% a deterioration. At 6 months, paired data for 207 patients were available. The marginal improvement was maintained, with a similar percentage of patients (35%) reporting an improved quality of life, 18% no change and 47% a deterioration. The mean baseline value was 0.87±0.19; however, the median value of 0.91 was adopted as a measure of central tendency.

Full EQ-5D results are presented in *Supplementary Material - Table 8*.

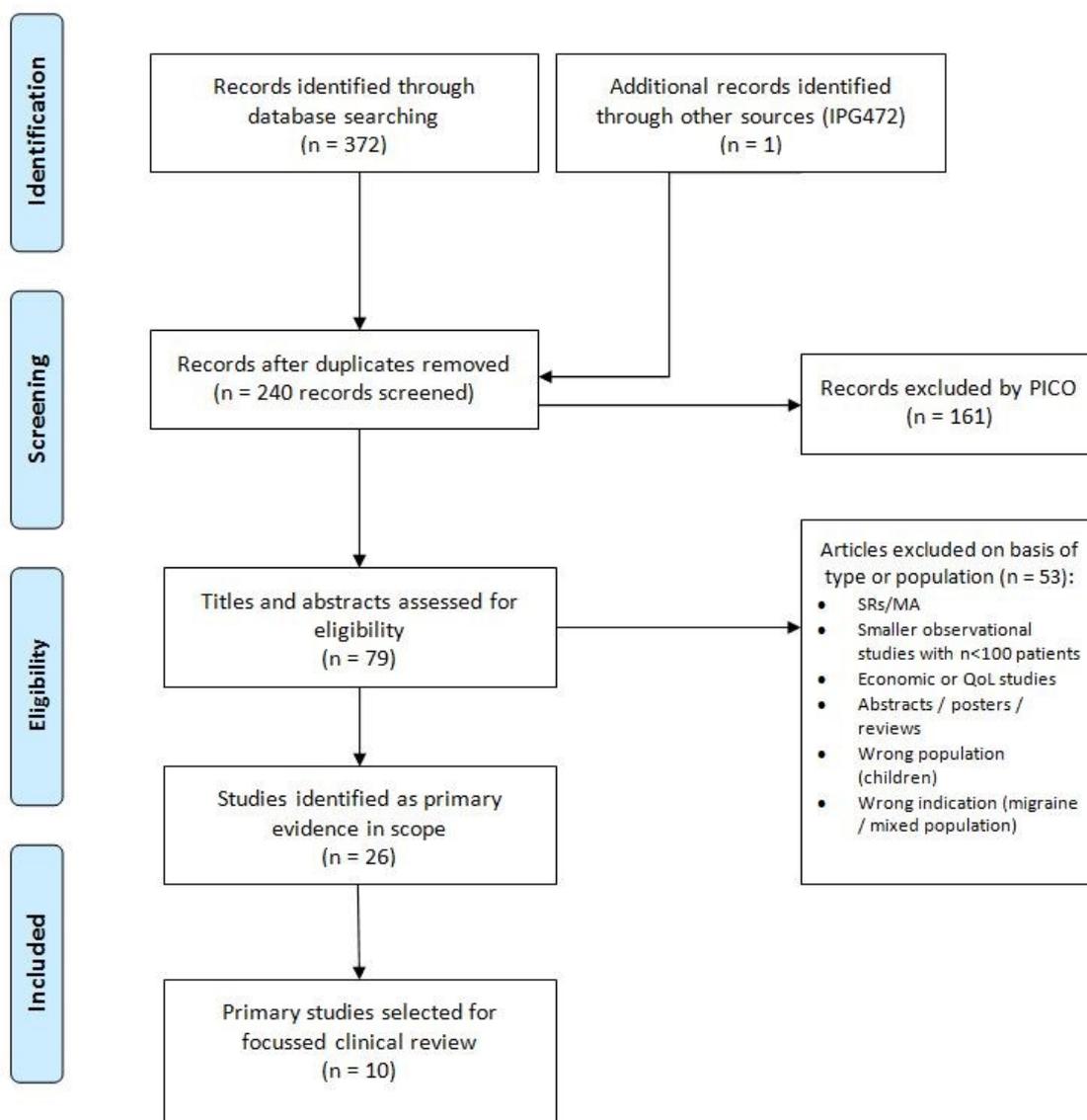
3.2 SECONDARY DATA COLLECTION (LITERATURE REVIEW)

The CtE PFOC literature search (August 2013 to November 2016) retrieved 240 potentially relevant articles. Abstracts from these articles were independently assessed for relevance by two EAC researchers. Of these, 161 were excluded immediately after screening as being not

relevant to the scope. Of the remaining 79 records, 53 were excluded for various reasons, including study size (18 studies reported on less than 100 patients).

The process of sifting using PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [9] is illustrated in [Figure 3](#) below.

Figure 3. PRISMA schematic of literature search for clinical evidence.



The literature search identified 26 primary publications that were in scope. From these, ten studies were selected for focussed review and 16 were summarised in tabular form. Studies not selected at this stage were smaller observation studies (more than 100 but less than 500 patients) or had methodological or reporting issues. Of the ten studies selected for focussed review, four were RCTs (including one identified from IPG472), four were observational studies with more than 500 participants, and two were observational studies set in the UK selected for their generalisability. Nineteen secondary studies (systematic reviews and/or meta-analyses) were identified. Although these, as synthesised data, were not technically in scope, four were selected for interim analysis to inform the NHS England questions, as described in the EAC literature review [3].

The principal clinical evidence on the use of PFOC to prevent recurrent ischaemic events is derived from three superiority randomised controlled trials (RCTs). These were the CLOSURE-1 trial (n = 909) [10], the RESPECT trial (n = 980) [11], and the PC trial (n = 414) [12], with the former investigating the use of the now discontinued STARFlex device, and the latter two using the St. Jude Medical AMPLATZER PFO Occluder. The EAC critically appraised these studies and concluded they were of reasonable methodological quality, although all were potentially subject to attrition bias. The RCTs were considered highly generalisable to the population covered by Commissioning through Evaluation (CtE). The primary outcomes of the RCTs were composites of recurrent ischaemic events and procedural and post-procedural mortality, analysed using intention to treat (ITT) analysis. All the RCTs reported statistically negative results for the primary outcome; that is, there was no significant benefit in PFOC compared with medical therapy alone. Thus, on the basis of these results the experimental evidence for the clinical benefit of PFOC is equivocal (but, in contrast, emerging evidence is reporting PFOC to be associated with significant benefits, see [Section 3.3](#)).

The EAC considered it likely that the lack of significance reported in the RESPECT trial was due to a type II statistical error. This was because there was a clear trend toward superiority of PFOC, with the point estimate of the hazard ratio (HR) being low but with wide confidence intervals (HR 0.49 [95% CI 0.22 to 1.11, p=0.08]). Significance was reached when per protocol or “as treated” analysis was employed. Analysis from a patient-level meta-analysis also indicated significant benefits of the AMPLATZER PFO Occluder device in important outcomes such as prevention of recurrent stroke. Larger trials with more participants, or reporting more outcome events over a longer time period, are required to demonstrate an unequivocal effect. Additionally, any benefits in reduction of ischaemic events should be considered in the context of peri-procedural and longer term adverse events, such as new onset atrial fibrillation (AF).

The six observational studies selected for focussed review were limited by the lack of a prospectively defined comparator and sources of confounding. A strength of these observational studies was that they were relatively large allowing for a degree of precision in clinical measurements. They provided useful data on procedural efficacy and safety, and some estimates of longer-term prognosis of patients receiving PFOC.

Results from the four systematic reviews were not entirely consistent. An individual patient meta-analysis of the controlled RCTs (n = 2303) reported that PFOC significantly reduced recurrent strokes, and that the AMPLATZER PFO Occluder was associated with a reduction in the composite measure of recurrent stroke, transient ischaemic attack (TIA) and early death HR 0.57 (95% CI 0.3 to 1.00, p=0.0480) [13]. However, a statistically significant benefit was not reported in a Cochrane review of the same studies [14]. A network analysis of three PFOC devices reported high number needed to treat (NNT) indicating low absolute benefits from the device compared with medical treatment alone [15]. Another systematic review (n = 4335) [16] reported significant benefit from the included pooled comparative observational studies, but not from the RCTs analysed.

An important issue identified with the published literature base for the PFOC procedure was that there was evidence that the type of devices employed (which are numerous) may not be clinically equivalent. One RCT [17] (n = 660), of generally poor methodology and reporting, compared the AMPLATZER PFO Occluder device directly with the GORE HELEX device (discontinued in 2011) and the STARFlex device, also since discontinued. It reported that the GORE HELEX device was associated with increased device embolisation, incomplete

device closure, and requirement for use of an additional device compared with the AMPLATZER PFO Occluder. However, results from the GORE HELEX device may not be generalizable to the GORE CARDIOFORM Septal Occluder used in the CtE programme. Issues with device equivalence need to be considered when assessing the published evidence on the procedure.

The economic evaluation was limited to evidence from one study reported in a full paper [18] and in an abstract by the same authors [19]. It adopted the perspective of the USA healthcare system payer and compared PFO closure to medical therapy. It used clinical data from a meta-analysis of three RCTs and reported that PFOC was cost-effective, having a cost per quality adjusted life year of less than \$50,000 within three years of the procedure. The resource and unit cost assumptions adopted in the decision tree analysis were poorly described and there was no transparency of the modelling of events over time. Costs did not generalise to the NHS England setting. Hence the study was judged to have poor internal and external validity. There is thus material uncertainty on whether its findings on cost-effectiveness apply in the English setting.

More well-conducted cost utility studies, preferably using English costs are required to inform commissioning of the procedure.

Further details are available in the standalone literature review document [3].

3.3 EMERGING IMPORTANT NEW EVIDENCE

The September 2017 publication of the New England Journal of Medicine (NEJM), included three important studies that are directly relevant to the analysis of the CtE registry data. Publication of these studies postdates the PFOC literature search performed by the EAC [3], and it has not been possible to critique the new studies for this report. However, the EAC recognises these studies, which have been peer-reviewed in a high-impact journal, reported data that are very relevant to the present registry. Therefore, a brief summary of the studies is provided, and key results have been used to inform [Question One](#), [Question Two](#), and the [Discussion](#).

The Patent Foramen Ovale Closure or Anticoagulants versus Antiplatelet Therapy to Prevent Stroke Recurrence (CLOSE) trial by Mas *et al.* (2017) was an investigator-initiated, multicentre, randomized, open-label, superiority trial set in France (32 sites) and Germany (2 sites) [20]. Relatively young patients (n = 663, aged 16 to 60 years) who had had a prior ischemic stroke suspected to be caused by embolism mediated through PFO were randomised to three groups in a 1:1:1 ratio (PFOC [several devices and anti-platelet regimens used]: anti-platelet drugs only: oral anticoagulation only). Mean follow up was 5.3 years ± 2.0 years (SD). Comparisons were made between PFOC and anti-platelet groups, and antiplatelet and oral anticoagulation groups. There was a procedural complication rate of 5.9% associated with PFOC, and PFOC was significantly associated with development of new AF (4.6%). However, over the course of follow up, no strokes occurred in the PFOC group (n = 238) compared with 14 strokes in the anti-platelet group (n = 235). This difference was significant (HR, 0.03; 95% CI, 0 to 0.26; p < 0.001).

The GORE REDUCE study, by Sondergaard *et al.* (2017), was a multinational, prospective, randomized, controlled, open-label trial [21]. Patients (n = 664) were randomised in a 2:1 ratio to receive one of two GORE PFOC devices (HELEX Septal Occluder, which was discontinued in 2011, or CARDIOFORM Septal Occluder) with anti-platelet therapy, or anti-platelet therapy alone. Patients were aged 18 to 59 years, had had a cryptogenic ischemic stroke within 180 days before randomization, and had a PFO with an identified right-to-left

shunt. After a median follow up of 3.2 years, clinical ischemic stroke occurred in 6 of 441 patients (1.4%) in the PFOC group compared with 12 of 223 patients (5.4%) in the antiplatelet-only group (HR, 0.23; 95% CI 0.09 to 0.62; $p = 0.002$). PFOC was associated with a serious device related complication rate of 1.4% and a significantly increased risk of new onset AF (6.6% vs. 0.4%, $p < 0.001$). However, 83% of the cases of AF or flutter were detected within 45 days after the procedure, and 59% resolved within 2 weeks after onset.

The final study published in the NEJM was an update of the RESPECT trial, which has been previously described in the EAC's literature review [3]. This paper reported updated outcomes of patients with a median follow up of 5.9 years [22]. Whereas an earlier publication of the study had reported a non-significant trend towards benefit for the primary outcome [11], a significant improvement was observed after extended follow up. Using ITT analysis, recurrent ischaemic stroke occurred in 18 patients in the PFOC group compared with 28 patients in the medical-therapy group. This was an event rate of 0.58 events per 100 PY compared with 1.07 events per 100 PY (HR 0.55; 95% CI 0.31 to 0.999; $p = 0.046$).

The two new trials and the update of the RESPECT trial all reported positive results for their primary efficacy outcomes, which is in contrast to earlier trials and publications of PFOC. The reasons for this are not clear, but could be related to methodological advances in the trial design, such as longer follow up time (this is clearly the case in Saver *et al.* [2017] [22]). Additionally, improved diagnostic work up (e.g. improved echocardiography and use of provocation) and patient selection (i.e. identifying patients where PFO is likely to be causal rather incidental) may have been a factor, as well as incremental improvements to the device themselves; if so, this has important implications for real-world clinical practice (see [Section 5](#)). Additionally, the removal of more subjective inclusion criteria and outcomes related to TIA may have effectively increased the power of the studies.

These encouraging results should also be considered in the context that although relative benefits are clinically significant, absolute benefits are somewhat small. There is also a clear indication now that PFOC causes new onset AF in around 1 in 20 patients, at a relatively young age; this may increase their risk of stroke in later life and reduce quality of life. Clearly, the risk of new onset AF will have to be balanced against the dis-benefit of suffering a thromboembolic event.

After the review was completed a presentation of an economic analysis was identified [44]. This study reported results for the cost-effectiveness of PFOC in addition to antiplatelet therapy for the secondary prevention of ischaemic stroke compared to medical therapy alone. The study was set in the USA and used clinical data from the RESPECT study [22]. It concluded that, at 20 years, the procedure had an incremental cost per quality adjusted life year of \$9,842 per patient compared with medical therapy. Hence it was cost-effective under conventional thresholds of willing to pay for a quality adjusted life year. This was judged by the EAC to be a well-conducted study but the costs of the procedure and subsequent clinical events did not generalise to the English NHS.

3.4 NHS ENGLAND QUESTIONS AND REQUESTS

3.4.1 Question One

“Does patent foramen ovale closure lower the risk of stroke or other embolic clinical events compared to no intervention (as predicted by natural history studies or from modelling)?”

Although it has been reported that cryptogenic stroke is associated with a higher risk of recurrent stroke compared with those where a cause has been identified [23], there is a paucity of information from natural history studies or models in the literature to accurately quantify this risk increase. Therefore, in order to answer this question, data from the registry (where nearly all patients received PFOC) has been compared with the control arms of the RCTs (where patients received similar care to the intervention arms but without the addition of PFOC). The trials that reported data on patients receiving systemic medical treatment only were the CLOSURE-1 trial (2012) [10] (STARFlex), RESPECT trial (2013) [11] (AMPLATZER PFO Occluder) and the PC trial (2013) [12] (AMPLATZER PFO Occluder). Patients in the CtE registry appear to have similar baseline characteristics and indications for treatment as those in the trials.

The registry recorded neurological events occurring in 3 patients in hospital, and a further 23 patients after discharge. Allowing for multiple events in patients, there were a total of 31 events, which were classified as ischaemic (9), undetermined (8), TIA (8), CVA/RND (7), haemorrhagic (2) and “other” (4). No patients died as a result of these events. The event rate was standardised using time to event analysis and compared with data from control arms reported in the literature in [Table 9](#). The time to event analyses of deaths, ischaemic neurological events and death or any neurological event are illustrated as Kaplan-Meier plots in [Appendix 6](#). [NOTE: this data has since been revised, see [Addendum](#)].

Table 9. Incidence of strokes in CtE registry and control arms of published RCTs.

| Study | Rate of neurological event (events per 100 PY) | Additional information |
|--|---|---|
| NHS England CtE registry | All neurological events: 3.4 (95% CI 2.1 to 5.0) Ischaemic event only: 1.3 (95% CI 0.6 to 2.5) | 3 patients with events in hospital and 23 patients with events after discharge. 31 events in total, of which 2 were haemorrhagic and no fatal strokes reported. |
| CLOSURE-1 trial [10] | Stroke: 1.55 TIA: 2.05 Primary composite endpoint*: 3.4 | ITT analysis (control group) 2 years follow up |
| RESPECT trial [11] | 1.38** | ITT analysis (control group) Median 2.1 years follow up |
| RESPECT trial (2017 update) [22]† | Ischaemic stroke: 1.07 | ITT analysis (control group) Median 5.9 years follow up |
| PC trial [12] | Stroke: 0.6 TIA: 0.83 Primary endpoint***: 1.3 | ITT analysis (control group) Mean 4.0 years follow up |
| CLOSE trial [20]†‡ | Stroke: 1.12 | ITT analysis (control group) Median 5.3 years follow up |
| GORE REDUCE trial [21]†‡ | Clinical stroke: 1.68 | ITT analysis (control group) Median 3.2 years follow up |
| <p>* Composite of stroke or TIA during 2 years of follow-up, death from any cause during the first 30 days, and death from neurologic causes between 31 days and 2 years. ** Primary endpoint was a composite of recurrent nonfatal ischemic stroke, fatal ischemic stroke, or early death after randomization. However, all primary events were non-fatal ischaemic strokes. *** Composite outcome of death, stroke, TIA, or peripheral embolism. No deaths in control arm. † Trials identified in Section 3.3. These have not been appraised. ‡ Event rate per 100 PY estimated by EAC from raw data counts and mean or median follow up as reported in study.</p> | | |

As the registry data were not exclusive to stroke but also included reversible ischaemic events such as TIA, the primary outcomes reported in the trials provide a reasonable proxy outcome (especially as deaths were uncommon in both the registry and the literature). It can be seen that the point estimate of neurological events from the registry is higher than that seen in the control arms of some of the identified RCTs. The event rate reported from the lower confidence interval (2.1 events per 100 PY) was higher than either of the point estimates for the AMPLATZER trials [11, 12] (1.38 and 1.3 events per 100 PY). However, it is likely that had these studies reported confidence intervals, they would overlap with those reported in the registry, inferring there may be no statistical difference in outcomes. The lower confidence limit of the registry did include the point estimate of the CLOSURE-1 trial [10], but comparing point estimates of both trial and registry, the registry event incidence was still higher (4.6 compared with 3.4). The CLOSURE-1 trial employed the discontinued STARFlex system, which may have inferior efficacy compared with the AMPLATZER PFO Occluder [24]. Regarding the newer studies (reported in [Section 3.3](#)), the reported outcomes on stroke were similar to those observed in the registry.

Data from the control arm of the individual meta-analysis by Kent *et al.* (2016) reported a primary composite outcome of 2.3 events (ischemic stroke, TIA, or death from any cause) per 100 PY, and an ischaemic stroke rate of 2.2 per 100 PY [13]. However, when only data from the AMPLATZER device trials was considered (from the RESPECT and PC trials), the incidence rate was 1.6 and 1.1 for the primary outcome and ischaemic stroke respectively, which appears lower than reported in the CtE registry.

The comparative RCTs employed a superiority design, because PFOC may be considered as adjunctive to systemic preventative medical treatment (antiplatelet drugs or oral anticoagulation), and, in most cases, additional clinical benefits over and above standard treatment need to be demonstrated to justify its use. Therefore the results reported by the registry, which ostensibly report a similar or worse primary outcome than the control arm from these studies, are unanticipated, although it must be stressed that direct comparisons with published trial data is limited by differences in reported outcomes, outcome definitions, study methodology, and more broad issues with generalisability (e.g. patient population, diagnostic work up etc.).

Conclusion

Time to event analysis has been used to compare the incidence of neurological events from the CtE registry with natural history data from the literature (in some cases using the proxy of primary outcomes from control arms of RCTs). The incidence of presumed ischaemic stroke in the registry appears to be similar or higher in the registry compared with that reported in the RCTs. However, a direct comparison of results from the CtE registry compared with data from trials is unsatisfactory because of residual uncertainty on how comparable these results are, and there are several plausible explanations for the differences seen.

3.4.2 Question Two

“Can UK clinical teams re-produce the success rates for patent foramen ovale closure reported in existing clinical trials, with equivalent or lower complication rates?”

For the purposes of this question, “success rates” has been defined separately as technical and procedural success rates, and the longer-term efficacy outcome of incidence of ischaemic stroke incidence. Complication rates refer to peri-procedural complications, which occur in hospital and may be classified as major or minor. Some complications were also

recorded following discharge although interpretation is often confounded by poor reporting of event data. For these outcomes, comparisons have been made either with the intervention arm of RCTs, or data published in the identified observational studies.

Technical and procedural success rates

The technical success of PFOC was defined as the proportion of patients in whom a device was successfully implanted (where it was attempted). Nearly all patients had a device successfully implanted, with a reported rate by participating centres of 99.3% (95% CI 98.6 to 99.8%). Procedural success was defined as technical success in the absence of major complications and was reported as 95.1% (95% CI 93.5 to 96.4%). Thus about one in twenty patients suffered an unsuccessful implantation or a potentially serious procedural complication, with the latter accounting for 1.0% (95% CI 0.4 to 1.8%) of patients. About 1 in 10 patients of those measured had residual shunt after 1 year follow up, which is important as these patients may be at continued risk of paradoxical embolism (see [Appendix 8](#)).

The rates reported in the CtE registry are compared with those in the data in [Table 10](#).

Table 10. Comparison of technical and procedural success reported in CtE registry with published literature.

| Study | | Proportion of successful procedures | Definition/comment |
|-----------------------|--------------------------|---|---|
| CtE registry | | <u>Device implantation</u> 99.3% (95% CI 98.6 to 99.8%) <u>Procedural success</u> 95.1% (95% CI 93.5 to 96.4%) | Device implantation refers to any successful implantation of the occlusion device. Procedural success is successful implantation in the absence of major complications. |
| RCTs | CLOSURE-1 (2012) [10] | 89.4% | Procedural success, defined as “successful implantation of one or more STARFlex devices at the closure site during the index procedure with no procedural complications”. |
| | RESPECT (2013) [11] | Technical success: 99.1% Procedural success: 96.1% | Technical success was successful implantation. Procedural success was technical success in absence of in-hospital serious adverse events. |
| | PC trial (2013) [12] | 95.9% | “Effective closure was defined as closure with no or minimal shunting”. |
| | Device trial (2013) [17] | 100% | “Technical success” Aggregated data from all devices |
| Observational studies | Taggart (2017) [25] | AMPLATZER Septal Occluder: 97% AMPLATZER Cribriform: 92% GORE HELEX: 92% CardioSEAL: 100% | Proportion of patients with successful implant and without residual shunt. Only 4 patients received CardioSEAL. |
| | Pezzini (2016) [26] | 92.2% | Proportion of patients with complete PFO closure (i.e. without residual shunt). |
| | Ingleddis (2013) [27] | Procedural success: 99% Effective closure: 93% | “Procedural success” assumed to mean successful device implantation. “Effective closure” assumed to mean no significant residual shunt. |
| | Wallenborn (2013) [28] | Successful implantation: 100% Successful closure: 92% | Successful closure defined no residual shunt at 1 month. 5.5% had a small shunt detected. 2.5% had a medium or large residual shunt. |

| | | | |
|--|-------------------------|-----|-----------------------|
| | Thomson (2014) [29] | 98% | “Procedural success”. |
| | Mirzaali (2015) [30] | 99% | “Procedural success”. |

Direct comparisons with published data are confounded due to differences in definitions of technical or procedural success, which were not always explicitly defined in the literature. However, in general the success rates reported in the registry matched those reported in the literature. The technical and procedural success rates were nearly identical to those reported in the AMPLATZER RESPECT trial [11], which shared the similar definitions. Procedural success in the CtE registry also appeared to be superior to that reported in the CLOSURE-1 trial, which investigated the use of the now discontinued STARFlex device [10].

Similarly high technical success rates were reported in the observational studies, including those performed in UK settings [29, 30]. There was some evidence from the literature that the rate of success was device specific [25] (see [Question 5](#)).

Efficacy rates

As reported in [Question 1](#), a total of 31 neurological events in 24 patients were recorded in the CtE registry. One patient was excluded from the time to event analysis, on account of missing data for their procedure date. Of the remaining 23 patients, the calculated event rate was 3.4 (95% CI 2.1 to 5.0) per 100 PY. This event rate is compared with those in the intervention arm of RCTs and data from observational studies in [Table 11](#).

Table 11. Comparison of neurological events with primary efficacy outcomes reported in the published literature.

| Study | | Proportion of patients with primary efficacy outcome. Events per 100 PY unless otherwise stated. | Definition/comment |
|---|--------------------------|--|---|
| CtE registry | | 3.4 (95% CI 2.1 to 5.0) Ischaemic event only: 1.3 (95% CI 0.6 to 2.5) | 23 patients, with a recorded procedure date, reported as having a neurological event. |
| RCTs | CLOSURE-1 (2012) [10] | 2.8* | Composite of stroke or TIA during 2 years of follow-up, death from any cause during the first 30 days, and death from neurologic causes between 31 days and 2 years. |
| | RESPECT (2013) [11, 22] | 0.66 0.58 (extended follow up) | Primary endpoint was a composite of recurrent nonfatal ischemic stroke, fatal ischemic stroke, or early death after randomization. However, all primary events were non-fatal ischaemic strokes ITT analysis data reported. |
| | PC trial (2013) [12] | 0.83** | Composite outcome of death, stroke, TIA, or peripheral embolism. Two deaths in control arm. |
| | Device trial (2013) [17] | 0.76* | The primary outcome was a composite of peripheral embolism, TIA, stroke, cerebral death. |
| | CLOSE trial [20]*† | 0.0 | No patients experienced stroke over 5.3 years follow up |
| | GORE REDUCE [21] † | 0.43* | Clinical ischaemic stroke rate over 3.2 years follow up. |
| Observational studies | Taggart (2017) [25] | 0.97 | Annualised rate of patients suffering stroke or TIA. |
| | Pezzini (2016) [26] | 2.73* | Ischaemic stroke, TIA, or peripheral embolism. |
| | Inglessis (2013) [27] | 0.79** | Recurrent ischaemic cerebrovascular event. |
| | Wallenborn (2013) [28] | 1.0 | Recurrent stroke, TIA, or peripheral embolism. |
| | Thomson (2014) [29] | N/A | Long-term efficacy not reported in study. |
| | Mirzaali (2015) [30] | 1.53 | Combined stroke and TIA. |
| <p>* Event rate per 100 PY estimated by EAC from raw data counts and mean or median follow up as reported in study. ** Event rate per 100 PY estimated by EAC from raw data counts and person years follow up reported in study. † Trials identified in Section 3.3. These have not been appraised.</p> | | | |

It can be seen that the point estimate of the event rate reported by the CtE registry is higher than that reported by any of the studies identified in the literature search. Furthermore, the lower 95% confidence interval, 2.1, is higher than all the studies with the exceptions of the CLOSURE-1 trial [10] and the observational study by Pezzini *et al.* (2016) [26]. The lower confidence interval of the ischaemic event rate reported in the registry (0.6) was higher than the point estimates reported in the extended RESPECT trial [22] or in the two recently

published RCTs [20, 21]. The reasons for this apparent difference are unknown but could be entirely due to differences in study methodology and generalisability (see [Section 4.3.1](#)).

Data reported from the individual patient meta-analysis by Kent *et al.* (2016) [13] indicated a rate of 1.5 per 100 PY for the primary composite outcome and 0.7 per 100 PY for ischaemic stroke. Event rates were lower when the STARFlex study was excluded, with rates of 1.0 and 0.4 for the primary outcome and ischaemic stroke reported respectively.

[NOTE: this data has since been revised, see [Addendum](#)].

Complication rate

The CtE registry reported an in-hospital rate of major complications of 1.0% (95% CI 0.4% to 1.8%) and a rate of 5.2% (95% CI 3.8% to 7.0%) following discharge. Therefore the overall rate of major complications or adverse events was 6.2%. New onset AF is known to be associated with PFOC [31], and, as a risk factor for embolic stroke, this was selected for further analysis. An in-hospital event rate of 1.0% (95% CI 0.4% to 1.9%) was observed, with a rate of 3.5% (95% CI 2.3% to 5.0%) developing after discharge. Minor complications occurred in 2.6% of patients during their index hospital episode (95% CI 1.6% to 3.8%). On follow up, 14.6% of patients developed minor complications (95% CI 12.2% to 17.2%). The full incidences of major and minor complications (by subtype) are reported in [Appendix 4](#). A comparison with the values published in the literature is reported in [Table 12](#).

Table 12. Major complications or serious adverse effects reported in the registry compared with published literature.

| Study | Proportion of major complications/adverse events | Proportion new onset or worsening atrial fibrillation reported | Definition of major complication/adverse event | |
|--|---|---|---|--|
| CtE registry* | In hospital: 1.0% (95% CI 0.4 to 1.8%) After discharge: 5.2% (3.8 to 7.0%) | In hospital: 1.0% (95% CI 0.4 to 1.9%) After discharge: 3.5% (2.3 to 5.0%) | Composite of death, neurological event, device embolisation, major cardiac structural complications, MI, major vascular injury, endocarditis, oesophageal rupture, major bleed, additional surgery. | |
| RCTs | CLOSURE-1 (2012) [10] | 3.2% | 5.7% | Major vascular procedural complication. |
| | RESPECT (2013) [11] | 4.2% | 0.2% | Serious adverse event rate was composite of 17 complications adjudicated to be due to procedure. (Overall serious adverse event rate was 23.0%). |
| | PC trial (2013) [12] | 21.1% | 2.9% | Adverse events described as “serious” but not necessarily procedure specific (17.6% in control group). |
| | Device trial (2013) [17] | N/R | 6% | Aggregate adverse event rate not reported in study. |
| Observational studies | Taggart (2017) [25] | 3.4% | In hospital: 1.0% After discharge: 2.9% | Composite of 14 procedural complications. |
| | Pezzini (2016) [26] | 4.9% | 1.5% | Serious adverse events. |
| | Inglessis (2013) [27] | 1.6% | N/R | Serious procedural-related adverse event (death, stroke, TIA, device embolisation, tamponade, deep vein thrombosis). |
| | Wallenborn (2013) [28] | N/R | 3.95% | Adverse event rate not reported. |
| | Thomson (2014) [29] | In hospital: 3% After discharge: 5.7% | 2.2% | Early and late complications reported. |
| | Mirzaali (2015) [30] | 2.3% | 4.7% | Procedural “minor” complications. Device removal, transient ST elevation, sustained arrhythmia. |
| NR: Not reported. * Data could not be aggregated to combined in-hospital and discharge for statistical reasons (poor follow up resulting in reduced denominator in “after discharge” data). | | | | |

Direct comparisons with the published literature are difficult because there was no consistent terminology used between studies. For instance, the PC trial [12] reported a rate of 21.1% for “serious adverse events” but it is likely the large majority of these were not directly related to the procedure. In addition, data were presented as percentage proportions which is dependent on follow up duration (if post-procedural complications are reported). However, in general, the reported rates of major complications and adverse effects ranged between 2% and 5%, which is consistent with that reported in the registry. In particular, the UK study by

Thomson *et al.*, (2014) [29] reported highly concordant results with the CtE registry. A large meta-analysis of observational studies (n = 7414) found a complication incidence of 4.1 events per 100 PY [32] which would also appear consistent with the CtE registry data.

Development of new onset AF was reported at a rate of between 0.2% for the RESPECT study [11] to 6.0% in the Hornung *et al.*, device comparison trial (2013) [17]. The reported CtE data is consistent with this range. There is evidence from the CLOSURE-1 trial that new onset AF was associated with the STARFlex device [10], although there was also a trend towards this for the AMPLATZER PFO occluder device evidenced by the PC trial [12].

Conclusion

Data from the CtE registry reported that the technical success was close to 100%, whilst the procedural success was around 95%. This high rate of success is consistent with data from trials and observational studies. The rate of serious peri-procedural complications observed by the registry was also largely consistent with the published literature. New onset AF appears to be a risk associated with PFOC reported by the registry and consistently by published data, although direct comparisons are complicated by differing follow up durations of studies.

There is less confidence from the registry data that PFOC performed as effectively as published trial and observational data suggests, with a rate of 3.4 (95% CI 2.1 to 5.0) reported for neurological events, and 1.3 (95% CI 0.6 to 2.5) specifically for ischaemic events. This appears to be materially higher than data reported from published RCTs and observational studies, but interpretation is limited by issues with study methodology and generalisability.

3.4.3 Question Three

“Is patent foramen ovale closure associated with an improved quality of life for these patients?”

Quality of life (QoL) was measured in the registry at baseline and at follow up (6 weeks, 6 months, 1 year, and 2 years) using the EuroQol system (EQ-5D-5L), converted to utility scores. The median baseline utility was 0.91 (IQR 0.82 to 1.00), and this changed to 1.00 at each of the follow up intervals (see *Supplementary material – Table 8*). The mean baseline utility value was 0.87 ± 0.19 and this increased to range from 0.90 to 0.91 at each of the follow up intervals.

A statistically significant change in the dimension of anxiety and depression was recorded at 6 weeks and 6 months post-procedure. Reduced anxiety or depression may have occurred because patients were reassured that their risk of a further stroke was reduced by the procedure.

3.4.4 Question Four

“Are there any longer-term cardiac complications associated with the use of these devices [for PFO closure] (e.g. erosion with penetration through the wall of the atrium/aorta)?”

This question cannot be answered through analysis of CtE registry data, which is restricted to 2 years maximum follow up. Out of 282 CtE patients eligible for follow up at 2 years, 112 (39.7%) provided follow data with no long-term cardiac complications recorded.

The literature search performed by the EAC identified an RCT with 4 years follow up [12] and an observational study with up to 8 years follow up [26], but potential longer term complications, such as atrial wall erosion, were not reported. The RESPECT trial has recently published reported long-term follow up data on patients of up to 10 years [22]. The authors reported the rate of pulmonary embolism was 0.41 per 100 PY in the PFOC group and 0.11 per 100 PY in the medical-therapy group (HR 3.48; 95% CI 0.98 to 12.34; $p = 0.04$), which is consistent with the putative mechanism of action of PFOC (or related to reduced anticoagulation use in the intervention arm). However, no long-term complications involving the device *per se* were reported.

It is likely that the incidence of long-term complications, such as cardiac erosion, in this population will be low and ascertained mainly in case reports [33], but these were excluded from the EAC’s literature identification.

Conclusion

The registry was not designed to identify potential longer-term complications of longer than 2 years. The incidence of complications appears to be very low before this time period. The EAC is unaware of any signal from the literature to indicate PFOC devices are associated with specific cardiac complications.

3.4.5 Question Five

“Which devices are used to undertake PFO? What are the device-specific efficacy and safety outcomes in CtE funded patients undergoing the procedure? In particular, is there any published or register evidence of complications in the long term from percutaneous PFO closure (e.g. erosion with penetration through the wall of the atrium/myocardium/pericardium)?”

Devices implanted

The manufacturers of the devices implanted in patients receiving PFOC at first attempt in the CtE registry are listed in [Table 13](#). As can be seen, St. Jude Medical (the AMPLATZER range) and GORE (the CARDIOFORM Septal Occluder) dominated the market share, with Occlutech (the Figulla Flex range) having a smaller presence.

Table 13. Devices used in CtE registry.

| Manufacturer (device) | Proportion of devices fitted in the CtE registry |
|------------------------------------|--|
| St. Jude Medical (AMPLATZER range) | 54.5% |
| GORE (CARDIOFORM Septal Occluder) | 30.1% |
| Occlutech (Figulla Flex range) | 13.1% |
| Other (inc. combination) | 2.3% |

Device specific efficacy

Regarding the primary efficacy endpoint of incidence of neurological event, there were 10 events in patients receiving the AMPLATZER range of devices (10/495), 11 in patients receiving the GORE CARDIOFORM Septal Occluder device (11/276), and 3 in those receiving the Occlutech Figulla Flex range of devices (3/110); see [Appendix 7](#). This was an event rate of 2.0% for the AMPLATZER devices compared with 4.0 % for the GORE CARDIOFORM Septal Occluder, but was not significantly different. The AMPLATZER range was associated with a higher rate of major complications than the GORE CARDIOFORM Septal Occluder (1.3% vs. 0%), but again this difference was not significant. Thus overall there was no significant difference seen between devices in terms of efficacy or aggregate safety.

One RCT identified in the literature directly compared three PFOC devices (see full literature review [3]). This was the study by Hornung *et al.* (2013) [17] which was a three armed trial (n = 660) comparing the AMPLATZER PFO Occluder, GORE HELEX (discontinued in 2011) and CardioSEAL STARFlex (also now discontinued) systems with a follow up of 5 years. The primary outcome was a composite of TIA, stroke, or death from neurological causes or any other paradoxical embolism. Secondary endpoints were the individual components of the primary outcome and complications. The primary outcome occurred in 1.4%, 4.1%, and 5.9% of patients with the AMPLATZER, HELEX, and STARFlex devices respectively. The AMPLATZER PFO Occluder was found to be statistically superior to the other devices for the composite outcome (p=0.042), but not any of the component outcomes. Complete PFO closure was recorded in 100% of AMPLATZER devices compared with 96.8% for the HELEX system and 98.8% for the STARFlex system. The HELEX system was found to be statistically inferior to the others in this regard (p=0.004). The HELEX system was also found to be associated with a significantly greater rate of device embolisation (1.3% compared with 0% for the other devices).

Two observational studies also reported limited between-device comparisons. Results from these studies should be considered in the context they are subject to confounding and bias. The study by Inglessis *et al.* (2013) found no difference in the rate of effective of PFO closure in the six devices investigated [27]. The study by Taggart *et al.* (2017) reported that both the AMPLATZER Cribriform device and the GORE HELEX device were associated with a greater rate of residual shunt compared with the AMPLATZER Septal Occluder [25].

Two meta-analyses of the CLOSURE-1, RESPECT and PC trials [10-12] reported a (non-significant) trend towards improved primary outcomes when disc-occluder devices (AMPLATZER PFO Occluder) were analysed compared with outcomes associated with the STARFlex device [13, 14]. A network meta-analysis by Stortecky *et al.* (2015) [15] reported the absolute benefit of the AMPLATZER PFO Occluder, STARFlex, and GORE HELEX systems in terms of number needed to treat (NNT) or number needed to harm (NNH). For the outcome of stroke prevention compared with medical treatment, the AMPLATZER PFO Occluder was associated with greater absolute benefit with an NNT of 29 (NNT 21 to NNT 109) than the GORE HELEX system (NNT 60 [NNT 21 to NNH 10]). The point estimate of the STARFlex device was associated with the potential to do harm (NNH 1518 [NNT 31 to NNH 12]).

There was no evidence from the CtE registry (see [Question Four](#)) or the literature regarding long-term adverse effects of device implantation such as cardiac wall erosion.

Conclusion

The AMPLATZER PFO Occluder (St. Jude Medical) and the GORE CARDIOFORM Septal Occluder were the predominant devices used on patients in the CtE registry. There was no evidence from registry data that any device outperformed another or was associated with increased risk of complications. There was some evidence from a comparative RCT that the GORE HELEX system was associated with lower rates of complete occlusion and increased risk of embolisation compared with the AMPLATZER PFO Occluder device. However, it cannot be assumed that published trial results from the GORE HELEX device are directly generalizable to the GORE CARDIOFORM Septal Occluder used in the CtE programme. This indicates that although differences in specific device efficacy have not been measured, clinically important differences in performance are plausible.

3.4.6 Question Six

“What are the short and medium term risks of percutaneous PFO closure?”

Percutaneous PFOC was recommended under normal arrangements in NICE IPG472, which stated “evidence on the safety of percutaneous closure of patent foramen ovale to prevent recurrent cerebral embolic events shows serious but infrequent complications” [34]. Evidence for the safety of the procedure derived from the CtE registry is described in [Question Two](#). Serious complications appear to be relatively rare, with a rate of 1.0% in hospital and 5.2% after discharge. There were a total of 3 recorded deaths (0.3%) (see [Appendix 4](#)). This appears to be consistent with published literature.

Conclusion

The evidence from the CtE registry suggests the short and medium term risks of percutaneous PFOC is consistent with the published data and on this basis an update of IPG472 is not required.

3.4.7 Question Seven

“What proportion of patients referred to an MDT for possible percutaneous PFO closure against Commissioning through Evaluation criteria were considered suitable for the intervention?”

The CtE registry reported that, once a patient was selected for the procedure at an MDT meeting, the large majority of patients were determined to be suitable candidates for PFOC and proceeded to have the intervention ([Table 14](#)). However, it is likely that most centres did not use the registry to capture all cases presented to the MDT meeting; that is, patients not selected for the procedure were not subsequently enrolled into the registry. Therefore this data cannot be used to reliably answer the question.

Table 14. MDT decision on suitability for PFOC.

| Decision by MDT (suitability for PFOC)* | Number of patients | Proportion of patients (%) |
|--|--------------------|----------------------------|
| No | 15 | 1.8 |
| Yes | 819 | 97.6 |
| Unknown | 5 | 0.6 |
| * 839 data fields complete (98.9%), with data missing in 9 (1.1%). | | |

Thirteen reasons for non-treatment were reported in the 15 patients not selected for PFOC (multiple choices permitted), and were that the presence of PFO could not be confirmed by the imaging specialist (3); only a minor shunt was detected and the patient was deemed

unlikely to benefit (2); PFO present but other mechanism for stroke thought more likely (2); PFO present, but no evidence of cerebral infarct on imaging (1); ASD confirmed so ASD closure performed instead (3); other (2).

The reasons for treatment with PFOC are listed in [Table 15](#), together with indications reported from another UK registry, that of Thomson *et al.* (2013) [29], which reported on experience with the GORE HELEX device. The principal reason for treatment with PFOC reported in the CtE registry was prior cryptogenic stroke (77.6% of patients) or TIA (13.5% of patients), with a combined total of 91.1%, similar to the Thomson registry. Migraine and decompression illness accounted for 5.4% of indications for PFOC. These are not valid reasons for treatment eligibility according to NHS England criteria [35] and are excluded from the CtE analyses ([Appendix 1](#)).

Table 15. Reasons for treatment specified at MDT meeting (CtE registry – multiple reasons permitted) and as reported by Thomson *et al.* (2013).

| Indication | Proportion (%) | |
|---------------------------|----------------|---------------|
| | CtE registry | Thomson study |
| Previous single stroke | 64.2 | 83.4 |
| Previous multiple strokes | 13.4 | |
| Previous single TIA | 7.9 | |
| Previous multiple TIAs | 5.6 | |
| Migraine | 4.7 | 2.2 |
| Decompression illness | 0.7 | Not reported. |
| Other | 3.4* | 10.4** |

* Desaturation syndrome (0.1%), myocardial infarction (presumed embolic) (1.8%), peripheral embolus (0.5%), prior to neurosurgical procedure (0.1%), other (0.9%).
 ** Including coronary paradoxical embolus, and embolus to other (noncerebral) organs, residual shunt after previous closure.

The data reported by the registry did not provide information on the absolute number of patients suitable for treatment at a national level and thus likely budgetary impact. The EAC did not identify data from the published literature that could inform a top down analysis to answer this question, which would be dependent on the prevalence and incidence of patients who have had a cryptogenic neurological event suspected to be caused by paradoxical embolism. It is possible a bottom up approach of analysis could be undertaken using centre data from the registry.

Conclusion

The registry reported around 98% of the patients referred for MDT assessment for PFOC progressed to receive the procedure. However, it is unlikely this accurately reflects real-life patient pathways (that is, the registry was not used to capture all cases presented to MDT). It is therefore unknown what proportion of patients were referred for MDT in the first instance, or what the national demand for this service is for this, or other, indication.

3.4.8 Question Eight

“Are favourable clinical outcomes with patent foramen ovale closure associated with particular patient characteristics (clinical or demographic)?”

Exploratory multivariate analysis was conducted using generalised linear modelling with binomial error distribution in order to estimate the effect of covariates. All numeric covariates were centred on their median before inclusion in multivariate analysis. However, it was found

that the binary logistic regression analyses did not converge, or were over-fitted for the following measures:

- device implanted outcome – covariates: procedure number (tertiles), gender, age, BMI, eGFR, pulmonary hypertension, NYHA (New York Heart Association) dyspnoea status, previous atrial septal procedure, atrial septal aneurysm;
- in-hospital major and minor complications outcomes – covariates: procedure number (tertiles), gender, age, BMI, eGFR, pulmonary hypertension, NYHA dyspnoea status, previous atrial septal procedure, atrial septal aneurysm, intraoperative echo imaging, and device(s) implanted.

Therefore a simpler set of covariates were tested for the CtE data and no significant association between age or sex and death was found.

The CLOSURE-1 trial [10] performed subgroup analysis on the primary outcome using the explanatory variables of sex (male or female); presence of atrial septal aneurysm; shunt size (none or trace, moderate or substantial); indication (stroke or TIA); and baseline medication (none, aspirin alone, warfarin alone, or aspirin plus warfarin) in subgroup analysis. None of these characteristics were significantly associated with improved or worsened outcomes.

The RESPECT trial [11], which found no significant improvement in the primary outcome compared with medical treatment overall (hazard ratio [HR] 0.49 [95% CI 0.22 to 1.11, $p=0.08$]) performed subgroup analysis on a number of demographic and clinical characteristics. The authors reported two factors that were associated with significantly improved outcomes compared with the control group. These were the presence of atrial aneurysm, which was associated with a HR of 0.19 (95% CI 0.04 to 0.87, $p=0.02$), and the presence of substantial shunt size (HR 0.18 [95% CI 0.04 to 0.81]). It is mechanistically plausible that repair of more substantial defects could result in greater efficacy gains.

The PC trial [36] reported no significant benefit of PFOC overall, with a HR of 0.63 (95% CI 0.24 to 1.62). Subgroup analysis of the primary outcome was conducted for age (<45 years or ≥ 45 years); presence of atrial septal aneurysm; index event (stroke or TIA [or pulmonary embolism]); and number of previous cardiovascular events (1 or ≥ 1). There was a trend toward younger people receiving benefit, although this was not significant (HR 0.16 [95% CI 0.02 to 1.31, $p=0.09$]). In contrast to the RESPECT trial, the presence of atrial septal aneurysm was not associated with clinical benefit, and in fact trended towards being a risk (HR 2.09 [95% CI 0.38 to 11.4], $p=0.78$). However, this study was likely to be underpowered to detect effects in specific subgroups.

The observational study by Taggart *et al.* (2017) [25] performed extensive subgroup analysis. The authors reported the following risk factors that were associated with recurrent neurological events: increasing age (HR 1.04 [95% CI 1.02 to 1.07, $p<0.001$]); hypertension (HR 2.07 [95% CI 1.15 to 3.72, $p=0.15$]); diabetes mellitus (HR 3.82 [95% CI 1.84 to 7.94, $p<0.001$]); right ventricular systolic pressure (HR 1.04 [95% CI 1.01 to 1.07, $p=0.013$]); and pulmonary artery systolic pressure (HR 1.05 [95% CI 1.02 to 1.08, $p<0.001$]). It is unclear if statistical correction for multiple comparisons was performed (e.g. Bonferroni correction).

The observational study by Wallenborn *et al.* (2013) [28] performed multivariate analysis of predictors of recurrent ischaemic events. The authors reported the number of prior ischaemic events (HR 1.4 [95% CI 1.2 to 1.7, $p<0.001$]) and the presence of diabetes mellitus (HR 2.4 [95% CI 1.1 to 5.2, $p=0.034$]) were prognostic risk factors. However, the

detection of thrombus formation was found to greatly increase the risk of recurrent stroke, with a HR of 6.8 (95% CI 2.4 to 19.3, $p < 0.001$).

The meta-analysis of RCTs by Kent *et al.* (2015) [13], which pooled individual patient data from the three RCTS comparing PFOC with medical therapy [10-12] performed subgroup analysis on the following risk factors: age; sex; smoking status; shunt size (measured by TOE); atrial septal aneurysm; index event (stroke or TIA); history of migraine; and radiology results (superficial stroke or others). In this analysis, none of the risk factors was associated with significantly improved outcomes, although male sex trended to this ($p = 0.064$). The presence of atrial septal aneurysm was associated with a HR of 0.65 (95% CI, 0.34 to 1.23), compared to a HR of 0.71 (95% 0.44 to 1.14) in those without the condition ($p = 0.845$).

Conclusion

No significant associations were found between age or gender and death in the CtE registry. One RCT reported evidence that the use of PFOC in the presence of atrial septal aneurysm and large shunt size was associated with greater clinical benefit, which appears to be mechanistically plausible. However, this effect was not observed by other experimental or observational studies.

3.4.9 Question Nine

‘What are the average full procedural costs of percutaneous patent foramen ovale closure to the NHS?’

[Table 7](#) demonstrates that the forecast cost for a PFO closure procedure ranged from about £6,940 to over £9,250 with a central estimate of around £8,230. The device cost included in each scenario is £■■■■ per patient (£■■■■ for one device) and it accounts for between ■■% to ■■% of the total cost, depending on the scenario. This was calculated by using the number of devices opened per patient from the database. The database also reported the devices used, by manufacturer, across centres. NHS Supply Chain provided the unit cost for each device for the main manufacturers. These prices include a 3% overhead for the NHS Supply Chain’s costs. These data enabled the EAC to calculate an average cost per device and per patient. An additional 15% overhead was added to the NHS Supply Chain cost to provide an estimate of the full cost to the NHS.

Under the central cost scenario, the pre-operative pathway accounted for 3%, the procedure 78% and subsequent management 19% of total costs respectively.

Conclusion

The forecast cost for a PFO closure procedure ranged from about £6,940 to over £9,250 with a central estimate of £8,230.

3.4.10 Question Ten

‘What are the potential cost savings for the NHS in patients receiving percutaneous patent foramen ovale closure?’

Cost consequences analyses were undertaken to compare the costs and clinical outcomes of PFOC plus medical therapy with medical therapy alone. This is reported in a separate output from the EAC [43]; this is a summary of the report provided in response to this question.

As noted in [Section 3.2](#) the literature review identified no published studies providing results which generalised to the English NHS setting. Hence a *de novo* economic model was built. Where possible, data from the CtE registry were used to inform the parameters in the economic model. Patients entered the model aged 45 years, the median age in the registry. They flowed through the model for 45 years, to age 90 years. Results were reported from two perspectives; NHS only and a wider NHS and social care perspective.

Costs and benefits were discounted by applying an annual 3.5% discount rate over each of the 45-years of the model to age 90 years. This is consistent with NICE methods for conducting technology appraisals [45]. The discount rate is applied to reflect the present value of the stream of costs and benefits accruing over the time horizon of the analysis. As a sensitivity analysis, results are presented with no discount factor applied.

The economic model was constructed as a combination of a decision tree to determine PFOC operative success and operative complications, followed by a Markov model for long term outcomes following discharge post-PFOC plus medication. In the decision tree, people could have a device implanted successfully or not and could develop major or minor bleeds. In the Markov model, in each cycle people could be in a stroke free state, experience a neurological event (ischaemic or haemorrhagic stroke or transient ischaemic attack), atrial fibrillation, bleeds or die.

In the PFOC arm of the model, patients had procedure-related risks and experienced strokes and bleeds at the rates observed at discharge in the CtE registry, as analysed in the Addendum to this document. Thereafter the rates for these events were extracted from the RESPECT trial [22], up to 5.9 years. Clinical events thereafter were extrapolated from 5.9 years to lifetime in the model (90 years).

Patients in the comparator arm received medical therapy consistent with that recorded in the CtE registry at baseline. Their modelled clinical event rates were taken from those of the comparator arm of the RESPECT RCT. The clinical event rates recorded in the trial were also extrapolated from 5.9 years to lifetime in the model. In the absence of published evidence to indicate that event rates diverge over time between the two arms, the EAC assumed that the event rates from 5.9 years in each arm continued for the rest of the patient's life.

The estimated cost of the PFOC procedure was calculated using resource use data from the registry and a costing template completed by participating sites. Stroke costs were taken from a cost study conducted by the Sentinel Stroke National Audit Programme [46]. Other costs were from national databases.

A range of sensitivity analyses were conducted on the event rates for ischaemic stroke, time horizon, age of patients and unit costs of the procedure and for the management of stroke.

The model was run for a cohort of 1,000 people with costs and patient outcomes aggregated from a start age of 45 years to aged 90 years.

The results from the base case are those which use the best point estimates for all the parameters that inform the model. Hence its results are the best estimate of the cost savings. As reported in [Table 16](#) from an NHS perspective the total discounted cost per patient receiving a PFOC procedure was estimated at £12,956 of which procedure-related costs were £8,233 (64%). The second largest contributor to costs (£2,918, 23% of costs)

were the costs to the NHS to manage patients who had subsequent strokes, with the cost of medicine and management in primary care being £1,737 or 13%.

For patients managed by medical therapy, the total discounted cost was estimated at £7,596 per patient. Stroke management accounted for £5,003 (66%) of these costs, with medicines and management in primary care accounting for £2,574 (34%).

Hence PFOC was estimated to cost an additional £5,360 per patient. The procedure cost of £8,233 (including bleeds) was not offset by savings in primary care (£837) or strokes and TIA avoided (£2,084).

Undiscounted costs are usually reported for budget impact analysis with a short (5-year) time horizon. Given NHS England may wish to use the results to inform such an analysis these are also presented. The estimated undiscounted cost of PFOC over 45 years was £17,053 per patient compared with £14,031 per patient managed on medical therapy. Hence the incremental undiscounted costs were £3,022 per patient. However, this approach does not reflect society's preference for benefits to be experienced in the present rather than the future whilst deferring costs from the present to the future. It is not a recommended approach for health technology appraisals.

Table 16. Total NHS costs per patient over a 45-year time horizon

| | Discounted costs per patient | | | Undiscounted costs per patient | | |
|---------------------------|------------------------------|---------------|---------------|--------------------------------|----------------|----------------|
| | PFOC | MT | Difference* | PFOC | MT | Difference* |
| Procedure & bleeds | £8,233 | £0 | +£8,233 | £8,233 | £0 | +£8,233 |
| Medication & primary care | £1,737 | £2,574 | -£837 | £3,048 | £4,442 | -£1,393 |
| Ischaemic stroke (NHS) | £2,809 | £4,686 | -£1,877 | £5,465 | £8,989 | -£3,524 |
| Haemorrhagic stroke (NHS) | £8 | £169 | -£160 | £16 | £321 | -£305 |
| TIA | £101 | £148 | -£47 | £174 | £250 | -£76 |
| Bleeds | £68 | £19 | +£49 | £117 | £29 | +£87 |
| Total | £12,956 | £7,596 | £5,360 | £17,053 | £14,031 | +£3,022 |

*A plus sign indicates higher cost with PFOC. Numbers are rounded.

Device costs include 15% overheads, about £500 per device. These are related to the costs of functions such as procurement, stores, finance and general management within NHS trusts. Removing these would reduce the incremental costs of PFOC. The base case analysis incremental cost would fall from £5,360 per patient to £4,859 per patient. The cost of the procedure would need to reduce by 65% to £2,854 before the NHS would achieve financial break-even on the procedure.

Under the wider NHS and social care perspective, the discounted costs per patient were £3,733 higher for patients undergoing a PFOC procedure. Total costs in the PFOC arm were £15,094 per patient, compared with £11,360 per patient managed by medical therapy. The benefits from avoided stroke management (£3,711) and reduced costs in primary care (£837) with PFOC were insufficient to offset the initial procedure costs of over £8,230 per patient.

Deterministic, probabilistic and scenario analyses reported that the PFOC arm was usually cost incurring. For example, in a probabilistic sensitivity analysis only 13% of iterations

resulted in PFOC being cost saving. The results were sensitive to changes in the rates of ischaemic stroke with PFOC and only medical therapy.

The key uncertainties related to the clinical values used, particularly for ischaemic stroke rates and the relative benefit of PFOC as patients age in each arm.

A key limitation is that the form of analysis does not value the quality of life benefit associated with fewer strokes. Such a valuation would be essential to inform a cost utility analysis where results are expressed as an incremental cost per quality adjusted life year. However, NICE advised the EAC that this form of analysis was not requested by NHS England. With cost consequences analysis, the decision makers do not have a threshold-based decision rule to inform their decisions on cost effectiveness. Hence it is not possible for the EAC to advise from an NHS perspective, whether the additional cost to the NHS of £5,360 is cost-effective, given the forecast savings in strokes and deaths.

Conclusion

The lifetime costs to the NHS of a patient receiving a PFOC procedure was estimated at £12,956. For patients managed by medical therapy, the total cost per patient was estimated at £7,596. Hence PFOC was estimated to cost an additional £5,360 per patient.

3.4.11 Question Eleven

‘What is the likely cost-effectiveness of percutaneous PFO closure in the NHS, based on UK costs?’

The response to [Question Ten](#) identified that an economic model estimated an incremental cost to the NHS of about £5,360 per patient with a PFOC procedure compared with medical therapy only. When the wider health and social care perspective was adopted the model predicted that PFOC would still be associated with higher costs of £3,733 per patient.

The model also reported changes in clinical outcomes as identified in [Table 17](#).

Table 17. Comparison of clinical events per 1,000 patients over a 45-year horizon

| Clinical event | PFOC | Medical therapy only | Difference | % change with PFOC |
|---------------------|--------------|----------------------|-------------|--------------------|
| Ischaemic stroke | 190 | 305 | -115 | -37% |
| Haemorrhagic stroke | 1 | 10 | -9 | -95% |
| Subsequent strokes | 83 | 141 | -58 | -41% |
| TIA | 175 | 251 | -76 | -30% |
| New onset AF | 61 | 25 | 36 | 143% |
| Deaths | 808 | 862 | -54 | -6% |
| Total | 1,318 | 1,594 | -276 | -17% |

Note figures are rounded so may not sum to last digit precisely.

The model predicted that over 45 years the total number of strokes per 1,000 patients (ischaemic, haemorrhagic and subsequent strokes) may reduce from 456 when patients are managed only on medical therapy to 274 following a PFOC procedure, a reduction in strokes of 182 or about 40%. Associated with this reduction were 54 forecast fewer deaths in the cohort receiving the PFOC procedure. However new onset AF events were forecast to increase to over 60 compared with 25 for those managed on medical therapy. Total adverse clinical events were forecast to decline by 17% from 1,594 to 1,318 or 17%. Note in the model some people had multiple events as the first stroke increased the likelihood of a subsequent stroke or death.

The key uncertainties with the clinical analyses are the validity of:

- Using the RESPECT study to model events post-discharge. A comparison of events rates in the registry at 2 years with those reported from Carroll et al [11] at 2.6 years identified similar rates. However, the patient characteristics suggest the patients in the RESPECT study may have had more co-morbidities (for example more patients had hypertension, hypercholesterolemia, diabetes and were smokers than patients in the registry).
- Extrapolating the observed absolute risks and risk reduction in primarily ischaemic strokes from the PFOC arm of the RESPECT study at 5.9 years [22] to the lifetime of patients in the model. There is no evidence of the long-term efficacy of the device or the natural history of the stroke-risk of these patients to validate such assumptions.
- Extrapolating the observed risk reduction in primarily ischaemic strokes from the medical therapy arm of the RESPECT study at 5.9 years [22] to the lifetime of the model.

The results are sensitive to the assumptions made about these parameters.

The key benefit omitted from this CCA analysis is that from the improved quality of life as a consequence of fewer strokes. This benefit was not measured in the CtE register although it did provide a measure of the procedure-related gain in quality of life (see response to [Question Three](#)).

The quality of life benefit associated with fewer strokes would be essential to inform a cost utility analysis where results are expressed as an incremental cost per quality adjusted life year. However, NICE advised the EAC that this form of analysis was not requested by NHS England.

With cost consequences analysis, the decision makers do not have a threshold-based decision rule to inform their decisions on cost effectiveness. Hence it is not possible for the EAC to advise from an NHS perspective, whether the additional cost to the NHS of £5,360 is cost-effective given the forecast savings in strokes and deaths.

Conclusion

The PFOC procedure is associated with estimated additional costs of £5,360 per person and will avoid about 275 adverse events in a cohort of 1,000 patients. The EAC cannot advise whether this is cost-effective from an NHS perspective.

3.4.12 Summary of answers to NHS England questions

Answers to the NHS England questions are summarised in [Table 18](#).

Table 18. Summary of NHS England answers.

| Final version of question, as amended NICE following discussion with EAC | Summary answer (from registry data supplemented by published literature) |
|---|--|
| 1. Does patent foramen ovale closure lower the risk of stroke or other embolic clinical events compared to no intervention (as predicted by natural history studies or from modelling)? | <p>Time to event analysis from the CtE registry reported a rate of 3.4 (95% CI 2.1 to 5.0) neurological events per 100 PY, of which 1.3 (95% CI 0.6 to 2.5) are attributed to ischaemic origin. In the absence of natural history or modelling studies identified from the literature, the primary outcome of control arm of published RCTs was used as a proxy comparator. The control arm data reported point estimate rates of between 1.12 and 3.4 events per 100 PY. However, the EAC cautions that a direct comparison with published trial data may not be valid for reasons of methodology and generalisability.</p> <p>The incidence of presumed ischaemic stroke in the registry appears to be similar or higher in the registry compared with that reported in the control arms of RCTs. However, as it is not possible to provide a statistical comparison between the data, no firm conclusions can be made about inferiority, superiority, or equivalence.</p> |
| 2. Can UK clinical teams re-produce the success rates for patent foramen ovale closure reported in existing clinical trials, with equivalent or lower complication rates? | <p>Procedural data were well reported in the registry. Technical success was close to 100%, whilst procedural success was around 95%. This is consistent with published data from trials and observational studies.</p> <p>There was evidence that the incidence of ischaemic events reported in the registry appeared to be higher than expected compared with published literature. However, the EAC cautions that a direct comparison with published trial data may not be valid for reasons of methodology and generalisability.</p> <p>The incidence of peri-procedural complications observed in the CtE registry was largely consistent with the published literature. New onset AF appears to be the most common adverse event.</p> |
| 3. Is patent foramen ovale closure associated with an improved quality of life for these patients? | <p>A statistically significant improvement in the dimension of anxiety and depression was recorded at 6 weeks and 6 months post-procedure</p> <p>No data were identified from the literature to answer this question.</p> |
| 4. Are there any longer-term cardiac complications associated with the use of these devices [for PFO closure] (e.g. erosion with penetration through the wall of the atrium/aorta)? | <p>The registry did not follow up patients for sufficiently long enough to answer this question.</p> |

| Final version of question, as amended NICE following discussion with EAC | Summary answer (from registry data supplemented by published literature) |
|--|---|
| 5. Do the commercially available current devices perform equivalently? | <p>The AMPLATZER PFO Occluder (St. Jude Medical) and GORE CARDIOFORM Septal Occluder were the principal devices used in the CtE registry. There was no evidence of difference in efficacy or safety between device manufacturers.</p> <p>A comparative RCT reported that the GORE HELEX system (discontinued in 2011) was associated with lower rates of complete occlusion, and greater rates of embolisation, than the AMPLATZER PFO Occluder. However, these results may not be generalisable to the GORE CARDIOFORM Septal Occluder device used in the CtE programme.</p> |
| 6. What are the short and medium term risks of percutaneous PFO closure? | There was no safety flag identified from the registry that would require an update of NICE IPG472. |
| 7. What proportion of patients referred to an MDT for possible percutaneous PFO closure against Commissioning Through Evaluation criteria were considered suitable for the intervention? | It is likely that most centres did not use the registry to capture all cases presented to the MDT meeting, and therefore this data cannot be used to answer the question. The demand for PFOC and therefore budgetary impact are unknown. |
| 8. Are favourable clinical outcomes with patent foramen ovale closure associated with particular patient characteristics (clinical or demographic)?” | <p>There were insufficient data reported in the registry to allow for subgroup analysis.</p> <p>Data from the literature indicate that the size of shunt and/or presence of an atrial septal aneurysm may be associated with greater benefits compared with medical management than patients that lack these risk factors, but this is not conclusive.</p> |
| 9. What are the average full procedural costs of percutaneous patent foramen ovale closure to the NHS? | The central estimate of the cost of a PFOC procedure is £8,230, range £6,940 to £9,250. |
| 10. What are the potential cost savings for the NHS in patients receiving percutaneous patent foramen ovale closure? | The PFOC procedure was estimated to cost the NHS an additional £5,360 per patient over their lifetime. The PFOC pathway had estimated costs of £12,956 per patient, compared with £7,596 with a medical therapy only pathway. The procedure cost of £8,233 (including bleeds) was not offset by savings in primary care (£837) or strokes and TIA avoided (£2,084). |
| 11. What is the likely cost-effectiveness of percutaneous PFO closure in the NHS, based on UK costs?” | <p>In a cohort of 1,000 patients with similar characteristics to those in the registry, over a 45-year period, the PFOC procedure plus medical therapy was estimated to reduce strokes from 456 when patients are managed only on medical therapy to 274, a reduction in strokes of 182 or 40%.</p> <p>Associated with this reduction were 54 forecast fewer deaths in the cohort receiving the PFOC procedure. The EAC cannot advise whether the additional cost to the NHS of £5,360 per patient is cost-effective given the forecast savings in strokes and deaths.</p> |

Section 4: Discussion

4.1 SUMMARY OF FINDINGS FROM PRIMARY DATA COLLECTION (CTE DATABASE)

The CtE registry enrolled a total of 1,126 patients, of which 995 were selected following MDT assessment based on suitability for the procedure (see [Appendix 1](#)). Included patients had a median age of 45 years (IQR 36 to 51 years). The large majority of patients (85.7%) had had an ischaemic stroke diagnosed by cranial imaging (computed tomography [CT] or MRI scanning). All patients had PFO identified by echocardiography which was thought to be the causal reason for the stroke (through paradoxical embolism). In most cases, the PFO was not associated with a haemodynamic shunt that might have caused symptoms (92.4% patients had no limitation of physical activity as measured by NYHA class). Procedural outcomes were reported in 901 patients (91%), for whom both admission and discharge data were available. Medium term safety and efficacy outcomes were reported in follow-up information in 78.3% procedures at 6 weeks, 68.3% at 6 months, 59.4% at 1 year and 39.7% at 2 years (of eligible patients). There were no significant differences in clinical characteristics between patients who were followed up and all patients at baseline.

Most patients were treated with a St. Jude Medical device from the AMPLATZER range (45.5%) or GORE CARDIOFORM Septal Occluder device (30.1%), with 13.1% receiving an Occlutech device from the Figulla Flex range. There was a high implantation rate of 99.3% (95% CI 98.6 to 99.8%), and procedural success of 95.1% (95% CI 93.5 to 96.4%). Nine patients (1.0%) had a major in-hospital complication, including 1 death. Twenty four patients experienced a minor complication in hospital. The large majority of patients had a one night stay in hospital.

Following discharge, there were 32 additional major complications reported, including 2 deaths. Neurological events were reported for 26 patients during or post-PFOC procedure discharge (with potential for multiple events per patient), consisting of 9 ischaemic, 2 haemorrhagic, 7 undetermined, 8 TIA, 7 CVA/RND and 4 “other” neurological event. Over the course of follow up, the event rate of all neurological events was 3.4 (95% CI 2.1 to 5.0) per 100 PY, and the rate of ischaemic event was 1.3 (95% CI 0.6 to 2.5) per 100 PY, over a total aggregated follow up period of almost 700 person-years.

The central estimate of the cost of the procedure was £8,230 (range £6,940 to £9,250). The largest component of the cost was the device (■%) followed by investigations (32%). Remaining costs were related to consumables, staff, hospital stay, theatre use and outpatient clinics.

Analysis of limited EQ-5D data indicated that the use of PFOC may relieve anxiety and depression, but there was no measurable impact on quality of life in the other domains.

4.2 COMPARISON TO SECONDARY DATA (RESULTS IN LITERATURE REVIEW)

The EAC performed a literature search which identified three RCTs [10-12] that had compared the PFOC procedure with medical treatment (documented in the EAC’s literature review paper [3]). Although the RCTs did not report statistically significant superiority of their primary outcomes, the EAC considered that there was likely to be some benefit associated with the use of the AMPLATZER PFO Occluder device. However, the absolute benefit may be modest and should be considered in the context of the potential for adverse events (in

particular, new onset AF) and use of NHS resources compared with standard medical preventative treatment. Since the writing of the EAC literature review, three further important, experimental studies have been published. These were the long-term follow up of the RESPECT trial [22], the CLOSE study [20], and the GORE REDUCE study [21]. These studies, which have not been appraised by the EAC, reported that PFOC was associated with significant reductions in the event rate of ischaemic stroke.

The CtE registry provided good data on the procedural efficacy and in-hospital safety of PFOC. Although statistical comparisons could not be performed due to data heterogeneity, peri-procedural outcomes were generally consistent with those reported in the literature from both experimental and observational studies. The data indicate that PFOC is a relatively safe procedure usually requiring one overnight stay, and that serious in hospital complications are rare.

Interpretation of medium-term data (neurological events) was limited by inconsistency of definition of outcomes between studies (such as inclusion of TIA). Comparison of the registry results with control arms of the RCTs was unable to demonstrate a clear benefit of PFOC in the overall cohort enrolled. Comparison with the intervention arms (i.e. patients from RCTs receiving PFOC) suggested that patients in the registry were not achieving the benefit reported in these studies (particularly the more recently published studies). However, interpretation was limited by issues concerning study methodology and generalisability (see [Section 4.3.1](#)).

The EAC literature search identified one study which was a cost-utility analysis from the perspective of the USA healthcare system. Using data from a meta-analysis of the 3 older RCTs and US costs, it reported that PFOC was cost-effective over a time horizon of 3 years. However, the EAC judged this study had poor internal and external validity, hence there was material uncertainty on whether its findings on cost-effectiveness apply in the English setting.

In summary, the EAC has identified some concerns regarding the efficacy of PFOC reported in the registry compared with the published literature. Although procedural efficacy and in-hospital complications appear to be broadly consistent, medium-term efficacy rates appear to be similar or slightly inferior to the control arms of RCTs, and possibly inferior to intervention arms. Neurological outcomes from the CtE registry also do not generally compare favourably with other observational studies, although the same caveats regarding making these comparisons (particularly concerning outcome measurement and terminology) apply (see [Table 11](#)). The reasons for the apparent lack of efficacy was unclear, but may be related to the method of measurement and definitions of outcomes, particularly the inclusion of subjective outcomes such as TIA. It should be emphasised that inferiority has not been unequivocally shown as it was not possible to apply statistical analysis. Additionally, it should be noted that in all the studies, including the recent CLOSE trial where no patients in the intervention arm suffered ischaemic stroke over 5 years of follow up [20], the absolute benefit of PFOC in reducing stroke is small, and the procedure is not without risk (in particular to the development of new onset AF).

4.3 LIMITATIONS AND FUTURE PROPOSALS (FOR NHS ENGLAND REPORT)

4.3.1 Limitations

The CtE registry was a single armed study and thus comparisons had to be made implicitly with results published in the literature [37]. This had 2 limitations. Firstly, no statistical or quantitative comparisons could be made with the comparator of interest, which was

conservative medical management (use of antiplatelet or oral anticoagulant drugs). Secondly, much of the published literature was not directly comparable to the registry. Specifically, evaluation of CtE results with trial data was limited by differences in outcome terminology and measurement, and possible issues with generalisability of the population (for instance, recent advances in research concerning PFO closure suggest thorough diagnostic workup is essential). Thus inferences of equivalence (or not) of CtE and trial data are subject to considerable uncertainty at best and are invalid at worst.

Other specific and non-specific limitations with the registry include the following:

- Although initially designed for 5 years follow up, registry follow up was limited to a maximum of 2 years. This meant that longer-term efficacy outcomes or data on longer-term complications were not available and questions pertaining to these were not answerable (see [Question Four](#)).
- In addition to the 2-year cut off point, most patients were not eligible for assessment at this time point because of the timeframe of the study and associated deadlines. Of the 898 patients who reported discharge data, follow up data at 2 years were only available on 282 (31.3%) at the cut-off date of the study.
- Kaplan-Meier analysis assumed “no event” status of patients unless an event was recorded. Thus the analysis relies on complete reporting of all event data. Patients who are lost to follow up are censored from the analysis, but it is unclear if these are representative of the overall cohort. Finally, patients may have multiple events (excluding death), but the Kaplan-Meier protocol only analyses time to first event.

An important issue which came to light late in the data collection phase of the study was that the registry had a degree of ambiguity in the reporting of outcomes, in particular concerning the classification of ischaemic event rates (for instance regarding permanence of disability and underlying cause of event [ischaemic or haemorrhagic]). Thus it is possible that there were differences in interpretation of neurological events during data entry. This was possibly compounded by an increase in activity of reporting follow up towards the study deadline. To resolve this issue, the EAC, NICOR, and clinical leads contacted centres directly to validate event rates and present clean data for analysis, which are presented in the [Addendum](#) section of this report.

4.3.2 Strengths

The CtE registry had several strengths. Firstly, the registry enrolled indicated patients consecutively and represented a pragmatic real-world cohort of patients receiving treatment with PFOC as performed in the NHS. Thus the external applicability of the registry to future practice is high, although improvements in the procedure protocol and any potential learning curve effect may ultimately lead to improved outcomes.

Secondly, this was a large study, initially recruiting more than 1000 participants. This makes the sample size larger than all the other experimental and observational studies identified by the EAC with the exception of the study by Wallenborn *et al.* (2013) [28]. However, the Wallenborn study was a retrospective analysis rather than a bespoke prospective registry. The CtE registry's large size gives it power to detect rarer outcomes and precision for more frequent event rates, and overall lends credibility to the results reported.

Thirdly, following an initial disappointing response from centres in providing follow-up data, this improved considerably towards the end of the study, such that there was about 700 PY follow up available for analysis. This improved the precision and certainty of time-to-event

analysis. Although follow up was still not optimal (39.7% of eligible patients at 2 years, see *Supplementary Table 3*), completion of data fields was regarded as good.

Finally, the CtE registry reported important clinical outcomes. In addition, the registry captured quality of life data and, through the use of *pro formas* directed at a centre level, estimated the cost of the procedure. This information may be of use in future cost-effectiveness studies.

4.3.3 Future proposals

The registry would be more robust with data linkage to ONS (Office of National Statistics) to validate existing mortality estimates and provide greater coverage. This could be potentially continued beyond the final follow up date of the study (2 years). Potentially, data linkage to HES (Hospital Episodes Statistics) could also provide further validation and coverage of morbidity, as well as informing cost information. The EAC is currently pursuing ONS and HES data linkage for this project but this may not be available in time for publication.

Section 5: Conclusions

The PFOC CtE registry included 995 patients of which 901 underwent device implantation. Patients had had a prior ischaemic stroke (confirmed by cranial imaging) presumed to be due to PFO (confirmed by echocardiography). The median age of the patients was 45 years and the large majority did not experience cardiac symptoms from the PFO. Patients were followed up to 2 years after the procedure was performed, and important clinical outcomes were determined. As the registry was single-armed, implicit comparisons with published literature, previously identified in bespoke review [3], were made in order to answer 11 questions asked by NHS England.

The registry reported that nearly all patients had a device successfully fitted (99.3% [95% CI 98.6 to 99.8%]), with a procedural success rate of 95.1% (95% CI 93.5 to 96.4%). This was comparable to results published in the literatures and emphasised that PFO is a relatively safe procedure. Over the course of around 700 PY analysed, there was a neurological event rate of 3.4 (95% CI 2.1 to 5.0) per 100 PY, and an ischaemic event rate of 1.3 (95% CI 0.6 to 2.5) per 100 PY. Manually corrected data, described in the [Addendum](#), reported a lower rate of neurological event rate of 2.2 (95% CI 1.2 to 3.6). As no natural history studies on this population were identified, the EAC compared these event rates with the control arms of RCTs [10-12], including an RCT with extended follow up [22] and two recently published RCTs [20, 21]. Patients in the registry had similar or higher event rates than those receiving drug treatments alone in the RCTs. When compared with the intervention arms of these studies, and most observational studies identified, the event rates appeared to be higher for patients in the registry than these comparator cohorts ([Table 11](#)). The registry reported a major complication rate of 5.2% (95% CI 3.8 to 7.0%) following discharge. A notable adverse event reported in the registry was new onset AF, which occurred in 3.5% (95% CI 2.3 to 5.0%) of patients following discharge; similar rates were reported in most the identified studies from the literature search. There was no evidence from the registry that any particular device was superior to another.

The registry reported a possible improvement in the anxiety and depression domain of the EQ-5D, indicating patients may have been reassured by the intervention. The registry was not designed to report long-term adverse effects, and did not provide useful information on the size of the population who might potentially benefit from PFOC. An additional survey performed by the EAC indicated the overall cost per procedure was on average £8,230 with a range of £6,940 to £9,250.

The evidence base for PFOC has expanded greatly over the last 5 years, with several RCTs now being published. Although earlier results on PFOC efficacy were equivocal, recent evidence from RCTs have provided strong evidence that the procedure can reduce the event rate of recurrent ischaemic stroke in carefully selected patients, although the absolute benefits are modest. Results from the CtE registry appeared to show less benefit associated with PFOC, in terms of reducing the incidence of ischaemic stroke, than might be expected from published observational and experimental evidence. The reasons for this are not known but could be related to issues with patient selection (e.g. diagnostic work up) or definitions of outcomes (for instance, inclusion of TIA as an ischaemic neurological event).

Economic modelling suggests that the procedure will increase costs to the NHS by about £5,360 per patient but will reduce adverse clinical events, primarily strokes (from 456 to 274 [40%] per 1,000 patients receiving the procedure) compared with medical therapy. The EAC

cannot advise whether, from an NHS perspective, this additional cost to the NHS of £5,360 per patient is cost-effective, given the forecast savings in strokes and deaths.

Section 6: Acknowledgements

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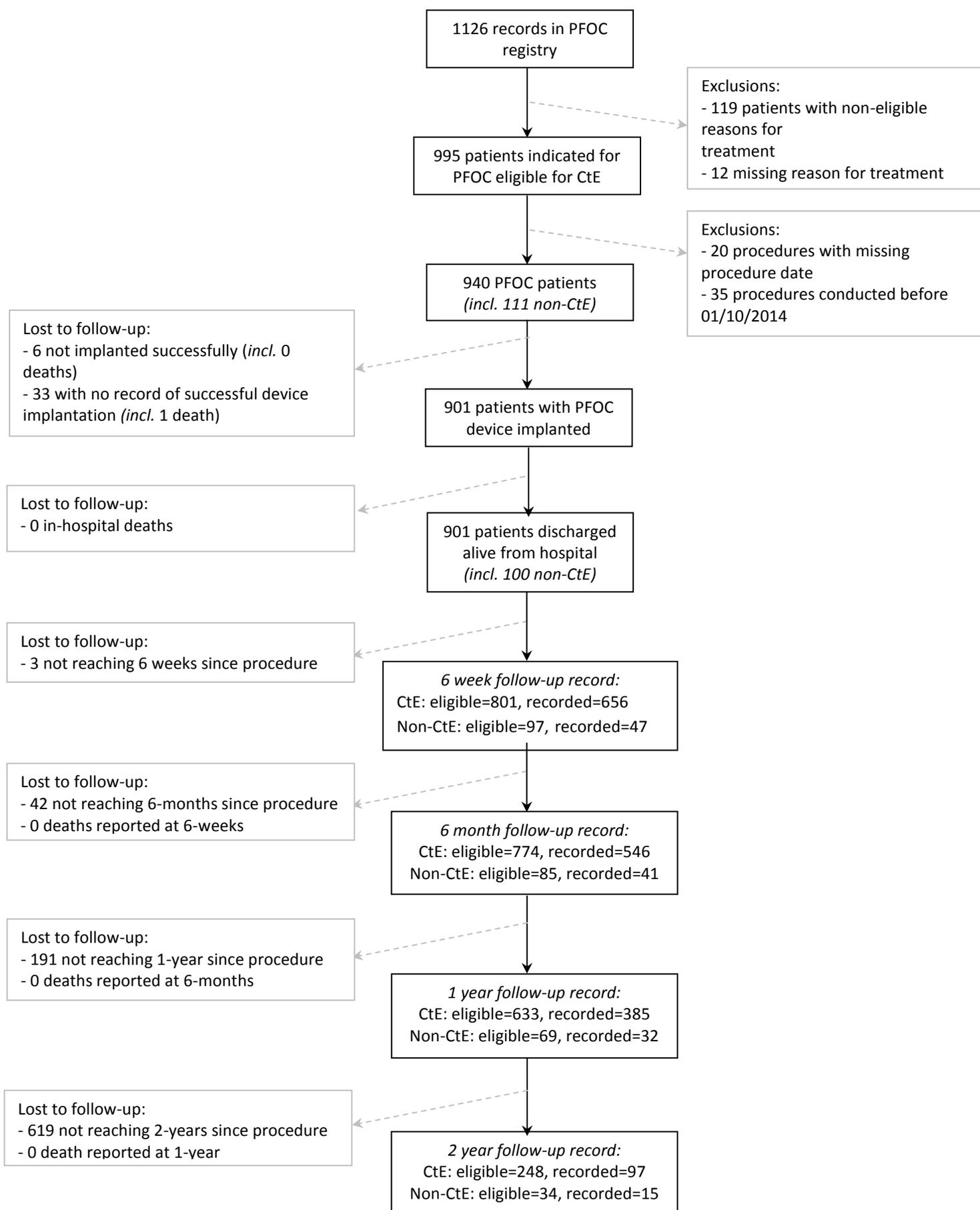
Section 7: References

1. Willits I, Jones R, Bousfield D, Arber M, Cole H, Sims AJ. OUTPUT ONE: Recommendations on three NHS England Commissioning through Evaluation (CtE) registry draft datasets for MitraClip, LAAO and PFO Closure cardiovascular procedures. In: EAC NY, editor. Unpublished; 2014.
2. Cole H, Willits I, Craig J, Sims AJ. OUTPUT TWO: Data quality monitoring process. Unpublished; 2015.
3. Willits I, Jones R, Arber M, Cole H. RX085 Commissioning through Evaluation (CTE) registry of 3 cardiovascular procedures. PFOC literature review document. Unpublished; 2016.
4. National Institute for Health and Care Excellence. Interventional procedure overview of percutaneous closure of patent foramen ovale to prevent recurrent cerebral embolic events (IPG472). London; 2013.
5. R Core Team. . R Foundation for Statistical Computing V, Austria, . URL <http://www.R-project.org/>. R: A language and environment for statistical computing. Vienna; 2013.
6. Agency for Healthcare Research and Quality (AHRQ). Registries for evaluating patient outcome: a user's guide: Volume 1. 3rd ed. Rockville, MD; 2012.
7. Agency for Healthcare Research and Quality (AHRQ). Registries for evaluating patient outcome: a user's guide: Volume 2. 3rd ed. Rockville, MD; 2012.
8. Willits I, Craig J, Cole H, Urwin S, Sims AJ. OUTPUT THREE: Draft registry data analysis protocol - PFOC. In: EAC NY, editor. Unpublished; 2015.
9. Liberati A, Altman G, Tetzlaff J, Mulrow C, Gøtzsche C, Ioannidis PA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. PLoS medicine. 2009;6(7).
10. Furlan AJ, Reisman M, Massaro J, Mauri L, Adams H, Albers GW, et al. Closure or medical therapy for cryptogenic stroke with patent foramen ovale. N Engl J Med. 2012 Mar 15;366(11):991-9.
11. Carroll JD, Saver JL, Thaler DE, Smalling RW, Berry S, MacDonald LA, et al. Closure of patent foramen ovale versus medical therapy after cryptogenic stroke. New England Journal of Medicine. 2013 Mar 21;368(12):1092-100.
12. Meier B, Kalesan B, Mattle HP, Khattab AA, Hildick-Smith D, Dudek D, et al. Percutaneous closure of patent foramen ovale in cryptogenic embolism. New England Journal of Medicine. 2013 Mar 21;368(12):1083-91.
13. Kent DM, Dahabreh IJ, Ruthazer R, Furlan AJ, Reisman M, Carroll JD, et al. Device Closure of Patent Foramen Ovale After Stroke: Pooled Analysis of Completed Randomized Trials. Journal of the American College of Cardiology. 2016 Mar 1;67(8):907-17.
14. Li J, Liu J, Liu M, Zhang S, Hao Z, Zhang J, et al. Closure versus medical therapy for preventing recurrent stroke in patients with patent foramen ovale and a history of cryptogenic stroke or transient ischemic attack. Cochrane Database of Systematic Reviews. 2015;9:CD009938.
15. Stortecky S, da Costa BR, Mattle HP, Carroll J, Hornung M, Sievert H, et al. Percutaneous closure of patent foramen ovale in patients with cryptogenic embolism: a network meta-analysis. European Heart Journal. 2015 Jan 7;36(2):120-8.
16. Wolfrum M, Froehlich GM, Knapp G, Casaubon LK, DiNicolantonio JJ, Lansky AJ, et al. Stroke prevention by percutaneous closure of patent foramen ovale: A systematic review and meta-analysis. Heart. 2014 March;100(5):389-95.
17. Hornung M, Bertog SC, Franke J, Id D, Taaffe M, Wunderlich N, et al. Long-term results of a randomized trial comparing three different devices for percutaneous closure of a patent foramen ovale. European Heart Journal. 2013 Nov;34(43):3362-9.
18. Pickett CA, Villines TC, Ferguson MA, Hulten EA. Percutaneous closure versus medical therapy alone for cryptogenic stroke patients with a patent foramen ovale: meta-analysis of randomized controlled trials. Texas Heart Institute Journal. 2014 Aug;41(4):357-67.

19. Pickett CA, Villines TC, Ferguson MA, Hulten EA. Cost effectiveness of percutaneous closure versus medical therapy for cryptogenic stroke in patients with a patent foramen ovale. *American Journal of Cardiology*. 2014 Nov 15;114(10):1584-9.
20. Mas JL, Derumeaux G, Guillon B, Massardier E, Hosseini H, Mechtouff L, et al. Patent Foramen Ovale Closure or Anticoagulation vs. Antiplatelets after Stroke. *N Engl J Med*. 2017 Sep 14;377(11):1011-21.
21. Sondergaard L, Kasner SE, Rhodes JF, Andersen G, Iversen HK, Nielsen-Kudsk JE, et al. Patent Foramen Ovale Closure or Antiplatelet Therapy for Cryptogenic Stroke. *N Engl J Med*. 2017 Sep 14;377(11):1033-42.
22. Saver JL, Carroll JD, Thaler DE, Smalling RW, MacDonald LA, Marks DS, et al. Long-Term Outcomes of Patent Foramen Ovale Closure or Medical Therapy after Stroke. *N Engl J Med*. 2017 Sep 14;377(11):1022-32.
23. Putaala J, Nieminen T, Haapaniemi E, Meretoja A, Rantanen K, Heikkinen N, et al. Undetermined stroke with an embolic pattern--a common phenotype with high early recurrence risk. *Ann Med*. 2015;47(5):406-13.
24. Li Y, Zhou K, Hua Y, Wang C, Xie L, Fang J, et al. Amplatzer occluder versus CardioSEAL/STARFlex occluder: A meta-analysis of the efficacy and safety of transcatheter occlusion for patent foramen ovale and atrial septal defect. *Cardiology in the Young*. 2013 August;23(4):582-96.
25. Taggart NW, Reeder GS, Lennon RJ, Slusser JP, Freund MA, Cabalka AK, et al. Long-term follow-up after PFO device closure: Outcomes and Complications in a Single-center Experience. *Catheterization & Cardiovascular Interventions*. 2017 Mar 29;89(1):124-33.
26. Pezzini A, Grassi M, Lodigiani C, Patella R, Gandolfo C, Zini A, et al. Propensity Score-Based Analysis of Percutaneous Closure Versus Medical Therapy in Patients With Cryptogenic Stroke and Patent Foramen Ovale: The IPSYS Registry (Italian Project on Stroke in Young Adults). *Circulation: Cardiovascular Interventions*. 2016 Sep;9(9).
27. Ingleessis I, Elmariah S, Rengifo-Moreno PA, Margey R, O'Callaghan C, Cruz-Gonzalez I, et al. Long-term experience and outcomes with transcatheter closure of patent foramen ovale. *Jacc: Cardiovascular Interventions*. 2013 Nov;6(11):1176-83.
28. Wallenborn J, Bertog SC, Franke J, Steinberg DH, Majunke N, Wilson N, et al. Recurrent events after percutaneous closure of patent foramen ovale. *Catheterization & Cardiovascular Interventions*. 2013 Oct 1;82(4):541-6.
29. Thomson JD, Hildick-Smith D, Cliff P, Morgan G, Daniels M, Henderson R, et al. Patent foramen ovale closure with the Gore septal occluder: initial UK experience. *Catheterization & Cardiovascular Interventions*. 2014 Feb 15;83(3):467-73.
30. Mirzaali M, Dooley M, Wynne D, Cooter N, Lee L, Haworth P, et al. Patent foramen ovale closure following cryptogenic stroke or transient ischaemic attack: Long-term follow-up of 301 cases. *Catheterization & Cardiovascular Interventions*. 2015 Nov 15;86(6):1078-84.
31. Spies C, Khandelwal A, Timmermanns I, Schrader R. Incidence of atrial fibrillation following transcatheter closure of atrial septal defects in adults. *Am J Cardiol*. 2008 Oct 01;102(7):902-6.
32. Agarwal S, Bajaj NS, Kumbhani DJ, Tuzcu EM, Kapadia SR. Meta-analysis of transcatheter closure versus medical therapy for patent foramen ovale in prevention of recurrent neurological events after presumed paradoxical embolism. *JACC Cardiovasc Interv*. 2012 Jul;5(7):777-89.
33. Trepels T, Zeplin H, Sievert H, Billinger K, Krumsdorf U, Zadan E, et al. Cardiac perforation following transcatheter PFO closure. *Catheterization and cardiovascular interventions : official journal of the Society for Cardiac Angiography & Interventions*. 2003 Jan;58(1):111-3.
34. National Institute for Health and Care Excellence. Percutaneous closure of patent foramen ovale to prevent recurrent cerebral embolic events (IPG472). London; 2013.
35. NHS England. Specialised Services Circular: Patent Foramen Ovale Closure CtE Provider Selection Confirmed. In: Department of Health, editor.; 2014.
36. Meier B. Patent foramen ovale and closure technique with the amplatzer occluder. *Scientifica (Cairo)*. 2014;2014:129196.
37. AHRQ. Role of Single Group Studies in Agency for Healthcare Research and Quality Comparative Effectiveness Reviews. 2013.

38. Curtis L, Burns A. Unit Costs of Health and Social Care 2016. In: Personal Social Services Research Unit UoK, editor.; 2016.
39. Department of Health. NHS reference costs 2015 to 2016. 2016.
40. National Clinical Guideline Centre. Preoperative tests Routine preoperative tests for elective surgery. Appendix M: Economic considerations for Delphi. 2016 [cited 2018 3rd January]; Available from: <https://www.nice.org.uk/guidance/ng45/evidence/appendix-m-economic-considerations-for-delphi-pdf-87258149464>
41. Information Services Division. Theatre Services. October 2016. 2016 [cited 2018 3rd January]; Available from: <http://www.isdscotland.org/Health-Topics/Finance/Costs/Detailed-Tables/Theatres.asp>
42. BNF. British National Formulary Online. 2017 June 2017 [cited 2017 18th December]; Available from: <https://www.bnf.org/products/bnf-online/>
43. Craig J, Mahon C, Urwin S, Arber M. Cost Consequences Analysis of Adopting Percutaneous Closure of Patent Foramen Ovale to Prevent Recurrent Cerebral Embolic Events. 2018.
44. Tirschwell DL, Marks D, MacDonald L, Smalling RW, Carroll J, Gu NY, Koullick M, Saver J, Thaler D. Cost-effectiveness of Percutaneous PFO Closure in Patients with History of Cryptogenic Stroke in the United States. ISPOR 22nd Annual International Meeting, Boston, MA, USA. 23 May 2017.
45. National Institute for Health and Care Excellence. Guide to the methods of technology appraisal 2013 Process and methods [PMG9]. London April 2013.
46. XU X-M, Vestesson M, Paley P, Desikan A, Wonderling D, Hoffman A, Wolfe CDA, Rudd AG, Bray BD, on behalf of SSNAP. The economic burden of stroke care in England, Wales and Northern Ireland: Using a national stroke register to estimate and report patient-level health economic outcomes in stroke. European Stroke Journal, vol. 3, 1: pp. 82-91, 2017.

Appendix 1 – Data flow diagram



Appendix 2 – Patient characteristics

Patient characteristics for all eligible PFOC patients and those with recorded information from follow-up appointments.

| Patient characteristics [†] | All eligible PFOC patients (n=940) | All patients with device implanted & follow-up (n=808) | P-value |
|---|------------------------------------|--|---------|
| Female | 405 (43.1%) | 349 (43.2%) | 1.00 |
| Age, years median (Q1,Q3) [range] | 45 (36,51) [17-82] | 45 (36,51) [17-81] | 0.97 |
| BMI, kg/m ² median (Q1,Q3) [range] | 26.5 (23.5,29.6) [14.2-48.9] | 26.5 (23.6,29.6) [14.2-48.9] | 0.86 |
| Ethnic origin: | | | 0.99 |
| Caucasian | 796 (92.0%) | 713 (92.1%) | |
| Black | 33 (3.8%) | 28 (3.6%) | |
| Asian | 27 (3.1%) | 24 (3.1%) | |
| Other | 9 (1.0%) | 9 (1.2%) | |
| eGFR median (Q1,Q3) [range] | 94 (82,107) [8-224] | 94 (82,107) [12-193] | 0.92 |
| Previous venous thrombosis/ thromboembolic disease | 40 (4.6%) | 34 (4.4%) | 0.91 |
| Thrombophilic condition | 30 (4.7%) | 29 (5.0%) | 0.89 |
| Smoking status: | | | 0.91 |
| Never smoked | 603 (71.4%) | 527 (71.0%) | |
| Ex-smoker | 184 (21.8%) | 167 (22.5%) | |
| Current smoker | 58 (6.9%) | 48 (6.5%) | |
| Diabetes | 26 (2.9%) | 22 (2.8%) | 1.00 |
| Hypertension | 100 (11.2%) | 93 (12.0%) | 0.65 |
| Hyperlipidaemia | 156 (17.8%) | 143 (18.8%) | 0.61 |
| Congestive Cardiac Failure (CCF) | 0 (0.0%) | 0 (0.0%) | NA |
| Pulmonary hypertension | 9 (1.0%) | 8 (1.0%) | 1.00 |
| Peripheral Vascular Disease (PVD) | 4 (0.4%) | 4 (0.5%) | 1.00 |
| Previous Myocardial Infarction (MI) | 20 (2.2%) | 19 (2.4%) | 0.87 |
| NYHA dyspnoea status | | | 0.98 |
| No limitation of physical activity | 808 (92.4%) | 727 (92.4%) | |
| Slight limitation of ordinary physical activity | 52 (5.9%) | 49 (6.2%) | |
| Marked limitation of ordinary physical activity | 11 (1.3%) | 9 (1.1%) | |
| Symptoms at rest or minimal activity | 3 (0.3%) | 2 (0.3%) | |
| Previous history of arrhythmia | 24 (2.7%) | 23 (2.9%) | 0.77 |
| Previous atrial septal procedure | 10 (1.1%) | 7 (0.9%) | 0.81 |
| Co-existent valve disease | 4 (0.5%) | 4 (0.5%) | 1.00 |
| Brain scan (MRI/CT) | | | 0.98 |
| Not conducted | 41 (5.2%) | 39 (5.4%) | |
| Conducted – no ischaemic lesion | 72 (9.1%) | 65 (8.9%) | |
| Conducted – ischaemic lesion | 675 (85.7%) | 623 (85.7%) | |
| Pre-procedural PFO assessment | | | 0.84 |
| Transthoracic echocardiogram (CFM or bubble contrast) | 445 (50.1%) | 377 (48.5%) | |
| Transoesophageal echocardiogram (CFM or bubble contrast) | 162 (18.2%) | 138 (17.7%) | |
| Transcranial Doppler | 3 (0.3%) | 3 (0.4%) | |
| Combination | 279 (31.4%) | 260 (33.4%) | |
| R-to-L shunt detected | 793 (96.9%) | 704 (97.0%) | 1.00 |
| Echo contrast R-to-L shunt (without provocation) | | | 0.97 |
| None | 115 (16.5%) | 106 (16.5%) | |
| Individual bubbles (<5 per still frame) | 114 (16.4%) | 102 (15.9%) | |
| Clusters/clouds/chamber opacification (≥ 5 per still frame) | 467 (67.1%) | 435 (67.7%) | |
| Echo contrast R-to-L shunt (with provocation) | | | 0.90 |
| None | 12 (1.8%) | 9 (1.5%) | |
| Individual bubbles (<5 per still frame) | 8 (1.2%) | 8 (1.3%) | |
| Clusters/clouds/chamber opacification (≥ 5 per still frame) | 647 (97.0%) | 603 (97.3%) | |

| Patient characteristics† | All eligible PFOC patients (n=940) | All patients with device implanted & follow-up (n=808) | p-value |
|--|------------------------------------|--|---------|
| Transcranial doppler | | | 1.00 |
| Test negative. No microbubbles | 88 (79.3%) | 83 (79.0%) | |
| Low-grade shunt 0-10 microbubbles | 3 (2.7%) | 3 (2.9%) | |
| Medium-grade shunt >10 microbubbles but without curtain effect | 12 (10.8%) | 11 (10.5%) | |
| High grade shunt - curtain effect, when the microbubbles are uncountable | 8 (7.2%) | 8 (7.6%) | |
| Atrial septal aneurysm | 88 (10.2%) | 83 (11.0%) | 0.63 |
| Cerebral vascular imaging (by carotid USS or MR/CT angiography) | | | 0.99 |
| Not done | 149 (19.3%) | 139 (19.5%) | |
| Normal | 594 (76.8%) | 547 (76.7%) | |
| Minor abnormality | 22 (2.8%) | 19 (2.7%) | |
| Moderate/severe lesion | 8 (1.0%) | 8 (1.1%) | |
| LVEF | | | 1.00 |
| Good (>50%) | 805 (99.1%) | 734 (99.1%) | |
| Moderate (30-50%) | 7 (0.9%) | 7 (0.9%) | |
| Poor (<30%) | 0 (0.0%) | 0 (0.0%) | |
| Aortic atheroma in arch | | | 0.85 |
| Not imaged | 615 (74.2%) | 552 (73.0%) | |
| Grade 1 | 212 (25.6%) | 202 (26.7%) | |
| Grade 2 | 2 (0.2%) | 2 (0.3%) | |
| Grade 3 | 0 (0.0%) | 0 (0.0%) | |
| Grade 4 | 0 (0.0%) | 0 (0.0%) | |
| Medications (pre-op): | | | 0.89 |
| Single antiplatelet | 540 (60.4%) | 442 (57.7%) | |
| Dual antiplatelet | 162 (18.1%) | 144 (18.8%) | |
| Anticoagulant alone | 78 (8.7%) | 72 (9.4%) | |
| Antiplatelet(s) & Anticoagulant(s) | 27 (3.0%) | 23 (3.0%) | |
| Other | 66 (7.4%) | 66 (8.6%) | |
| None | 21 (2.3%) | 19 (2.5%) | |
| PFO tunnel length, mm | 6 | 6 | 0.85 |
| median (Q1,Q3) [range] | (3,10) [1-20] | (3,10) [1-20] | |
| Max PFO diameter, mm | 9 | 9 | 0.90 |
| median (Q1,Q3) [range] | (6,12) [1-30] | (6,12) [1-30] | |
| † Not all data fields were complete for every patient at baseline and follow up. The percentages presented in this table are calculated using the number of patients with each characteristic reported as the denominator. | | | |

Appendix 3 – Procedural characteristics

Procedural details for all eligible PFOC patients and those with recorded information from follow-up appointments.

| Procedural characteristic [†] | All eligible PFOC patients (n=940) | All patients with follow-up (n=808) | p-value |
|--|------------------------------------|-------------------------------------|---------|
| Treating hospital | | | 0.01* |
| University Hospital of North Staffordshire NHS Trust (now Royal Stoke University Hospital) | 75 (8.0%) | 72 (8.9%) | |
| Brighton & Sussex University Hospitals NHS Trust | 68 (7.2%) | 63 (7.8%) | |
| University Hospitals Bristol NHS Foundation Trust | 66 (7.0%) | 62 (7.7%) | |
| Guy's and St Thomas' NHS Foundation Trust | 59 (6.3%) | 54 (6.7%) | |
| Kings College Hospital NHS Foundation Trust | 66 (7.0%) | 50 (6.2%) | |
| Nottingham University Hospitals NHS Trust | 47 (5.0%) | 45 (5.6%) | |
| Harefield Hospital | 55 (5.9%) | 39 (4.8%) | |
| Oxford University Hospitals NHS Trust | 46 (4.9%) | 42 (5.2%) | |
| Barts Health NHS Trust | 51 (5.4%) | 41 (5.1%) | |
| Liverpool Heart & Chest Hospital NHS Foundation Trust | 49 (5.2%) | 46 (5.7%) | |
| University Hospitals Leicester NHS Trust | 41 (4.4%) | 39 (4.8%) | |
| University Hospital Southampton, NHS Foundation Trust | 39 (4.1%) | 37 (4.6%) | |
| Leeds Teaching Hospitals NHS Trust | 35 (3.7%) | 32 (4.0%) | |
| University Hospital Birmingham NHS Foundation Trust | 35 (3.7%) | 34 (4.2%) | |
| Spire Bristol | 32 (3.4%) | 0 (0.0%) | |
| Royal Wolverhampton NHS Trust | 29 (3.1%) | 29 (3.6%) | |
| Papworth Hospital | 29 (3.1%) | 25 (3.1%) | |
| The Newcastle upon Tyne Hospitals NHS Foundation Trust | 25 (2.7%) | 23 (2.8%) | |
| Essex Cardiothoracic Centre | 22 (2.3%) | 19 (2.4%) | |
| St. George's Healthcare NHS Trust | 22 (2.3%) | 15 (1.9%) | |
| Central Manchester Hospitals NHS Foundation Trust | 24 (2.6%) | 16 (2.0%) | |
| Royal Brompton Hospital | 22 (2.3%) | 22 (2.7%) | |
| Sheffield Teaching Hospitals Foundation Trust | 3 (0.3%) | 3 (0.4%) | |
| Elective procedure | 928 (99.3%) | 802 (99.3%) | 1.00 |
| Anaesthesia | | | 0.96 |
| General anaesthesia | 671 (74.2%) | 591 (74.6%) | |
| Local anaesthesia & sedation | 160 (17.7%) | 136 (17.2%) | |
| Local anaesthesia only | 73 (8.1%) | 65 (8.2%) | |
| Intra-operative echo imaging | | | 0.99 |
| TOE (planned) or TTE | 663 (72.9%) | 578 (72.9%) | |
| ICE planned | 206 (22.6%) | 177 (22.3%) | |
| Unplanned | 10 (1.1%) | 9 (1.1%) | |
| None | 31 (3.4%) | 29 (3.7%) | |
| Atrial septum crossed | 864 (98.9%) | 763 (99.3%) | 0.44 |
| Venous sheath size (F): median (Q1:Q3) [range] | 10 (8,11) [6-14] | 10 (8,11) [6-14] | 0.65 |
| Cerebral protection device used | 1 (0.2%) | 1 (0.2%) | 1.00 |
| No. of devices attempted | | | 0.90 |
| 1 | 854 (96.9%) | 779 (96.7%) | |
| 2 | 24 (2.7%) | 23 (2.9%) | |
| 3 | 3 (0.3%) | 4 (0.5%) | |
| Device used: | | | 0.91 |
| St. Jude Medical (AMPLATZER range) | 502 (54.5%) | 430 (53.4%) | |
| GORE CARDIOFORM Septal Occluder | 277 (30.1%) | 254 (31.6%) | |
| Occlutech (Figulla Flex range) | 121 (13.1%) | 105 (13.0%) | |
| Other (incl. combination) | 21 (2.3%) | 16 (2.0%) | |

| Procedural characteristic [†] | All eligible PFOC patients (n=940) | All patients with follow-up (n=808) | p-value |
|--|------------------------------------|-------------------------------------|---------|
| Fluoroscopy time, mins median (Q1:Q3) [range] | 5 (3,8) [0-82] | 5 (3,8) [0-78] | 0.96 |
| X-ray dose, mGray.cm ² median (Q1:Q3) [range] | 591 (189,1417) [0-20,000] | 566 (185,1320) [0-20,000] | 0.48 |
| Contrast dose, ml median (Q1:Q3) [range] | 0 (0,15) [0-320] | 0 (0,10) [0-320] | 0.39 |
| Procedural duration, mins median (Q1:Q3) [range] | 45 (30,60) [0-229] | 44 (30,60) [0-229] | 0.58 |
| Note: | | | |
| † Not all data fields were complete for every patient at baseline and follow up. The percentages presented in this table are calculated using the number of patients with each characteristic reported as the denominator. | | | |
| * p-value not significant after application of Bonferroni corrections applied for multiple comparisons. | | | |

Appendix 4 – Outcomes

Outcomes for all eligible PFOC patients. Note: patients may have multiple events (hence sum of breakdown of complication events is not necessarily equal to total major or minor complications).

| | In-hospital (n=940) | | After discharge (6w,6m,1y,2y combined) (n=808) | |
|--|-----------------------------|-------------------------|--|-------------------------|
| | Total no. of patients | % [95% CI] | Total no. of patients | % [95% CI] |
| Major complications: | 9 | 1.0 [0.4:1.8] | 42 | 5.2 [3.8:7.0] |
| Death | 1 | 0.1 [0.0:0.6] | 2 | 0.2 [0.0:0.9] |
| Neurological event: 2 ischaemic and 1 other categorised as a CVA/RIND | 3 | 0.3 [0.1:0.9] | 23 | 2.8 [1.8:4.2] |
| Device embolisation | 3 | 0.3 [0.1:0.9] | 0 | 0.0 [0.0:0.5] |
| Major cardiac structural complications | 0 | 0.0 [0.0:0.4] | 1 | 0.1 [0.0:0.7] |
| MI | 1 | 0.1 [0.0:0.6] | 1 | 0.1 [0.0:0.7] |
| Major vascular injury | 0 | 0.0 [0.0:0.4] | 1 | 0.1 [0.0:0.7] |
| Endocarditis | 0 | 0.0 [0.0:0.4] | 0 | 0.0 [0.0:0.5] |
| Oesophageal rupture | 0 | 0.0 [0.0:0.4] | - | - |
| Major bleed | 1 | 0.1 [0.0:0.6] | 13 | 1.6 [0.9:2.7] |
| Additional surgery | 1 | 0.1 [0.0:0.6] | 4 | 0.5 [0.1:1.3] |
| Minor complications: | 24 | 2.6 [1.6:3.8] | 118 | 14.6 [12.2:17.2] |
| Device malfunction | 0 | 0.0 [0.0:0.4] | - | - |
| Air embolism | 0 | 0.0 [0.0:0.4] | 2 | 0.2 [0.0:0.9] |
| Malposition | 4 | 0.4 [0.1:1.1] | 0 | 0.0 [0.0:0.5] |
| New/worsening AF | 9 | 1.0 [0.4:1.9] | 28 | 3.5 [2.3:5.0] |
| Other arrhythmias | 0 | 0.0 [0.0:0.4] | 0 | 0.0 [0.0:0.5] |
| Minor cardiac structural complications | 1 | 0.1 [0.0:0.6] | 61 | 7.5 [5.8:9.6] |
| Transient ST elevation (no MI) | 0 | 0.0 [0.0:0.4] | - | - |
| Minor embolic events | 0 | 0.0 [0.0:0.4] | 0 | 0.0 [0.0:0.5] |
| Minor vascular injury | 5 | 0.5 [0.2:1.3] | 5 | 0.6 [0.2:1.4] |
| Migraine/worsening migraine | 3 | 0.3 [0.1:1.0] | 21 | 2.6 [1.6:3.9] |
| Oesophageal trauma | 0 | 0.0 [0.0:0.4] | - | - |
| Nickel allergy | 0 | 0.0 [0.0:0.4] | 0 | 0.0 [0.0:0.5] |
| Minor bleed | 5 | 0.5 [0.2:1.3] | 7 | 0.9 [0.3:1.8] |
| Any complication (minor & major combined) | 32 | 3.6 [2.5:5.0] | 153 | 18.9 [16.3:21.8] |
| Device implanted | 901 | 99.3 [98.6:99.8] | - | - |
| Procedural success (device implanted in absence of major complications) | 894 | 95.1 [93.5:96.4] | - | - |

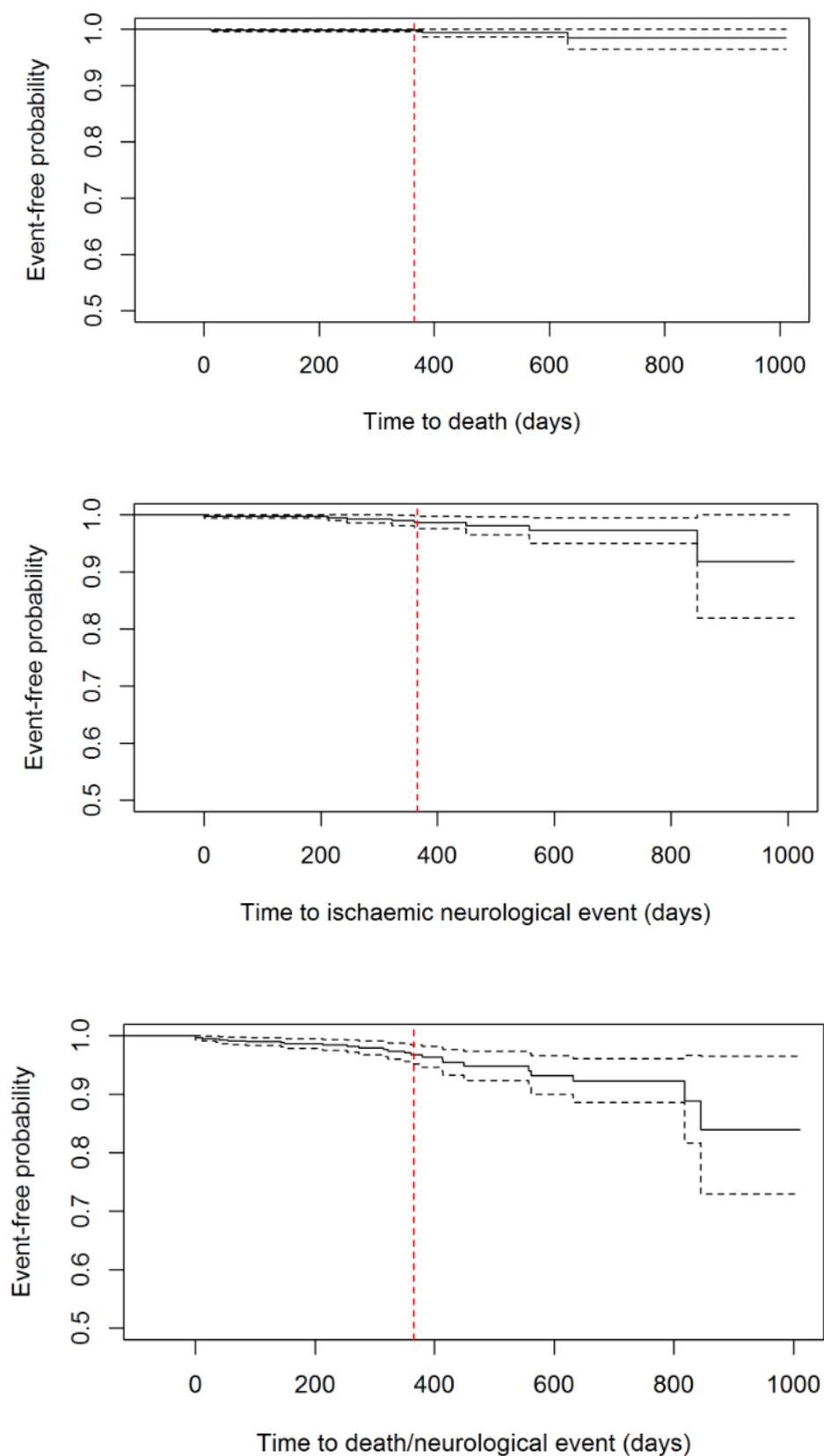
Appendix 5 – Outcomes (time to event analysis)

Patient outcomes (in-hospital and after discharge as reported at any follow-up combined) for all eligible PFOC patients.

| | No. of patients with event | Total follow-up (person-years) | Event rate (per 100 person-years follow-up) [95% CI] | No. of patients at risk at 1-year | 1-year event-free probability (95% CI) |
|---|----------------------------|--------------------------------|--|-----------------------------------|--|
| Major complications: | | | | | |
| Death | 3 (0.3%) | 698.7 | 0.4 [0.1:1.3] | 304 | 0.999 [0.996 to 1.000] |
| Neurological event | 23* (2.5%) | 684.7 | 3.4 [2.1:5.0] | 294 | 0.969 [0.953 to 0.985] |
| <i>Ischaemic event only</i> | 9 (1.0%) | 691.1 | 1.3 [0.6:2.5] | 299 | 0.987 [0.976 to 0.998] |
| MI | 2 (0.2%) | 692.9 | 0.3 [0.0:1.0] | 300 | 0.997 [0.994 to 1.000] |
| Device embolisation | 3 (0.3%) | 694.6 | 0.4 [0.1:1.3] | 301 | 0.997 [0.993 to 1.000] |
| Additional surgery | 5 (0.5%) | 694.3 | 0.7 [0.2:1.7] | 302 | 0.994 [0.989 to 1.000] |
| Minor complications: | | | | | |
| Peripheral embolism | 0 (0.0%) | - | - | - | - |
| * 24 patients were reported as having a neurological event, however, date of event was missing from 1 patient who was consequently omitted from time to event analysis. | | | | | |

Appendix 6 – Kaplan-Meier curves

Time to event (solid lines), corresponding 95% confidence limits (dashed lines), and proportions of patients event-free at 1 year (red dashed line).



Appendix 7 – Neurological events by device type

| Device Manufacturer | Patients with reported neurological event | Patients with no reported neurological event | TOTAL |
|------------------------------------|---|--|-------|
| St. Jude Medical (AMPLATZER range) | 10 | 485 | 495 |
| GORE CARDIOFORM Septal Occluder | 11 | 265 | 276 |
| Occlutech (Figulla Flex range) | 3 | 110 | 117 |
| TOTAL | 24 | 860 | 884 |

Appendix 8 – Echo contrast results

| | Echo contrast results | Pre-procedure | | 6 months | | 1 year | | 2 years | |
|-----------|--|---------------|------------------|----------|------------------|--------|------------------|---------|------------------|
| | | n | % [95% CI] | n | % [95% CI] | n | % [95% CI] | n | % [95% CI] |
| At rest | Study done, no bubbles seen | 113 | 16.6 [13.2:20.2] | 341 | 94.2 [92.3:96.6] | 158 | 89.8 [85.8:93.8] | 33 | 86.8 [78.9:97.3] |
| | Individual bubbles [†] | 109 | 16.0 [12.6:19.6] | 14 | 3.9 [1.9:6.2] | 10 | 5.7 [1.7:9.7] | 2 | 5.3 [0.0:15.7] |
| | Clusters/clouds/chamber opacification [‡] | 460 | 67.4 [64.1:71.1] | 7 | 1.9 [0.0:4.3] | 8 | 4.5 [0.6:8.5] | 3 | 7.9 [0.0:18.4] |
| Manoeuvre | Study done, no bubbles seen | 10 | 1.5 [0.5:2.7] | 270 | 76.9 [72.9:81.4] | 114 | 72.2 [65.8:79.3] | 26 | 78.8 [66.7:91.5] |
| | Individual bubbles [†] | 8 | 1.2 [0.2:2.4] | 53 | 15.1 [11.1:19.6] | 23 | 14.6 [8.2:21.7] | 1 | 3.0 [0.0:15.7] |
| | Clusters/clouds/chamber opacification [‡] | 633 | 97.2 [96.2:98.4] | 28 | 8.0 [4.0:12.5] | 20 | 12.7 [6.3:19.8] | 6 | 18.2 [6.1:30.8] |

[†]<5 per still frame

[‡]≥ 5 per still frame

Appendix 9 – Cost of a PFO closure procedure

[Table A.9.1](#) identified all the inputs and sources used to calculate the central cost. [Table A.9.2](#) provides information on the sensitivity analyses conducted to provide high and low cost ranges.

Table A.9.1 Cost of pathway for a PFO closure procedure

| Parameter | Usage | Unit cost | % patients | Total cost | Source |
|---|--------------|---------------------|------------|-------------|---|
| Pre-operative assessment costs | | | | | |
| Consultant cardiologist | 50 mins | £104.00 per hr | 100% | £86.67 | 1 MDT of 2 cardiologists and 1 nurse for 15 mins per patient + pre-assessment clinic taking 20 mins cardiologist and 60 mins nurse time. Costs from PSSRU [38]. |
| Nurse band 6 | 75 mins | £44.00 per hr | 100% | £55.00 | |
| Echocardiogram with contrast | 1 | £87.83 | 100% | £87.83 | Imaging use from clinical experts; costs from NHS Reference costs [39]. |
| ECG | 1 | £40.35 | 100% | £40.35 | |
| Blood gases | 1 | £6.42 - £9.84 | 100% | £8.13 | Tests from clinical experts; costs from 'Preoperative tests' by National Clinical Guideline Centre [40]. |
| Haemostasis of prothrombin time | 1 | £29.42 | 6% | £1.82 | Tests from clinical experts; warfarin use from database and costs from 'Preoperative tests' by National Clinical Guideline Centre [40]. |
| FBC | 1 | £3.00 | 100% | £3.00 | Tests from clinical experts; costs from NHS Reference costs [39]. |
| U&E | 1 | £3.00 | 100% | £3.00 | |
| Sub-total pre-operative assessment | | | | £286 | All costs include overheads. |
| Peri-operative costs: | | | | | |
| Cardiologist | 1.4 | £104.00 per hr | 60.0 mins | £145.70 | Operators from database, cost PSSRU [38]. |
| Registrar | 0.6 | £40.00 per hr | 60.0 mins | £23.96 | |
| Anaesthetist | 0.75 | £105.00 per hr | 45 mins | £59.06 | Staffing structure from clinical experts; cost PSSRU [38]. |
| Cath lab assistant band 3 | 1 | £25.00 per hr | 45 mins | £18.75 | |
| Echocardiographer | 0.75 | All band 6, nurse | 34 mins | £19.41 | |
| Nurse | 1.00 | £44.00 per hr; | 45 mins | £33.00 | |
| Cardiac physiologist | 0.75 | rest £46.00 per hr. | 34 mins | £19.41 | |
| Radiographer | 0.75 | | 34 mins | £19.41 | |
| Procedural time in theatre | 45 mins. | £██████ per hr. | | £██████ | Time from database; cost from Information Services Division (ISD) cost of theatres excluding staff and consumables costs[41]. |
| ToE or ICE or TTE/other | 73.0%, 23.5% | £1,437 | 100% | £1,388.03 | Use from database; costed as EY502 |

| Parameter | Usage | Unit cost | % patients | Total cost | Source |
|--|------------------------|--|---------------|------------|---|
| | and 0.1%. None 3.4% | | | | complex echocardiogram for an elective inpatient from NHS Reference costs [38]. |
| Anaesthetic Drugs - Desflurane & Remifentanyl | 1 | £82.18 | 74% | £60.98 | Drugs agreed with clinical experts; price from a submitted template. |
| Local anesthesia - Lidocaine local max 200 mg | 1 | 10-mL prefilled syringe = £8.48 | 8% | £0.69 | Drugs agreed with clinical experts; price from BNF [42]. |
| Local anesthesia + sedation midazolam and fentanyl | 1 | Midazolam £1.00; fentanyl 100' patch (releasing approx. 100 micrograms/hour for 72 hours), 5 = £57.86. | 18% | £3.73 | Drugs agreed with clinical experts; prices from BNF [42]. |
| Heparin 2 hrs per surgery and 8/12 hrs after. | 1 | £5.80 | 100% | £5.80 | Drugs from clinical experts; costs from BNF [42]. |
| Cefuroxime X 2 1.5 g, 8 hours apart | 1 | £10.10 | 100% | £10.10 | |
| Consumables | 1 | £■■■ | 100% | £■■■ | 2 templates provided costs of £■■■ and £■■■. The experts advised using £■■■ per procedure, the same as LAO procedure. |
| Devices opened per patient | 1.034 | £■■■ | 100% | £■■■ | Number and mix of devices from dataset; cost of device from NHS Supply Chain and includes VAT. |
| Sub-total peri-operative | | | £6,379 | | All costs include overheads. |
| Post-operative management | | | | | |
| Inpatient stay | 0.7 days | £356 per day | 100% | £299 | Stay mean value from dataset; costed using mean cost for codes EY23A to C for Standard Other Percutaneous Transluminal Repair of Acquired Defect of Heart. Reference costs [39] |
| Transthoracic Echocardiogram | 1 | £1,437 | 79% | £1,135 | Use from database; costed as EY502 complex echocardiogram for an inpatient from NHS Reference costs [39]. |
| Out-patient follow-up | 1 | £191 | 100% | £191 | Use from clinical experts; cost Cardiac Surgery consultant-led outpatients. Reference costs [39]. |

| Parameter | Usage | Unit cost | % patients | Total cost | Source |
|--|-------|-----------|------------|---------------|------------------------------|
| Sub-total post-operative management | | | | £1,564 | All costs include overheads. |
| GRAND TOTAL | | | | £8,229 | |

Note figures are rounded so may not sum to last digit precisely.

Table A.9.2 Low and high cost scenarios for pathway for a PFO closure procedure

| Scenarios | Changes from central case | New cost |
|---|--|----------------------|
| Pre-operative assessment central cost £286 | | |
| Low cost | Use 20% decrease in costs. | £229 |
| High cost | Use 20% increase in other costs. | £343 |
| Peri-operative costs central cost £6,379 | | |
| Low cost | Use first quartile reported for procedure time and 20% decrease in all other costs except device. | £5,798 |
| High cost | Use third quartile reported for procedure time and 20% increase in all other costs except device. | £6,960 |
| Post-operative management central cost £1,564 | | |
| Low cost | Use length of stay time of 0.5 days and tariff cost for Complex Echocardiogram for Congenital Heart Disease elective patient. (£618) and 20% lower unit cost for inpatient day and outpatient. | £913 |
| High cost | Use 1 day length of stay and 20% increase in all other costs. | £1,947 |
| Total cost central cost and % accounted for by device: | | £8,229 (100%) |
| Total cost low cost and % accounted for by device | | £6,939 (84%) |
| Total cost high cost and % accounted for by device | | £9,251 (112%) |

Note figures are rounded so may not sum to last digit precisely.

Thus the forecast cost for a PFO closure procedure ranges from about £6,940 to £9,250, with the central case being around £8,230. The device cost (£1,564 per patient; £1,564 per device) accounting for about 19% to 22% of the total cost.

Addendum – Manually corrected neurological event rates

Background

The final raw data was originally extracted from the live PFOC CtE registry on 10/08/2017.

On reviewing the initial draft PFOC CtE report with the Clinical Leads, some potential errors in the reporting of the primary outcomes concerning neurological events, ischaemic events, and composite outcomes involving these events were identified in the raw data.

This was partly because of the design of the input fields in the registry, which were ambiguous with the potential for double counting of outcome events, because there were separate fields for the occurrence of a neurological event (with descriptors) and a separate field for type of neurological event, such that:

- Neurological event occurred with the following options: None; Yes, ischaemic; Yes, haemorrhagic; Yes, undetermined; unknown.
- Type of neurological event with the following options: None or not applicable; CVA/RIND; TIA; other; unknown.

It was observed that there were instances where there was logical inconsistency between the data entered by the provider centres in these fields. In addition, there was conflation between the terms CVA (cerebrovascular accident) and RIND (reversible ischaemic neurological deficit) which were presented as a single option despite meaning quite different things.

To fix this issue, the EAC contacted each provider centre, via NICOR, to ask for a narrative clinical report on each patient in whom an inconsistently reported neurological event had been identified in the registry data. Following responses from the provider centres, two clinical leads (RH and MdeB) discussed the narrative on each case and came to consensus view on what the neurological outcome(s) were. This process was fully documented by the EAC and records have been kept (available on file). Manually corrected data from the RH and MdeB consensus work informed a revised analysis of the 10/08/2017 raw data extract by the EAC, to correct the reported neurological event rates. This validation exercise and resultant corrected neurological event rates are the basis of the final PFOC results in this addendum.

The validated and manually corrected neurological event rates were materially different to those reported in [Section 3](#) of this document from the uncorrected raw data extract (10/08/2017). However, as this report had already undergone the NHS England Steering Group consultation process, it was decided that manual corrections to these clinical outcomes should be reported in the form of this addendum.

The timing of this additional EAC analysis of manually corrected data was such that the corrected neurological event rates were available for the cost consequence analysis (CCA) work [43] and final responses to NHS England [Question 10](#) and [Question 11](#).

Finally, in order to ensure that the live PFOC CtE registry was corrected to match the consensus work of RH and MdeB, the provider centres were asked to edit their entries in the live NICOR registry to match the manual corrections made to the 10/08/2017 extract. This ensures the reliability of any future extract and analysis of the PFOC CtE registry data; specifically, for the planned data linkage to Office of National Statistics (ONS) mortality data

and Hospital Episode Statistics (HES) data, as a means of independently validating the mortality rates and neurological outcomes reported in the CtE registry, plus obtaining additional information such as readmissions in HES for these PFOC patients. On completion of the edits by the provider centres, an additional PFOC raw data extract was delivered to the EAC on 04/01/2018, which will be submitted by NICOR to NHS Digital for data linkage to ONS and HES (pending signatures to the Data Sharing Agreement [DSA]).

This report addendum briefly summarises the changes in results from analysis of the manual correction of the reported neurological events and implications for the NHS England CtE questions and the report's [Conclusions](#).

Manually corrected results

Neurological events included events with permanent (stroke) or transient sequelae (TIA or RIND) of ischaemic or haemorrhagic aetiology. The data reported could discriminate by aetiology, but not by permanence. The manually corrected data reported that 16 patients had a neurological event, of which 15 had a recorded date of event (2 in hospital and 13 following discharge) allowing for time to event analysis. This equated to an overall event rate of 1.7% (95% CI 1.0 to 2.8%). In total, there were 21 events in the manually corrected dataset, indicating multiple events in some patients. Thus, in comparison to the original (uncorrected) raw data reported in [Section 3](#), there was a relatively modest reduction in the number of patients experiencing an event (from 24 to 16), and a larger reduction in the overall amount of events reported (from 31 to 21). Two patients experienced their first event in-hospital, with the remaining thirteen first events occurring following discharge. Kaplan-Meier survival analysis (illustrated in [Figure A1](#)) indicated that the corrected neurological event rate per 100 PY was 2.2 (95% CI 1.2 to 3.6). The corrected 1 year probability of being event free (i.e. not having a neurological event) was 97.9% (95% CI 96.5 to 99.3%).

Overall, three people died during the study (1 in-hospital and 2 following discharge). *Note that this event rate is unchanged from the original (uncorrected) raw data.* When these mortality data were combined with the neurological event rate, the composite value using Kaplan-Meier analysis was 2.6 events per 100 PY (95% CI 1.5 to 4.1%). One year survival from death or neurological event was 97.7% (95% CI 96.3 to 99.2%).

The manually corrected data reported that nine patients had an ischaemic event, one of which was in-hospital, with eight occurring after discharge. Using Kaplan-Meier survival analysis ([Figure A2](#)), this equated to a revised rate of 1.3 events per 100 PY (95% CI 0.6 to 2.5). Event free survival at 1 year was 98.5% (95% CI 97.2 to 99.7%).

The original (uncorrected) data for outcomes (time to event analysis) are reported in [Appendix 5](#). This is compared with the manually corrected data for neurological events in [Table A1](#).

Table A1. Number of all neurological events in original (uncorrected) dataset compared with manually corrected dataset (raw data extract 10/08/2017).

| Event type | Original data | | Manually corrected data | |
|--------------------|----------------------------|-------------------------|----------------------------|-------------------------|
| | No. of patients with event | Event rate per 100 PY | No. of patients with event | Event rate per 100 PY |
| Neurological event | 23* (2.5%) | 3.4 (95% CI 2.1 to 5.0) | 15* (1.7%) | 2.2 (95% CI 1.2 to 3.6) |
| Ischaemic event | 9 | 1.3 (95% CI 0.6 to 2.5) | 9 | 1.3 (95% CI 0.6 to 2.5) |

* One patient not included in time to event analysis due to missing time to event.

Implications for NHS England [Question One](#)

As discussed, the neurological event rate was lower in the manually corrected data set, whilst death rates and rates of ischaemic events were unchanged. The manually corrected data are reported in [Table A2](#) (based on [Table 9](#) of the original (uncorrected) data).

Table A2. Corrected incidence of neurological events in CtE registry and control arms of published RCTs.

| Study | Rate of neurological event (events per 100 PY) | Additional information |
|--|---|--|
| NHS England CtE registry | All neurological events: 2.2 (95% CI 1.2 to 3.6) Neurological event or death: 2.6 (95% CI 1.5 to 4.1%) Ischaemic event only: 1.3 (95% CI 0.6 to 2.5) | 2 patients with events in hospital and 14 patients with events after discharge. 21 events in total, of which 1 was haemorrhagic and no fatal strokes reported. |
| CLOSURE-1 trial [10] | Stroke: 1.55 TIA: 2.05 Primary composite endpoint*: 3.4 | ITT analysis (control group) 2 years follow up |
| RESPECT trial [11] | 1.38** | ITT analysis (control group) Median 2.1 years follow up |
| RESPECT trial (2017 update) [22]† | Ischaemic stroke: 1.07 | ITT analysis (control group) Median 5.9 years follow up |
| PC trial [12] | Stroke: 0.6 TIA: 0.83 Primary endpoint***: 1.3 | ITT analysis (control group) Mean 4.0 years follow up |
| CLOSE trial [20]†† | Stroke: 1.12 | ITT analysis (control group) Median 5.3 years follow up |
| GORE REDUCE trial [21]†† | Clinical stroke: 1.68 | ITT analysis (control group) Median 3.2 years follow up |
| <p>Bold text reports values that have changed following repeat analysis of data (new dataset).</p> <p>* Composite of stroke or TIA during 2 years of follow-up, death from any cause during the first 30 days, and death from neurologic causes between 31 days and 2 years.</p> <p>** Primary endpoint was a composite of recurrent nonfatal ischemic stroke, fatal ischemic stroke, or early death after randomization. However, all primary events were non-fatal ischaemic strokes.</p> <p>*** Composite outcome of death, stroke, TIA, or peripheral embolism. No deaths in control arm.</p> <p>† Trials identified in Section 3.3. These have not been appraised.</p> <p>†† Event rate per 100 PY estimated by EAC from raw data counts and mean or median follow up as reported in study</p> | | |

Comparison with the published evidence shows that although results from the CtE registry have improved, they are still broadly similar to outcomes seen from the control arms of RCTs. However, all the caveats previously discussed still apply; that is, a direct comparison cannot be made (see [Section 4.3.1](#)).

Implications for NHS England [Question Two](#)

The revised version of [Table 10](#), incorporating manually corrected neurological outcome data, is reported in [Table A3](#).

Table A3. Comparison of manually corrected neurological events with primary efficacy outcomes reported in the published literature.

| Study | Proportion of patients with primary efficacy outcome. Events per 100 PY unless otherwise stated. | Definition/comment |
|--|--|--|
| CtE registry | All neurological events: 2.2 (95% CI 1.2 to 3.6) Neurological event or death: 2.6 (95% CI 1.5 to 4.1%) Ischaemic event only: 1.3 (95% CI 0.6 to 2.5) | 16 patients, with a recorded procedure date, reported as having a neurological event. |
| RCTs | CLOSURE-1 (2012) [10] | 2.8* |
| | RESPECT (2013) [11, 22] | 0.66 0.58 (extended follow up) |
| | PC trial (2013) [12] | 0.83** |
| | Device trial (2013) [17] | 0.76* |
| | CLOSE trial [20]*† | 0.0 |
| | GORE REDUCE [21] † | 0.43* |
| Observational studies | Taggart (2017) [25] | 0.97 |
| | Pezzini (2016) [26] | 2.73* |
| | Inglessis (2013) [27] | 0.79** |
| | Wallenborn (2013) [28] | 1.0 |
| | Thomson (2014) [29] | N/A |
| | Mirzaali (2015) [30] | 1.53 |
| Bold text reports values that have changed following repeat analysis of data (new dataset). | | |
| * Event rate per 100 PY estimated by EAC from raw data counts and mean or median follow up as reported in study. | | |
| ** Event rate per 100 PY estimated by EAC from raw data counts and person years follow up reported in study. | | |
| † Trials identified in Section 3.3 . These have not been appraised. | | |

As can be seen, despite the reduction in neurological event rate with manual correction of the raw data, the point estimate for this value seen in the registry is higher than those reported in the most trials, with the exception of the CLOSURE-1 trial [10], which reported similar results. The manually corrected data are also similar to the observational study by Pezzini *et al.* (2016) [24] which reported a similar composite outcome. However, arguably

the most relevant outcome is the rate of ischaemic events, because this is the outcome that PFOC is designed to prevent. As the rate of ischaemic events was unchanged, then so are conclusions with respect to this outcome. Once again, all the caveats previously discussed still apply (see [Section 4.3.1](#)).

Conclusion

The manually corrected dataset contained moderately fewer neurological first events and substantially fewer repeat events compared with the original (uncorrected) reported data. However, the crude and adjusted rate of ischaemic events was unchanged and this is arguably the most important primary efficacy outcome relating to PFOC. There are limitations in the data, most notably that the clinical sequelae and permanence of neurological events remain poorly described, and this is of vital importance when comparing the outcome data to that in the published literature. Overall, the EAC considers that the manually corrected data do not significantly alter the conclusions that can be inferred from comparisons with clinical outcomes in the published data. Such comparisons are limited due to differences in definitions used, methodology, and issues with generalisability, particularly concerning populations. However, the manual correction exercise improves confidence in the validity of the neurological event rates, which have been applied by the EAC as inputs to the cost consequences analysis (CCA) [43] and answers to NHS England [Question 10](#) and [Question 11](#).

Figure A1. Time to event (solid lines), corresponding 95% confidence limits (dashed lines), and proportions of patients neurological event-free at 1 year (red dashed line).

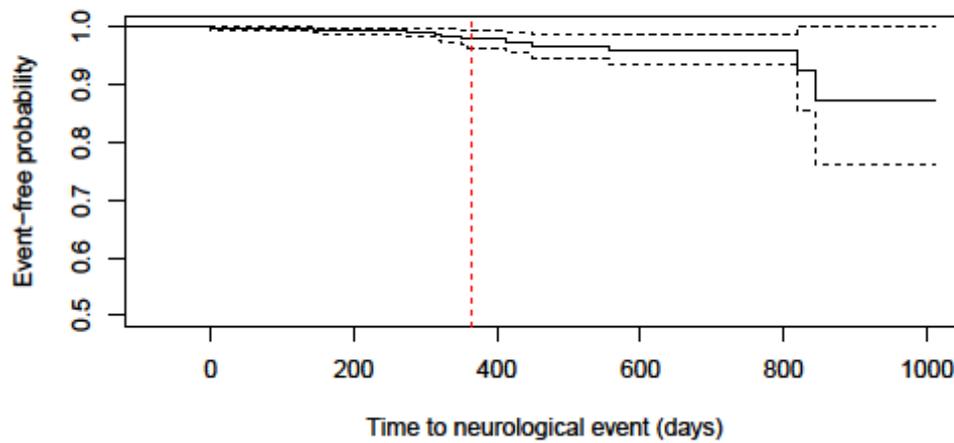


Figure A2. Time to event (solid lines), corresponding 95% confidence limits (dashed lines), and proportions of patients ischaemic event-free at 1 year (red dashed line).

