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NHS adoption of NHS-developed technologies

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NHS Adoption of NHS-developed Technologies

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Criteria for inclusion

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Glossary of terms/abbreviations

AHSC	Academic Health Science Centres
CAL	Computer Assisted Learning
CDSS	Clinical decision support system
EBM	Evidence-based medicine
EBP	Evidence-based practice
ERAS	Enhanced Recovery After Surgery
EU	European Union
EWS	Early Warning Signs
GP	General Practitioner
HITF	Healthcare Industries Task Force
HTA	Health technology assessment
IP	Intellectual Property
IRAS	Integrated Research Application System
IS	Information Systems
NIC	National Innovation Centre
NICE	National Institute for Health and Clinical Excellence
NIHR	National Institute for Health Research
NIII	NHS Institute for Innovation and Improvement
NPD	New Product Development
NTAC	NHS Technology Adoption Centre
PCT	Primary care trust
QA	Quality Assurance
QIPP	Quality, innovation, productivity and prevention
QOL	Quality of Life
RBVF	Resource-Based View Of The Firm
RCT	Randomised Clinical Trial
SDO	NIHR's Service Delivery and Organisation Programme
SME	Small to Medium Sized Enterprise

TAM   Technology Acceptance Model

TARS   Technology Adoption Readiness Scale

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Executive Summary

Background

For more than a decade, reports have been calling for greater and swifter development and adoption of innovative technologies by the NHS. Much research has been undertaken into the organisational factors and processes that determine the extent and rate of technology assimilation within NHS organisations but one question that has not been answered is whether NHS-developed technologies are adopted into the NHS any differently from those technologies developed commercially. This is an important question for two reasons. First, it is important to know whether the balance of influence on technology development between technology users and technology suppliers impacts on the success or failure of the adoption process. For example, it may be the case that because NHS developers are motivated by professional concerns and problems with which they have personal involvement they have limited concern for the future market and are therefore essentially producing innovations for which there is little or no applicability elsewhere. On the other hand, commercial technology suppliers may focus on extending or improving their current range of products and ignore unmet needs that care providers in the NHS are experiencing. Secondly, there are costs associated with developing technologies within the NHS and supporting their commercialisation and these costs may not be justified if the benefits gained from successful adoption into other parts of the NHS are not materialising.

Aims

The highest level aim of this research is to help the NHS fulfil its aspiration to become more effective in technology adoption. More specifically it is looking at the adoption of technologies into the NHS and investigating how the origin of the technology impacted on the adoption process. It is seeking answers to the following specific questions:

1. To what extent has the development process that produced a technological innovation determined specific aspects of the technology that have an impact on its adoption?

2. For a specific adoption context, what are the main factors that mediate the success of adoption and to what extent is this success related to the technology's origin?

3. How do external adoption drivers in combination with an innovation's origin impact on the potential for adoption?

4. Does the adoption process differ for NHS-developed technologies when compared with those that are commercially-developed?

Methods

This study started with a literature review. It began with an examination of reports published by the NIHR SDO programme that have addressed areas that are important to the study of innovation and adoption in the NHS. The remainder of the review takes key issues raised in the SDO reports with respect to the adoption of innovative healthcare technologies into the NHS and examines them further. This review helped with the framing of the research questions and informed the remainder of the research.

The research was conducted in two stages. Stage 1 identified 33 technologies that met the criteria 'NHS-developed' and through a series of telephone interviews with the developers of those technologies, their industrial partners (if any) and adopters, and by studying any published information about them, built up a data set looking at their characteristics. Five important dimensions of these characteristics were used to select six theoretically important technologies for further study. This further study was undertaken in Stage 2 of the research.

The purpose of Stage 2 was to compare the adoption of NHS-developed technologies with the adoption of equivalent commercially-developed technologies so the first task was to identify a competing or equivalent technology for each of the six technologies selected at the end of Stage 1. When this had been done, primary and secondary research started in order to gather data that would allow six pairs of comparative case studies to be developed which in turn would allow similarities and differences between and across pairs could be identified.

Results

The six technologies that were identified for investigation in Stage 2 were:

- a telehealth system

- a basic item of equipment

- a technology for informing diagnosis

- a technology for monitoring during surgery

- a clinical assurance technology

- an engineered component

These were identified on the basis that they would provide six theoretically interesting case studies.

Across stages 1 and 2, the research showed that the relationship between an innovation's NHS origin and its subsequent adoption by the wider NHS is not a simple one. The blurred boundary between NHS-developed and commercially-developed technologies makes it difficult to prove beyond doubt that one or other origin has a positive or negative impact on adoption. There is, however, strong evidence to suggest that the origin of an individual technology does give rise to certain characteristics that encourage or inhibit its adoption, but looking across a range of technologies there is not a consistent pattern of benefits or disbenefits. In short, being NHS-developed can, under certain circumstances, bring significant advantages in terms of securing adoption, but this is not the case for all technologies. There are circumstances where it does constrain adoption. For example, NHS origin can have a negative impact on potential adoption due to the technology produced having a rather narrow focus. Narrow applicability may be the result of a single inventor taking a somewhat blinkered view of the purpose of the technology being developed or the range of its possible uses. In contrast, the more market-oriented approach taken by a commercial developer usually ensures that the scope of a technology is extended to attract as broad a market as possible. It was also found that the simpler the technology, the less marked the effect of origin.

By examining specific issues that arose in the pairs of cases, such as, external adoption drivers, evaluation and evidence, professional and structural barriers to adoption and adoption decision-making, it has been possible to make a number of suggestions. These suggestions centre on: the need to consider the market implications at an early stage and take these into account when deciding the form, scope and wider design features of the innovation; the need for a project champion; changes to the form and quantity of technology evaluation that is undertaken; improvements to adoption support; and changes to culture and the need for ways to build commitment during adoption. Overall, it is suggested that consideration should be given to creating systems for technological innovation in healthcare that have structures and processes to support adoption at their heart. These systems would need to operate at different levels. At one extreme there could be a need to look across the NHS and at the other a system would need to operate at the level of the individual technology and treat each innovation as an individual project or part of a portfolio of projects, depending upon the nature of the technology.

Conclusions

It is clear from this research that the origin of the technology does affect adoptability in terms of both the extent of adoption (within a site and across sites) and the level of success achieved in an individual adopting site. It is also clear that being NHS-developed sometimes has a positive effect and sometimes a negative. Paying attention to the issues identified

by this research could increase the proportion of NHS-developed technologies that gain a positive advantage from their NHS origin. However, it is fair to say that this research has shown that many of the adoption problems encountered by NHS-developed technologies are shared by those developed independently of the NHS so many of the recommendations that will be set out here apply to technology adoption by the NHS generally.

The overall aim has to be to create an effective system for innovation. This report concludes that this system should draw on open innovation strategies developed in other sectors and makes some suggestions as to how this should be done.

The Report

1 Introduction

The very wide diversity of healthcare technologies is in part reflected in the definition of medical devices used in the EU Medical Devices Directive[1]:

> ...any instrument, apparatus, appliance, software, material or other article, whether used alone or in combination, together with any accessories, including the software necessary for its proper application intended by the manufacturer to be used for medical purposes for human beings for the purpose of:
>
> - diagnosis, prevention, monitoring, treatment or alleviation of disease,
>
> - diagnosis, monitoring, treatment, alleviation of or compensation for an injury or handicap,
>
> - investigation, replacement or modification of the anatomy or of a physiological process,
>
> - control of conception,
>
> - and which does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means, but which may be assisted in its function by such means.[1 p.23]

This definition focuses primarily on healthcare technologies that are either physical objects or pharmaceuticals but healthcare technologies can take many other forms. For example, they also include 'soft technologies'[2] such as the practices, procedures and services designs used in patient care that also contribute to the healthcare technology system. These soft technologies include knowledge embodied in the processes and procedures used to support patient care - e.g. surgical procedures, care plans and protocols.

Because of this diversity it is important to adopt a definition of healthcare technology that recognises the complex nature of healthcare technology and the systems within which they are used. The definition of healthcare technology used in this research is the definition put forward by the International Network of Agencies for Health Technology Assessment. It has been chosen because it provides a wider perspective on healthcare technologies within wider healthcare systems. It says that healthcare technologies include:

> ...prevention and rehabilitation, vaccines, pharmaceuticals and
> devices, medical and surgical procedures, and the systems within
> which health is protected and maintained[3 p.99]

For more than a decade, reports (for example, Culyer[4], Baker[5 6], *The NHS Plan*[7], Cooksey[8] and Darzi[9]) have been calling for greater and swifter development and adoption of innovative technologies by the NHS. Most recently, Liddell, Ayling and Reid's report entitled *Innovation Health and Wealth, Accelerating Adoption and Diffusion in the NHS*[10 p.7] has said:

> The purpose of the NHS, and everyone working in it, is to promote health
> and wellbeing, and to provide high quality healthcare, free at the point of
> delivery to everyone who needs it. ... Innovation has a vital role to play in
> fulfilling this purpose by improving the quality of care for patients,
> releasing savings through productivity, and enabling the NHS to make its
> contribution as a major investor and wealth creator in the UK.

In recent years the Department of Health has set up a number of new institutions and agencies to support innovation. For example, the Modernisation Agency was set up in 2001 with the aim of improving and redesigning services[7 p.60] and NHS-based innovation hubs were introduced in 2004/2005 and, as part of their remit, given responsibility for technology transfer out of the NHS[11]. Further reviews highlighted additional requirements for innovation and adoption support, for example the *HITF Report*[12], leading to the creation of the NHS Institute for Innovation and Improvement (NIII) and the National Innovation Centre (NIC) and the NHS Technology Adoption Centre. Following the *Cooksey Report*[8] Academic Health Science Centres (AHSCs), Health Education and Innovation Centres (HIECs) and biomedical research centres and units were set up to improve knowledge translation and increase the speed at which research knowledge is embedded into clinical practice. The National Institute for Health and Clinical Excellence (NICE) has also become much more involved with non-medicine health technologies. Now further changes are envisaged. (See *Health, Innovation and Wealth*[10] . The current infrastructure of organisations will be redeveloped with some bodies being discontinued, merged or replaced, as the NHS seeks to provide more effective support for innovation and adoption. Though adoption of new ideas and technologies is regarded as a challenging issue and reflects the complex network of interactions required to achieve adoption[13].

Another move has been to fund research into innovation in healthcare through the National Institute for Health Research (NIHR). One of the many outputs from the NIHR's Service Delivery and Organisation Programme (SDO) - a systematic literature review of the organisational factors which influence adoption in the NHS by Robert *et al.*[14] – formed the stimulus for the work reported here. The review explored a wide range of organisational factors and processes which are likely to determine the extent and rate of technology assimilation within NHS organisations. The review was very comprehensive but one aspect it was not able to shed much light on is

whether NHS-developed technologies are adopted into the NHS any differently from those technologies developed commercially. This is an important question for two reasons. First, it is important to know whether the balance of influence on technology development between technology users and technology suppliers impacts on the success or failure of the adoption process. For example, it may be the case that because NHS developers are motivated by professional concerns and problems with which they have personal involvement they have limited concern for the future market and are therefore essentially producing innovations for which there is little or no applicability elsewhere. On the other hand, commercial technology suppliers may focus on extending or improving their current range of products and ignore unmet needs that care providers in the NHS are experiencing. Secondly, there are costs associated with developing technologies within the NHS and supporting their commercialisation and these costs may not be justified if the benefits gained from successful adoption into other parts of the NHS are not materialising.

NHS-developed innovations are also of interest to the wider academic community because they represent an important class of open innovation[15], and combine aspects of user-led[16] and lead user innovation[17].

NHS staff such as clinicians, nurses and those in professions allied to medicine, are often particularly well-placed to recognise the clinical need that denotes an opportunity for innovation. The majority of staff lack the time and other resources to develop significant innovations but some of them do go on to develop viable solutions in the form of new devices and equipment, information systems, redesigned services and procedures and the like. The resulting technological innovations are thus often the product of pre-existing knowledge held by the NHS staff that can be re-configured or translated into new knowledge; they benefit from a staff member's tacit and situated knowledge[18] of how things work and what forms of presentation of an idea would be acceptable or unacceptable to colleagues and potential users.

Research questions

The highest level aim of this research project is to help the NHS fulfil its aspiration to become more effective in technology adoption. It does this by providing insights into the enablers and barriers to successful adoption of technologies by the NHS.

Before the research began a set of initial research questions was drawn up to guide the research. These were:

- Do user-developed products perform differently in the technology assessment processes (evidence-based and preference-based) underpinning adoption decisions?

- What part do informal professional networks play in adoption decisions?

- Does the origin of the technology impact on the compatibility of a technology for adoption within an NHS organisation.

- Do user-developers have a greater opportunity to gather evidence and develop implementation guidelines that support the adoption decision process and does this allow them to achieve better trialability?

- Does the source of the technology impact upon the perceived relative advantage and the perceived complexity and if so, how?

However, after a fuller literature review had been conducted and initial conversations had taken place with members of bodies supporting innovation in the NHS such as Innovation Hubs, the NHS Technology Adoption Centre (NTAC) and the NHS National Innovation Centre (NIC) it became clear that some of the questions, such as 'What part do informal professional networks play in adoption decisions?' were too narrow. A mapping of the area to be covered by the research (see Figure 1) was therefore looked at again to re-determine what the focus of the research should be given the purpose was to shed light on NHS adoption of NHS-developed technologies and compare adoption of NHS-developed technologies with non-NHS-developed.
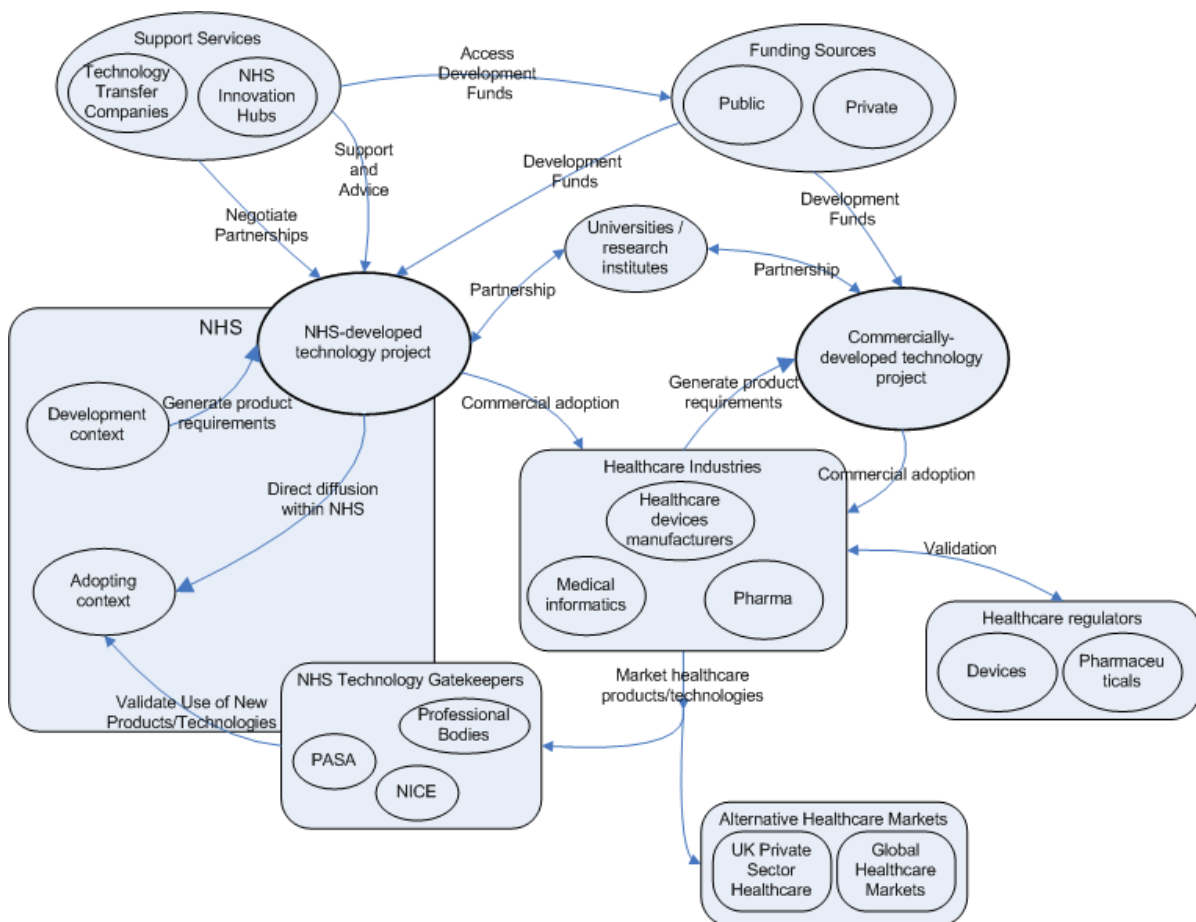
Figure 1. The initial focus of the research

The work done to build Figure 1 in combination with the findings of the literature review led to the following revised set of questions:

- To what extent has the development process that produced a technological innovation determined specific aspects of the technology that have an impact on its adoption?

- For a specific adoption context, what are the main factors that mediate the success of adoption and to what extent is this success related to the technology's origin?

- How do external adoption drivers in combination with an innovation's origin impact on the potential for adoption?

- Does the adoption process differ for NHS-developed technologies when compared with those that are commercially-developed?

Structure of this report

This report begins with a review looking at the literature that underpins this study of the adoption of NHS-developed innovations by the NHS itself. First it reviews several key reports on specific aspects of innovation and adoption in the NHS. It then considers the wider literature that supports an understanding of innovation characteristics, adoption context, external adoption drivers, and adoption processes. It then sets out the methodology used to undertake this research.

The research has been conducted in two stages. Stage 1 was a survey to ascertain the characteristics of a wide a range of NHS-developed technologies. The findings of this stage are presented in Section 4 and are used to identify six theoretically important NHS-developed technologies that are taken forward into Stage 2. Stage 2 took each of the six technologies in turn and paired it with an equivalent commercially developed technology. Case studies were then developed for each of the resulting pairs of technologies. These case studies are presented in Sections 5 to 10.

A discussion of the research findings can be found in Section 11. This is followed by a final section headed 'Recommendations and conclusion'. Suggestions for future research are provided at the end of this section.

2 Innovation and adoption of healthcare technologies: a literature review

This review considers the literature that underpins a study of the adoption of NHS-developed innovations by the NHS itself. This area cuts across many of the streams within the extensive innovation literature because the role of the NHS in developing and adopting healthcare technology is complex. Innovation can be regarded as a specific process but it can also be viewed as a product of a process. In terms of innovation as a product, NHS-developed innovations may be artefacts, procedures, organisation designs or complex combinations of two or all three of these. When considering the processual nature of innovation, the role played by the NHS and its staff may be viewed in many ways: as consumers of healthcare technology; as sophisticated users of technology; as active developers of new technologies; or as a complex hybrid of two or more of these roles. Because the NHS is a complex network of hundreds of organisations, political, structural and cultural factors all influence the extent and success of innovation and adoption initiatives.

This review is structured in two sections. The first examines several key reports on specific aspects of innovation and adoption in the NHS. These reports provide a foundation for identifying the literature relevant to this report. The second allows the guiding questions for the study to be defined. It looks at innovation characteristics, adoption context, external adoption drivers, and adoption processes.

2.1 SDO Studies addressing technology adoption

Over the past few years six reports published by the NIHR SDO programme have addressed areas that are important to this research. Though they are not all explicitly about technology adoption they do all consider wider issues that are related to technology adoption. The first two reports considered look at adoption in broad terms and encompass the uptake of technical knowledge, the adoption of specific technologies and adoption in relation to the technology-enabled change of large-scale services. The next two consider knowledge mobilisation and networks identify bodies of knowledge from the wider literature that inform an understanding technology adoption. The final two reports each look at specific cases of technology adoption.

How to Spread Good Ideas A systematic review of the literature on diffusion, dissemination and sustainability of innovations in health service delivery and organisation

Greenhalgh *et al.*[19] make a very important contribution to the understanding of adoption of innovation by the NHS. Their report's primary focus was the adoption of organisational innovations that affect health service delivery and organisation. Although their focus was not specifically on technology all of the case studies they present have some technology content. Two of the cases they examine, telemedicine and electronic patient records systems, clearly have high levels of technology dependence (see p.297) but even organisational innovations they look at, such as integrated care pathways and GP fundholding, have some level of technological dependence. Indeed, Greenhalgh *et al.* acknowledge that even innovations that may seem to be simply organisational depend on embedded technologies. Their report thus presents a useful starting point for this review.

Greenhalgh *et al.* consider many of the themes identified by Rogers[20] in his work on the diffusion of innovations and look at them in the context of healthcare systems in general and the NHS specifically. Overwhelmingly, their conclusion is that adoption of innovations is complex with multiple factors influencing the extent, success or failure of the adoption. Particular factors they note (p.323) are:

- attributes of the innovation

- adoption process engaged (or not) by individuals

- communication and influence

- inner context or user system

- external context

- implementation process

- Nature, capacity and activities of external change. E.g. active dissemination campaign

Greenhalgh *et al.*'s report also echoes concerns about technology adoption from the wider literature. Very importantly it warns against taking a technological determinist view of healthcare technology adoption that assumes technology can be treated as a 'black box' and its implementation will inevitably lead to specific pre-identified changes. Such an assumption has been shown to be unreliable by many notable studies, not least Barley in his study of the implementation of CT scanners[21][22], but is nevertheless prevalent in the real world.

Organisational factors influencing technology adoption and assimilation in the NHS: a systematic literature review.

A second SDO-funded systematic review by Robert *et al.*[14] built upon the 2004 Greenhalgh report. It examined the factors affecting adoption of technologies into healthcare. As a starting point, Robert *et al.* focused on the 'Inner Context' or user system and forwarded two key notions to explain why organisations adopt (or do not) innovations (p.24): organisational antecedents; and organisational readiness for innovation. Organisational antecedents may be the structural characteristics of the organisation, including size, maturity, formalisation, resource levels, and the like, or non-structural characteristics that relate to the technological capabilities for adoption such as absorptive capacity, leadership, organisational climate and strategic priorities. Organisational readiness is the extent to which a particular organisation is ready to accept an innovation based on and is based on tension for change, innovation-system fit, assessment of implications, support and advocacy, dedicated time and resources, and the capacity to evaluate the innovation.

Robert *et al.* organise many key issues into a conceptual model of technological adoption and assimilation in healthcare organisations[14 p.87]. This model, reproduced in Figure 2, comprises three significant elements: the innovation; the innovators; and the user system. Though the model conflates a range of elements including structures, processes and system states, it provides a useful starting point for describing the system through which NHS-developed technologies are adopted into the NHS.
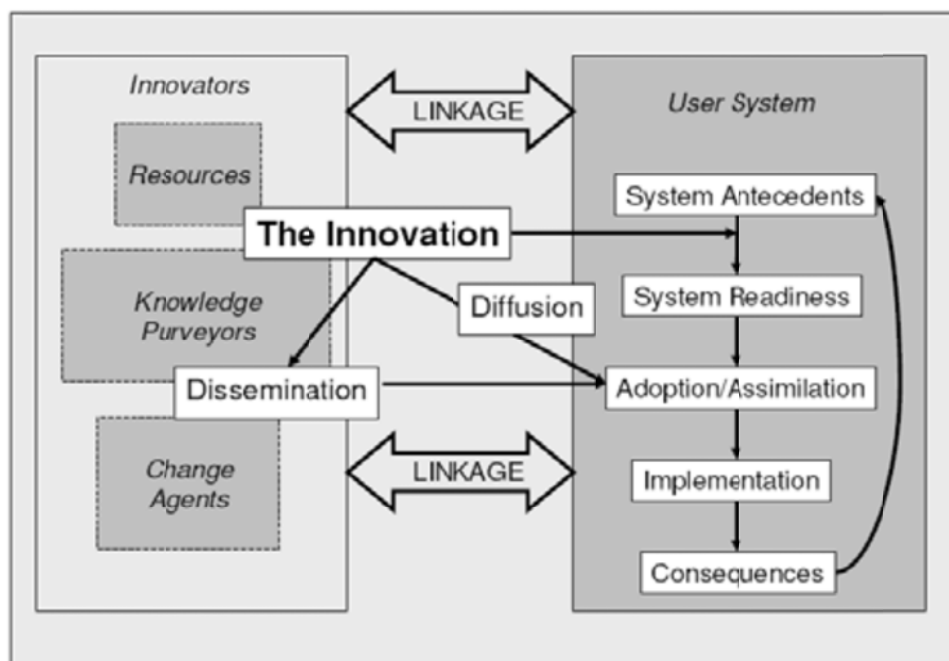
Figure 2. Conceptual model of technological adoption and assimilation in healthcare organisations[14 p.87]

Robert *et al.*'s far-reaching review also encompassed literature related to some important areas of the organisational theory literature. For example, it considered routinisation theory and the role of organisational routines in structuring healthcare processes. The literature about organisational routines is very relevant in terms of understanding how routines structure practices in organisations[23] and how organisational learning is preserved across generations of staff[24]. Robert *et al.* highlight the importance of routines in structuring behaviour for individuals, groups and at an organisational level. In relation to technology adoption the report identifies the extent to which it is important to consider routines because they can underpin the nature of work, professional identify and the role of technologies.

Technology structuration theory was also included. By reviewing a range of structure-agency models such as scripts[22], adaptive structration theory[25] and interpretive flexibility[26 27], Robert *et al.* highlighted the role of technology adoption in creating and re-creating social structures. Robert *et al.* also highlighted the role of technology in enabling the agency of individuals to affect change to organisational structures and re-shape the technology itself. Finally it emphasised the relevance of actor-network theory[28] when looking at how adoption of technology takes place within complex networks of relationships and understanding how the embedding of new technologies into a network can have unintended consequences.

Robert *et al.* set out four broad challenges for healthcare organisations in adopting innovative technologies. The first relates to adoption decision-making. This includes the formal structures that are needed to support effective decision-making and the role of health professionals, patients and external sources of advice, in assimilating and monitoring the implementation of innovative technologies. The second challenge is the need to ensure organisations have sufficient absorptive capacity to allow in-ward flow of knowledge, skills and know-how and to support adoption processes. The third challenge is the need to create an organisational climate in which adoption processes are not limited by political, financial, managerial or informational factors act and are therefore able to support innovation adoption rather than inhibit it. The fourth challenge concerns the organisational readiness of an organisation to adopt technological innovations. In essence this represents the specific organisational capabilities that are required to facilitate effective technology adoption.

Research utilisation and knowledge mobilisation: a scoping review of the literature

A different perspective on innovation adoption issues is available from Crilly *et al.*[29]. They report the findings of a systematic review of the literature addressing the problem of mobilising knowledge created through research within the NHS. This review was conducted in the context of a need to improve knowledge translation, and in particular the perceived gaps in the

process of translating knowledge from "bench to bedside"[8]. Much of Crilly *et al.*'s report is concerned with how research impacts on practice in healthcare organisations. Its underlying themes are evidence-based practice and policy and it presents a number of propositions that guide further investigation of the role of knowledge mobilisation in healthcare (p.213). Each of these are relevant to managing knowledge to support technology adoption.

The shift towards evidence-based medicine[30] and policy[31] raises key questions about technology adoption. For technologies that enable/require changes in procedures and processes being able to meet the demand for an evidence-base will require clear recognition of whose evidence counts and agreement about what is regarded as a legitimate epistemological basis for validating knowledge. For example, should the basis of evidence for implementing a new technology into a specific context be focused on strict scientific reproducibility, reflected in the primacy of systematic reviews of multiple clinical trials? Or alternatively, should the basis of evidence that underpins the use of a new technology take into account broader forms of evidence and wider concepts of knowledge? and how does the contested nature of knowledge affect decisions to adopt a technology?

Information technologies are almost becoming a ubiquitous feature of healthcare technologies. Crilly *et al.* highlight that from a knowledge management perspective the role of information technologies has gone beyond simply providing a data-processing function and becoming increasingly social and interactive. The implication of this for technology adoption is that human interaction with embedded information technologies will change how individuals and teams work and how patients interact with healthcare services.

Crilly *et al.* also emphasise the role of knowledge management in underpinning the ultimate performance of healthcare organisations. Within their report it is evident that technology and its adoption can be seen as both a result, and an enabler, of organisational learning, communities of practice and R&D activities. Though not making an explicit link, the report sets the basis on which technology adoption needs to be considered from the perspective of the resource-based view of the firm (RBVF)[32-35]. In fact, the adoption of technologies may be viewed from the perspective of how healthcare organisations develop new technological capabilities, or abandon old ones. This shows that technology adoption should not be seen simplistically in terms of technical implementation. Instead, a healthcare organisations ability to adopt new technologies should treated as a dynamic capability[34-38].

Networks in Health Care: a Comparative Study of Their Management, Impact and Performance

Ferlie et al.'s review[39] focused on the role of network forms of organisation within the NHS to facilitate service improvement and innovation. It raises issues that are pertinent to understanding how technological innovations are adopted into practice. The role of networks of various types in the technology adoption process is shown to be subtle and far-reaching and the report acknowledges several advantages and disadvantages of various network forms within the healthcare sector. The report is careful to highlight how network forms of organisation effect change differently to market-based or centralised, command and control structures (p.184). Ferlie et al. show that the recent change within the NHS from large vertically integrated organisations, towards more network oriented forms of organisation is part of a more general shift observed in several other sectors.

Ferlie et al. highlight the medical and healthcare professions as specific forms of network, building on earlier concepts such as the invisible college. They reiterate that the healthcare sector can be characterised in terms of professional networks embodying the rather clannish character of professional groups that transcend allegiance to specific organisations. In terms of the success of technology adoption, the power of professional groups to accept or reject a technology can be very important. Professional bodies influence the accreditation and training standards that advocate, or reject, a specific technology. Furthermore, the extent to which professional bodies validate a new knowledge is crucial to the uptake of a new technology. The power of such professional bodies is such that it seems that individual health professionals will be less likely adopt a new technology before their own profession has accepted it.

Ferlie et al. also reflect on more recent moves to standardisation of expert knowledge. This is perhaps best expressed in the move towards the bureaucratisation of medicine (see for example Harrison[40]). This is linked to the increased emphasis on evidence-based practice that has in part replaced reliance on the professional judgement of individual clinicians. Ferlie et al.'s report might suggest that the challenge in gaining the adoption of a technology has changed from the need to convince individual clinicians to change practice, to one of convincing regulatory bodies of the relevance of a technology to a specific guideline. Though the extent to which evidence-based practice has now overridden professional judgement remains to be proven.

Ferlie et al. discuss the extent to which networks are now seen as an alternative organisation form, shifting power and control away from the management of healthcare service through strict hierarchical structures, and links it to the application of 'New Public Management' within the healthcare sector. For example, in areas such as cancer care and

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cardiology, formal networks have been created to review performance, consider alternative practices, communicate knowledge and champion changes in practice. Such networks are important to the adoption of new technologies. They provide mechanisms through which knowledge associated with innovative technologies can be created, validated, stored and disseminated. Instrumental use of the network form may be critical to creating the consensus amongst key stakeholders that is essential for adoption.

Ferlie *et al.* focus closely on the role within networks of 'epistemic communities of practice' and its effect on technology adoption. They highlight that methods for creating and validating knowledge will differ between groups, such as medical scientists, research scientists, social scientists, policy makers and commissioners. In the context of technology adoption this might suggest that differences in epistemology needs to be considered when looking for the most appropriate way to evaluate a new technology. If this is not done key stakeholders may question the validity of those evaluations.

The review also includes discussion of the advantages and drawbacks of networks that is of particular relevance to technology adoption. They note that a strength of networks is that they are well placed to address the 'wicked problems' commonly encountered within public-sector services (p.186), see also Ferlie *et al.*[41]. Considering the extent to which technological innovations create or ameliorate such problems is important, especially in key strategic areas that address complex issues, for example, dealing with long-term health conditions. The potential for networks to act as implementation networks makes them especially relevant to adoption and diffusion of technologies, especially in the case of novel technologies.

The use of networks to promote technology adoption is however, potentially problematic. Ferlie *et al.* point out that the potential for a network to lose focus or become simply a 'talking shop' is a very real one. It can also be difficult to find a balance between being overly focused on implementation of top down initiatives or over emphasising emergent initiatives at the expense of high-level objectives. Insufficient resources, a heavy administrative burden and the need for skilled management can also make networks ineffective. Ferlie *et al.* also suggest that there is potential for networks to become dominated by an 'elite professional group'. This may have a pro-adoption effect - for example, where a network is linked to key opinion leaders and other senior members of a professional group, the network can act as a strong advocate for adoption of a specific technology – but it may lead to an innovative technology being resisted by a professional group that has the power to prevent adoption.

Understanding the Implementation and Integration of e-Health Services.

Mair *et al.*'s[42] study is specifically concerned with implementation of e-Health technology and its successful integration with NHS services and so provides useful insights into adoption of technology into healthcare settings. Its emphasis on the broad domain of information systems for management, communication and decision-support rather than a specific category of healthcare technology means that it takes a slightly different perspective from the other SDO reports considered here.

The conclusion of Mair *et al.*'s report provides some useful guidelines for research into the more general area of adoption. Having undertaken a systematic review of they have found that though there is a consideration of the context in which adoption occurs, especially in terms of organisational factors, more specific issues of the workability of a system are less well reported (p.44). In particular they stress the need for clear analysis of the work required by health professionals to make e-Health systems function well in practice, for example through the use of their Technology Adoption Readiness Scale (TARS) (p.93).

A further point made by Mair *et al.* is the need for monitoring and evaluation of new e-Health services. The primary purpose of this should be to build an evidence-base to inform adoption by other organisations. This perhaps resonates with a wider issue raised in all of the reports looked at here. It is the question of how evaluation should be carried out and for whom the outputs of evaluation should be targeted. As Ferlie *et al.* note, different groups of stakeholder produce and use different types of knowledge and knowledge objects. Because a randomized clinical trial is seen as the 'gold standard' in technology evaluation staff are perhaps discouraged from evaluating implementations using methodologies other than the randomised clinical trial, even where those methodologies would be more appropriate and/or it is not practicable to undertake a randomised clinical trial.

Other issues relating to technology adoption were also addressed by Mair *et al.* For example, the level of dialogue between designers, implementers and users of e-Health systems, mirroring concerning in the wider IS literature around user-involvement in systems development (see for example[43 44]). They also pointed to the need for the rationale, safety and reliability of systems to be communicated clearly to potential system users.

Finally, Mair *et al.* builds upon their own previous work on a model of normalisation of technology into practice. The Normalisation Process Model[45] provides further insights into technology adoption and is discussed later in this review.

Evaluation of the National Infarct Angioplasty Project

The issue of technology adoption has also been addressed by Goodacre *et al.*[46] in an SDO-funded evaluation of the National Infarct Angioplasty Project. Their study looked at the implementation of primary angioplasty using a radically re-designed service, signifying a change in service design from the existing thrombolysis-based service. In doing so they considered the whole healthcare technology system and not just a single device or procedure. In light of the discussion above it is interesting that they note in the foreword to their report that while there was a large body of evidence supporting the long-term benefits of primary angioplasty in treating heart attack, an evaluation at the level of service-delivery was still needed.

Goodacre *et al.*'s evaluation was broad and far reaching. It considered four areas: models of delivery; workforce implications; patient/carer satisfaction; and economic evaluation. The findings considered factors such as variations in the extent of implementation (for example, the extent to which a full 24/7 services were established across all sites) and provided detailed analysis of issues raised during implementation. The findings also reflected more general concerns about adoption of technologies into the NHS including:

- requirements for radical transformation of existing service delivery models;

- serious implications for job roles, skill levels, working practices and quality of working life issues;

- Impact on the experience of patients and carers and the need to manage expectation;

- risk that implementation of sub-optimal service designs preclude the achievement of a technology's full benefit;

- mismatch between national payment tariffs and local costs over the short, medium and long term (see also Moore[47]);

- tension between the role of national implementation programmes to drive radical change and pressure for incremental, locally-driven change.

Overall, Goodacre *et al.'s* evaluation highlights the range of evaluation information that is, or could be, used by potential technology adopters when considering embedding new technologies into new service-designs and emphasise that there is a need to move beyond a narrow consideration of outcomes or cost-benefit analysis.

Summary

Table 1 brings together the key themes highlighted in these six recent SDO reports. It relates the issues raised and locates them within the framework suggested by Greenhalgh *et al.*[19].

Table 1.   Themes developed in the SDO Reports

Report	Greenhalgh *et al.*[19]	Robert *et al.*[14]	Crilly *et al.*[29]	Ferlie *et al.*[39]	Mair *et al.*[42]	Goodacre *et al.*[46]
Type of innovations addressed	Adoption of organisational innovations into the NHS.	Technological innovation adoption and assimilation in healthcare	Mobilising research-based clinical and managerial knowledge	Shift to network and knowledge -based forms of organisation in healthcare.	Implementation and integration of e-Health services.	Embedding Innovative technologies into new service designs
Innovation characteristics considered	Attributes of innovation • Relative advantage • Compatibility • Complexity • Trialability • Observability Re-invention[20]	Inner-context and user system	Evidence-based healthcare Nature of knowledge Knowledge translation	Role of networks: • Governance • Implementation • Evaluation	Introduction of a technology into a challenging professional, organisational and institutional context.	Establishing an innovative, technology-based, system of care into existing acute care organisations.
Adoption Context	Pan-NHS adoption in NHS service delivery and organisation	Organisational antecedents and readiness for innovation	R&D and knowledge management superstructures	Research networks Epistemic communities of practice	Interaction between health professionals and e-Health implementers	Emergency care organisations
External adoption Drivers	Communication and influence • Opinion leaders • Champions • Boundary spanners • Change agents	Decision making Absorptive capacity Receptive organisational context Organisational readiness	Managerial and clinical research.	Wicked problems Initiating networks: • policy/territorial community • professional network • intergovernmental network • producer network	Pressure to implement ICT-based innovations into re-configured healthcare services	Local and incremental change *vs* National Programmes
Adoption Process	System-wide factors	Broad issues in adoption/assimilation and implementation	Organisational learning RBVF Communities of practice	Role networks assume as sources of support and facilitation for mobilising knowledge	Implementation tools User engagement Safety and reliability Compatibility issues Manage national and local priorities Workforce impact, monitoring and evaluation	Role change and skill development Service configuration Managing expectation of patients/public Piloting Care guidelines

2.2 Key factors affecting technology adoption in the NHS

The six SDO reports reviewed have raised a number of key issues with respect to the adoption of innovative healthcare technologies into the NHS. The remainder of this review will examine these further by using the literature to develop a model of the system through which NHS-developed technologies are adopted into the NHS. It is this model that will guide the first stage of this research. Figure 3 sets out the framework that will be used for this.
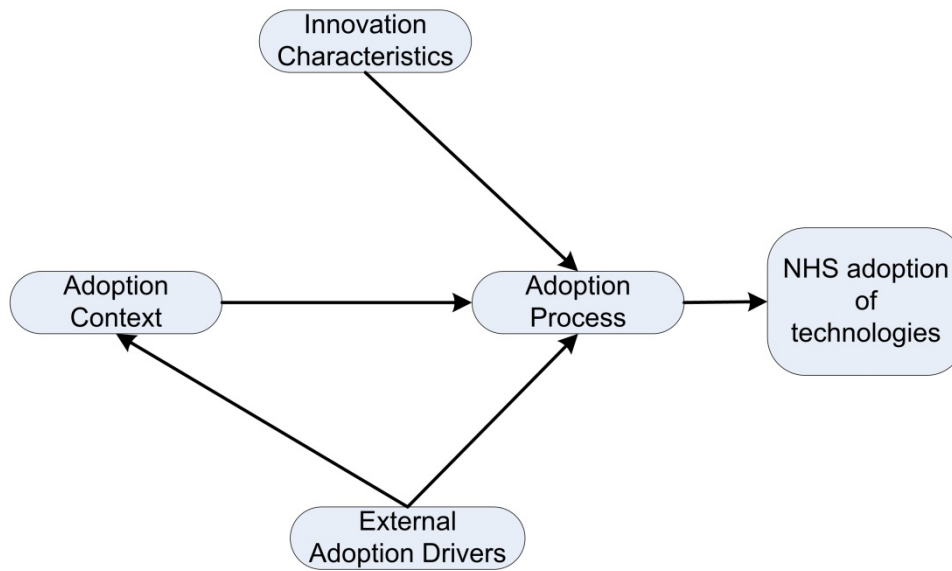
Figure 3. Factors affecting NHS adoption of NHS-developed technologies

Adoption of healthcare technologies is affected by the attributes of the technologies themselves such as their perceived relative advantage, their compatibility with existing structures and processes and their complexity. It is also affected by the nature of the adopting context. Acting upon this context are the external drivers of adoption such as legal, economic, political and social factors. The extent and success of adoption will also be dependent on the nature of the adoption process itself. Specific process models and methodologies for managing implementation project are important but, factors such as support from formal and informal networks may also have a profound effect on the progress of adoption and diffusion of innovations.

2.2.1 Innovation characteristics

The extent to which adoption of an innovation takes place relies on a range of factors, including the characteristics of the innovation itself. Part of the adoption decision is likely to be based on the technical specification of an innovation but the wider innovation literature suggests that other innovation characteristics will also be relevant. Greenhalgh *et al.*[48 p.594]

discussed the attributes of an innovation that affect adoption as suggested by Rogers[20], namely, relative advantage, compatibility, complexity, trialability and observability. Their conclusion was that although there is evidence to suggest that technologies do have characteristics that impact on their adoptability, innovation attributes on their own do not provide a full understanding of adoption behaviour.

Several authors have suggested that technologies have certain inscribed characteristics that reflect encoded knowledge[36 49 50]. Encoded knowledge may have been deliberately embedded into software, as would be found in decision-support systems, but, more subtly, technologies can also reflect tacit knowledge[51]. Suchman has termed this situated knowledge and describes how it is developed through pragmatic and situated interaction with a technology[18]. Situated knowledge is the product of complex social learning processes and is therefore difficult to capture[52].

Situated knowledge embedded within a technology can mean that a specialist technology fits with the specialist practice of a certain professional group and is therefore more attractive to that group, thus making the technology more likely to be adopted. However Sole and Edmondson[53]highlight that because situated knowledge results from learning processes and interactions in a distinct locale it may not always transfer well to another locale and therefore be of limited use. This point is also picked up by Orlikowski[26] who notes that technology reflects the organisational rules and procedures from the organisation where it was developed. The implication of this is that a technology is not independent of the values, skills and knowledge of the originating organisation. An innate characteristic of the technology will be inscribed ways of working that reflect particular values, world views, procedures, processes or even existing service-designs.

Innovation/development process

The characteristics of a healthcare innovation can in part be determined by the nature of the processes through which it has passed before becoming available for adoption. For a simple technology the effect might be minimal or non existent but as complexity increases the effects are likely to grow. Complex innovations will follow trajectories mediated by the capabilities and resources made available during development. The concept of knowledge assets is important here. Teece[54] has explored the relationship between the progress and success of innovation processes and the extent to which complementary assets have been accessed. The innovation process does not simply rely on the novel idea produced in a moment of invention. Critical to successful innovation is matching up a novel idea with other complementary assets, such as intellectual property and organisational capabilities[34].

Rosenberg[55] emphasised that the innovation process cannot be treated as a black box; clarity is needed about the detail of the activities that constitute innovation. Since then, various process models of innovation have been suggested. These have increased in sophistication over time as the range of activities and their inter-relationships have been described in greater depth. Several authors have reviewed these models and have linked them to distinct generations of model, with each generation having a distinct emphasis. (For a full review see[56-59]). First and second generation models were concerned with viewing technological innovation in terms of either a technology push[60] or pull[61]. Third-generation models recognised the limitations of these early perspectives and incorporated the concept of close coupling. This allows innovation activities to be seen as a logically sequential, though not rigidly continuous, interaction between research and customer demand[62 p.50]. Fourth-generation models incorporated the iterative process of interaction and collaboration between technology suppliers and customers[20 62 63]. The most sophisticated process models to date (fifth-generation) are concerned with increased strategic and technological integration[64]. This integration of processes has led to the recognition of the role of national systems of innovation[65-67], evolutionary models[68-71] and distributed models[72 73].

The simplicity of linear models of innovation is attractive but not very useful if it is simply hiding the true complexity of the innovation process. In recent years they have been generally discredited due to their lack of sophistication. Van de Ven *et al.*[74 p.10] argue that the parallel and recursive activities involved in innovation are better characterised as forming a nonlinear, dynamic system. Godin[75] suggested that linear models have continued to guide public policy, principally because they lend themselves to easy statistical measurement but at best they represent '...a theoretical construction of industrialists, consultants, and business schools, seconded by economists.'

The convenience of assuming process linearity has been taken up by the innovation diffusion literature. For example, when describing his six-phase linear model of diffusion, Rogers[20 p.158] is careful to note how it is affected by serendipitous events and so should be used as a '...general guide to the process from which many innovations will deviate'. This suggests that both innovation and diffusion are subject to the effects of not just specific processes but also the diverse range of relationships and interactions that underpin the innovation process.

A more realistic model for innovation in a sector such as healthcare are those that recognise innovation's distributed and systemic nature. It has been suggested that innovations are created by innovation systems rather than being an output of a series of discrete processes[76]. The national and regional systems of innovation literature adopts a macro view of innovation processes and highlight the importance of an infrastructure of institutions to support innovation[65 67 77]. Within industrial sectors, sectoral systems of

innovation are based around networks of relationships[78] or technological fields[79]. It follows from this that the mode of innovation development will not only define the process of innovation but also the relationships and types of interactions that impact upon its progress. Several modes of innovation development have been identified ranging from those that are highly structured, through to those that are more evolutionary.

In many sectors, management of innovation has focused on the new product development (NPD) process. This emphasises planned phases of development to reduce risk, control costs and to ensure delivery of new products that meet defined customer requirements. Though varying between different classes of technology, there are common themes of clearly defined development phases. Cooper[80][81] describes an innovation funnel model, distinctive in its use of a series of stage-gates to actively manage progress of projects through to subsequent development stages. This approach has been very influential and has informed the specific processes applied in several technology sectors. Similarly, approaches such as technology roadmapping attempt to link the portfolio of current technologies and capabilities with those required in the future. (See[82-85] and for a review of roadmapping techniques see Kostoff and Scaller[86].) Within healthcare there are distinctive sectorial approaches to the development of new products, such as the drug-development pipeline used within the pharmaceuticals industry. (See Northrup[87 p.54].)

An important theme in the NPD literature is the role of consumers and users of technology in the development of new or improved products. For example, in the healthcare sector, clinicians have made a significant contribution to the development of new healthcare technologies. Chatterji *et al.*[88] concluded that physicians were very active innovators and found that in the US almost 20 percent of approximately 26,000 medical device patents had been developed by physicians. Of course patenting a technology does not automatically translate into successful innovation.

Several authors have explored the role that end users of technology can have in its innovation processes. (See, for example, user-led innovation[16]. One model through which end users are supported in developing new technologies requires them to take on the role of lead users. Von Hippel[17 p.23] defines lead users as members of a user population who are at the leading edge of trends in the population and anticipate relatively high benefits from obtaining a solution to their needs. As a result of this anticipation they are willing to put effort into innovation. Hippel cites the work of Lettl *et al.*[89] as an example of medical equipment innovation being driven by clinicians. However, much of the emphasis of the lead user approaches is based on the assumption that lead users will provide input into development of technologies, but the balance of control of the development and marketing will remain with technology manufacturers. As such, an important role of lead users is to articulate previously unarticulated requirements and propose viable solutions. Lettl[90] noted that

their exposure to specific problem situations means that healthcare staff are in a position to define problem situations and then specify or develop viable, innovative solutions. As such, healthcare staff can be important lead users in the development of healthcare technologies. For examples of medical technology developed by lead users see[17 91 92].

Chesbrough has integrated many aspects of the research into innovation processes into a model of open innovation[15]. Central to Chesbrough's approach is that innovation is not simply the preserve of internal R&D departments, a point that is likely to apply specifically to healthcare technology suppliers. As the previous examples show, institutions that deliver healthcare, and the people who work within them, can play an integral role in the healthcare technology industry innovation system.

Central to an Open Innovation philosophy is the expectation that organisations will seek innovative solutions from outside (inward innovation) but will also manage internally developed innovations by passing them out of the firm in order to exploit them (outward innovation). (See, for example, Lichtenthaler[93].) Within the UK there has been a gradual increase in interest in improving technology transfer from public sector research institutes (for example the Baker Report[5]). The development of a strategy for exploiting IP from within the NHS was outlined in a Department of Health framework and guidance paper[11]. A particular focus of policy became the role of NHS organisations as active partners in innovation in relation to the wider healthcare technology industry (see the HITF Report[12]). These initiatives have focused specifically on the role of NHS staff in innovation processes and attempted to address how innovation support can be provided to those NHS staff. During the first few years of the 21st Century the UK government encouraged the development of technology transfer offices within the NHS, known as NHS innovation hubs. These were modelled closely on commercial and university technology transfer offices. These were primarily focused on transfer of technology developed within the NHS to wider markets. Some successes have been reported (for examples see[94],[95]) but the extent of success achieved in capturing and exploiting IP generated within the NHS for the benefit of the NHS remains uncertain. The concerns set out by Savory[96] that a more broadly based, culturally-sensitive approach is required, still stand.

Role of health professionals in innovation

A paper written at the start of this research[97] examined the role of professionals working within healthcare in innovation. It showed that the literature on the role of users in innovation has predominantly considered the private sector context. (See, for example, Thomke and von Hippel[98] and von Hippel[17].) However, there are reasons to believe that the healthcare sector is different from many others. Since ancient times, surgeons have taken the role of both designer and user of surgical instruments[99] and clinicians have driven innovations in the design of healthcare service

delivery models[100]. Lettl[90] argues that the enactment of these combined roles stems from the inventive and innovative personalities of the role occupants, alongside a context in which there is a high problem pressure and a lack of availability of relevant competences and resources. Expression of this behaviour has been highlighted by the entries submitted to recent innovation competitions, run within the NHS. Some very widely-used innovations have been developed by doctors, nurses, manager and auxiliary staff, often without formal involvement of NHS senior management[94]. The paper also maps the complex routes taken by projects based inside the NHS and the range of support on which they draw. This is reproduced here as Figure 4.
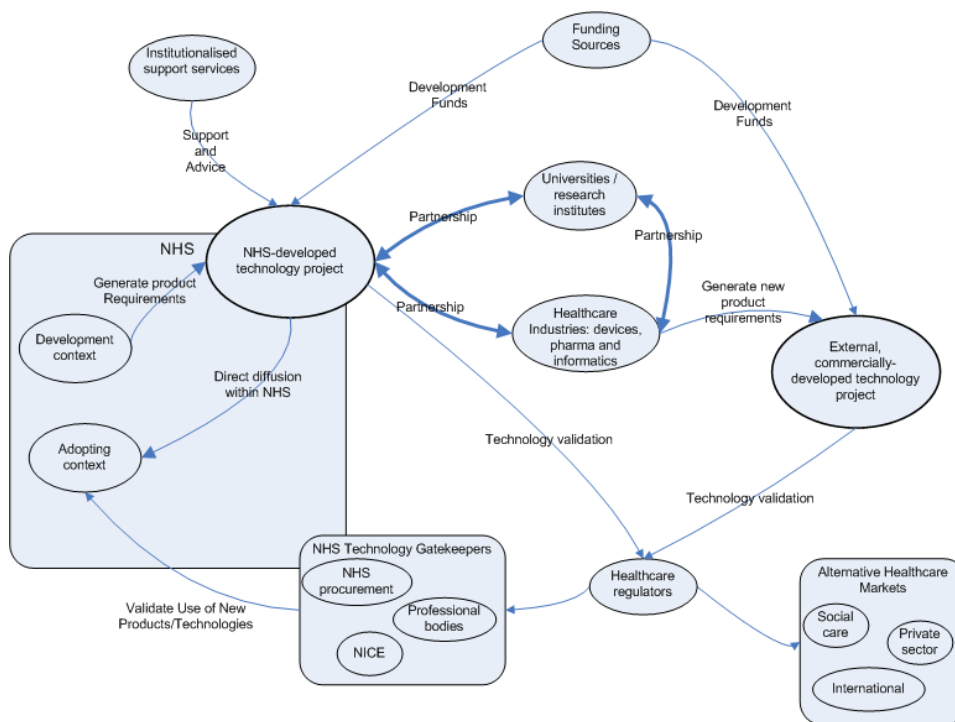
Figure 4. Routes to market for NHS-developed technologies[97]

2.2.2 Adoption Context

The organisational context has been identified as an important factor in adoption of technology. It is widely understood that existing technological infrastructure creates both potential for, and barriers to, adoption of new technologies. Similarly, organisational factors such as structure and existing organisational capabilities can impact on the assimilation of new technologies. Leonard-Barton[101] suggests that the development of core rigidities that tie the organisation to a specific technology is a danger for all organisations. The extent to which an organisation is able to adopt a new technology is closely linked to its ability to absorb and use new knowledge.

Readiness and absorptive capacity

Whether a specific organisational context is 'ready' to accept a technology is likely to depend on many factors. Where information technologies are concerned, the technology acceptance model (TAM) developed by Davis[102-105], highlights the impact on a technology's acceptance of users' perception of usefulness and ease of use. However, the testing of TAM (for example, see[106]) has been based predominantly on an individual's acceptance or rejection of a specific technology. The model has not considered the acceptance of technologies by teams, other social groups or by those who are part of the wider organisational/process context. In considering readiness it is therefore necessary to recognise that a broad set of social factors will affect adoption.

Ability to absorb and apply knowledge is a prerequisite for an organisation that seeks to facilitate technological innovation. An organisation's ability to apply knowledge from outside has been termed absorptive capacity[107 108], or hybridisation[109 110]. In the healthcare sector, the term knowledge translation is used to refer to the transformation of research knowledge into practical healthcare applications[111]. Savory has suggested that an organisation's ability to absorb, re-create and subsequently diffuse knowledge associated with technological innovation can be viewed as a knowledge translation capability[112]. Kogut and Zander[36 113] highlight the inherent difficulty in transferring knowledge and emphasise that knowledge cannot be transferred unless it has been codified first. They also point out that it is easier for organisations to adopt proximate technologies than those that are completely foreign to an organisation. This preference for familiar technologies results in an organisation's capability development following a path that is very dependent upon the organisation's previous technological capabilities.

Several mechanisms exist for transferring knowledge. Boisot[114] highlights abstraction as an important process for supporting knowledge transfer. Abstraction is the process through which knowledge that was situated in a specific context is transformed so that it has a more general application. Abstracted knowledge has, therefore, been stripped of detail that is only relevant to a specific context. (Abstracting knowledge from its original context is said to reduce its stickiness[115-117].) Typical examples of abstracted knowledge include scientific laws, generalised heuristics and 'best practice'.

Linkages between individuals, teams, departments or divisions are central to the transfer of knowledge within and between organisations. These links can vary between strong, formal relationships and weak, highly informal ones. Intuitively, it might be expected that strong links will always be most effective for sharing knowledge but research has shown this not to be the case[118]. Strong linkages are most effective for transferring complex knowledge, though they are relatively costly to maintain. Weak linkages have been found to be more effective for transferring simple forms of

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knowledge and these can be maintained for lower cost with, for example, less need for frequent contact or reciprocal arrangements. Strong links can inhibit wide searches for information by restricting searches to established communication channels[119]. It has also been suggested that loose inter-personal ties are least likely to transfer redundant knowledge, that is knowledge already available within a group[120]. The implication of these strengths and weaknesses for maximising knowledge translation capability is to have strong ties where there is a clear need but also provide organisational support to promote weak ties.

Within healthcare, the challenge of absorbing new knowledge and the technologies to which it is related is significant. Central to this is the ability of health professionals to absorb new knowledge by, for example, interpreting the evidence from evaluations. Citing the very slow uptake of day-surgery for hernia operations, Maynard[121] argues that use of evidence to support changes in practice in healthcare has been poor for many decades. He puts the blame for this on failures in both the supply and demand side for clinical evidence. Where the supply side of is concerned, he suggests it:

> may be corrupted by poor quality science, imperfectly detected by weak peer review and by quasi-academic competitors such as consultancy firms, patient lobbies, 'experts' and think tanks who may be driven not by the simple pursuit of knowledge as in the academic nirvana, but also by varying forms of partisan self-interest. (p.254)

For the demand side failures he suggests clinicians, politicians, policy-makers and other stakeholders have limited capacity for evaluating new evidence:

> The demand side of the market for evidence is characterized by considerable potential interest, but a fragmented capacity to access and process information in a way that is consistent with the efficient formulation and appraisal of public policy. Political imperatives are to act swiftly rather than to think, articulate objectives, design evidence-based options, pilot them with evaluation and implement or not. (p.254)

This would suggest that the absorptive capacity of the NHS to adopt technologies is limited by lack of availability of the right quality and quantity of evidence and because of shortages of the skills, resources and political climate that is needed to evaluate evidence and draw the right conclusions.

Team learning has been shown to be important in the implementation of new technologies. Edmondson *et al.*[122] found that even amongst high performing surgical teams, differences in team learning affected the uptake of new technology. This suggests social learning processes that enable learning at team, group and other levels are an integral part of the

adoption of new technology, with success closely correlated to efficient learning processes.

The importance of individual and social learning to adoption was also highlighted by Funk *et al.*[123]. They investigated the barriers that prevented nursing staff from using research findings. The top four factors they found were:

- Values, skills and awareness of the adopter. How well equipped is the adopter to make sense of the innovation? How open to change are they and do they have the skills need to understand the innovation and evaluate it?

- Characteristics of the adopter's organisation. How supportive are other categories of staff? Does the adopter have sufficient organisational power to effect adoption?

- Characteristics of the innovation in terms of the quality of research underpinning it. Is there clear evidence of effectiveness and is the evidence credible to the adopter?

- Characteristics of the communication relating to the innovation. Is the information in a form and easily accessible to the adopter?

All of these resonate with wider adoption issues.

Building on the work of Funk *et al.*, Close *et al.*[124] also looked at hospital nurses' use of research findings. They concluded that ability to make changes to practice was affected by: the amount of time provided for research, research facilities; peer support; and the authority the nurses held in the organisation. Very importantly, they also found nurses lacked the skills required to make sense of the statistics supporting use of a research finding. This suggests that training staff so that they are able to analyse, understand, and interpret research findings is an important pre-requisite for adoption of evidence-based practices.

Ability to make use of research findings is not just a hurdle for nursing staff. It can apply, to varying degrees, to categories of healthcare staff This suggests that the integration of staff with research as part of their remit into teams providing and/or managing care may facilitate more effective technology adoption. An example that highlights this is the case of research radiographers and their role in assimilating new techniques and technologies into normal practice. A survey of the profession in 2007 showed that radiographers with an explicit research role had a key role in adoption of new techniques, especially where the application of computerised technology in radiotherapy is concerned[125]. The study concluded that the presence of a research radiographer within a department was vital for improving uptake of new techniques and technology. Importantly, it also found insufficient funding and training and lack of clearly defined allocation of research time, all tended to inhibit effective transfer of new research into individual clinics.

2.2.3 External Adoption Drivers

Not surprisingly, decisions to adopt technology are only influenced by factors internal to an organisation. The SDO reports reviewed earlier in this section highlighted the extent to which external drivers influence adoption of technologies. For example, government have an interest and an important part to play in funding, supporting, encouraging or mandating the adoption of healthcare technology.

Two drivers, in particular, deserve further consideration. The first is the extent to which external networks influence technology adoption. The second is whether the growing application of regulatory processes to healthcare systems leads to increased adoption of technologies that monitor and control healthcare processes. The latter may have a broader impact in encouraging adoption of technologies that support the implementation of protocols or other standardised procedures and in turn trigger adoption of technologies needing fewer skills and/or less exercise of professional judgement.

Networks

Networks can be an important structure through which the results of research can be communicated. They can support communication between organisations and enable specialist staff to maintain relationships based on disciplinary rather than organisational affiliations. Currie *et al.*[126] highlight the role of networks in public-services, including healthcare, as a means of gaining improvement in service-delivery. They identified four ideal types of network: managed networks; inter-organisational partnerships; professional networks; and communities of practice. All four of these have the potential to influence innovation and adoption of healthcare technologies.

Edwards highlights that managed networks within the healthcare sector are concerned with the formal integration of staff across organisations delivering a healthcare service:

> Development of managed networks represents a strategy improving healthcare delivery and involves 'linked groups of health professionals and organisations from primary, secondary and tertiary care working in a coordinated manner, unconstrained by existing professional and (organisational) boundaries to ensure equitable provision of high quality effective services'[127 p.63]

Development of managed networks in the UK NHS has been encouraged by government policy as a means of improving care and many networks are now well established. (For specific examples of such networks see Ferlie *et al.*[39].) The aim of these networks is primarily to provide a basis for sharing and dissemination of evidence. Their formal constitution can, however, also make them accountable for achieving performance improvements. One

such example is the NHS Cancer Plan[128]. Addicott *et al.*[129] note that the UK cancer networks' formal constitution and their role in co-ordinating clinical services mean that they are more politically accountable than more informally constituted networks and that there is a danger of managed networks becoming over-regulated at the expense of energy and creativity.

The role of professional networks are a significant feature of the medical profession. The 'invisible college' has long been recognised as a powerful force in scientific research communities. Crane[130] suggests two aspects of a social organisation are important: the interaction between the most active and influential members of the area and the 'rank and file'; and the role of 'outsiders'. In clinical research it is likely that groupings based around professional specialities will play a vital role in validating new knowledge and defining 'best practices'. As noted by Menchik and Meltzer[131] professional networks are important influence systems and provide a forum in which members can gain status and esteem for their work and where members can influence the behaviour of other network members. They also highlight the extent to which professional networks, underpinned by journals and conferences, are central to the peer validation of new medical knowledge and its diffusion across a professional speciality. As such, the role of professional networks can be seen as critical to the adoption and implementation of new knowledge and technologies. West *et al.*[132] stress that in developing dissemination strategies it is critical to consider the available social networks of health professionals. However, an alternative perspective is that professional networks primarily serve the interests and autonomy of their members. (See, for example, Sheaff[133] and Waring[134].) Nevertheless, in the context of innovation and improvement of healthcare there are signs that professional networks have successfully drawn in health professionals and allowed them to operate as '...shapers and quiet system architects'[41].

Communities of practice have been identified as specific types of network in which members of communities are able to share explicit and tacit knowledge[135]. A distinctive feature of communities of practice is that members share similar roles or carry out similar work. Wenger[136] has suggested three further distinctive features: reciprocity between members; shared sense of belonging; and a common repertoire of languages, routines, artefacts, instruments and styles. Within healthcare communities of practice are important social structures through which knowledge is created and shared. Their importance lies in being able to reach outside professional silos and cut across organisational boundaries. Unlike managed networks theirs is an informal position and this gives them a distinctive role in supporting innovation and technology adoption.

Regulation and clinical governance as a driver of change

One important example of how a tension for change in the NHS has generated innovation is the development of clinical governance systems.

Since the 1990s, the development of clinical governance systems has been a major component of the NHS's quality improvement strategy[137]. The clinical governance agenda forms an integral part of the strategy for setting standards, improving quality and monitoring services[138]. A direct result of several high profile clinical failures, such as those at Bristol and Liverpool hospitals[139] [140], has been that the emphasis of clinical governance has broadened and self-regulation and clinical autonomy have been restricted.

The nature of clinical governance has changed over the last decade. Initially high-level performance indicators underpinned clinical governance initiatives[141]. Subsequent additions to clinical governance initiatives have refocused away from national targets towards improvement approaches based on defined processes such as those found in National Service Frameworks (NSFs)[142]. Wider initiatives have seen the creation of institutions to evaluate new healthcare technologies through rigorous health technology assessments, most notably the creation of the National Institute for Clinical Excellence (NICE).

An integral part of clinical governance is the adoption of evidence-based approaches to treatment of patients but also the configuration of services. Harrison suggests that the development of clinical governance is an example of wider modernisation initiatives within the NHS[40]. More specifically, he suggests that the implementation of clinical governance represents a shift towards a scientific bureaucratic approach to medicine. Such an approach emphasises the implementation of externally derived medical knowledge within standardised rule-based protocols, even though this may cut across traditional assumptions about use of professional judgement. The extent to which this shift has actually affected behaviour has been contested by Greenhalgh *et al.* who suggest that this overly rational approach treats the spread of innovative practice simplistically and often ignores contextual issues[19]. Furthermore, the extent to which guidelines have been implemented successfully has been questioned. It has been suggested that context and underlying social relations have had a significant effect on take-up, one example being implementation of National Service frameworks in GP surgeries[143].

The shift towards bureaucratic scientific medicine however is potentially very disruptive to healthcare processes and structures. First of all, it opens the effectiveness of the processes up to scrutiny. By placing measures on process outcomes it has been possible to compare the performance across institutions. This benchmarking has shown not just where best-practices exist but where poor practices continue. Critically, where poor performance does exist its increased visibility means that the pressure to align processes with care guidelines or evidence-based procedures is significant.

Secondly, the prescription of an optimum process means that the capabilities required of staff delivering healthcare processes has to change. Instead of demonstrating specialist knowledge and relying on clinical judgement, health professionals may be expected to follow precisely

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prescribed processes. This has important implications for who undertakes a procedure and where it takes place. For example, procedures normally carried out by specialist staff in secondary care settings may be transferred to community-based staff with less training. Christenson[144][145] has highlighted that it is this shift in the user of a technology that is significant in defining a healthcare technology as disruptive. Thus the shift towards scientific bureaucratic medicine creates opportunities for technological innovation. One of these is the development of information systems that can be used to manage scientific bureaucratic medicine and wider clinical governance initiatives. Another opportunity is the development of sophisticated systems for gathering data and allowing analysis and information retrieval to support the application and monitoring of care guidelines. The development of such systems goes beyond administration. Increasingly, the development of new technologies has the effect of 'informating'[146] healthcare processes by allowing aggregation of detailed data across large numbers of patients. This technological innovation then also becomes a part of the system of scientific bureaucratic medicine by collecting and analysing data, so contributing to bodies of evidence. For example, collection of data has shown that adherence to resuscitation guidelines varies considerably. In one study it was found that only 40 per cent of patients received treatment in accordance with specific guidelines[147].

2.2.4 Adoption Process

Evaluation and evidence to support adoption decisions

A key part of the decision-making process that underpins technology adoption is the availability of supporting evidence for a technology's effectiveness. Within a healthcare setting the evaluation of a technology can take a number of forms and include technical, economic and social assessments. Adoption decisions involve a number of stakeholders and so it is important that the evidence used to support adoption is not just sufficient but also relevant and addresses the concerns of all parties. The health technology assessment (HTA) process is the established mechanism for assessing an innovative technology's effectiveness. The primary function of this is to assess: 'whether a specific technology works, for whom, at what cost and in comparison to which alternative technologies.'[148] Within a translational research pathway HTA is a key component of the final assessment of whether there is a valid business case for using the technology in clinical practice. This assessment has been termed as the fourth hurdle in translational research and is closely coupled to remuneration decision-making within healthcare systems This hurdle is different from those encountered in earlier stages in translational research pathway because they are concerned with technical assessments of efficacy, safety, and the like whereas the focus of the fourth hurdle is health economics. It thus marks a move away from scientific assessment to

consideration of the complete value chain for a technology[149]. The economic evaluation assesses the technology's potential for cost minimisation, cost benefit, cost effectiveness and cost utility[3 p.107]. However, wider aspects of a technology may also be considered within an HTA, such as ethics, legal, organisational and social. For this reason HTA constitutes a complex assessment requiring data from a broad range of sources and sophisticated assessment methodologies. It is rooted in the assessment of pharmaceutical technologies but is now being used, with little or no modification, to assess a much broader range of technologies.

This raises the question whether assessment methodologies should be applied without careful reference to the type of technology being assessed. For example, where the case of diagnostic technologies is concerned, in 2011 the UK's Centre for Health Technology Evaluation said the following:

> The evaluation of diagnostics differs from the evaluation of treatments in several ways. The most important difference is that diagnostic tests have few direct outcomes, that is, outcomes affecting the patient that come directly from the test itself. Most outcomes of interest follow from treatments that are either initiated or not initiated based on the results of the tests. The second important difference is that tests are frequently done in conjunction with other tests or measurements, and, where this is the case, it is the composite of the series of tests that is used in clinical decision-making.

> These two important differences make the evaluation of diagnostics complex. Only very rarely do studies of diagnostic tests follow patients through treatment to final outcomes. Also, evaluation of diagnostics usually requires that the clinical management process is described and that the effects of that process are known or assumed. If the effects of treatment are not known, analyses can be performed, but the validity of the results will be less certain in ways that may not be completely specifiable. This increases the uncertainty with which decisions can be made on use of diagnostic technologies.[150 pp19]p.19

Many countries now have institutions that formally operate the HTA systems such as NICE in the UK and CADTH in Canada. (For a comprehensive review see Hutton *et al.*[151].) However as the range of technologies they assess increases, the challenge might be to provide a suitable range of HTA methodologies that are appropriate to all the groups that are available. Furthermore, there is also the question of lack of consistency and coherence between arrangements in different countries[152].

Within healthcare, the dominance of a scientific paradigm means that for pharmaceuticals and other healthcare technologies, experimental approaches to validation are seen as fundamental. The gold-standard for assessing healthcare technologies is therefore the randomised clinical trial. It can be argued that such trials represent a relatively narrow approach to assessment that underemphasises the context in which a technology is

used. It has therefore been suggested that other methodologies that extend the scope of healthcare technology assessment are needed[3 p.134]. For example, surgical procedures have been identified as particularly problematic where evaluation using randomised clinical trials is concerned[153]. One alternative that has been suggested is the use of registries to monitor outcomes of procedures[154].

HTA processes increasingly rely on systematic reviews to assess whether a technology is effective. As a result, the style and structure of academic papers describing trials of healthcare technologies has become critical. Although such reviews are applicable to pharmaceuticals, other healthcare technologies may present challenges. For example, diagnostic technologies can differ on several performance measures including: type of technology employed; fixed and variable costs; risk and acceptability to the patient, and balance between accuracy, speed and convenience of use. Reid *et al.* highlighted the limitations of many trials of diagnostic tests and suggested the need for adherence to methodological standards[155]. At the root of their concern was the diverse range of approaches to assessment being employed and the consequences of this when comparing different studies.

Recent research has attempted to apply a wider approach to evaluation in healthcare by applying realistic evaluation. This approach was initially developed by Pawson and Tilley[156] to assess programmes, such as public health initiatives. At the heart of this approach is a concern to identify not just what outcomes are achieved but also the specific factors that show utility in a specific context. Two examples of the use of realistic evaluation in healthcare include: the assessment of large-scale service changes[157]; and clinical guidelines[158]. Its potential use specifically within health technology assessment is, however, only yet at an embryonic stage.

Implementation

Almost the final stage of adoption is implementation. After that, all that remains it to monitor the effects of adoption and seek further opportunities for innovation and improvement. Karsh[159] suggests that implementation science should be applied to healthcare technologies emphasises the need for implementation processes to include:

- top management commitment
- clear lines of responsibility/accountability
- structured implementation project
- training
- pilot testing
- clear communications
- user-participation

Closely related to the implementation of new technologies is the literature on implementation of evidence-based practice. For example, Ryecroft-Malone *et al.*[160] have proposed the PARIHS framework to identify the key factors in implementing evidence-based practice. This framework does not explicitly address implementation of technology but it is relevant because technology often codifies evidence-based practice in which case implementation of the technology and evidence-based practice occurs simultaneously.

More recent work on the PARIHS framework has attempted to make it more sutable to guide task-oriented implementations, such as a new procedures or care processes[161]. All of these approaches share a concern to ensure that evidence, contextual readiness and facilitation issues are addressed during implementation and that a means of assessing implementation success is put in place. A recent review[162] has concluded that the PARIHS framework provides a useful heuristic for planning implementation in a healthcare setting, though it also stresses that in the examples of implementations where PARIHS had been applied it had been applied mainly retrospectively and not at the planning stage. Importantly though, the framework highlights a range of factors relating to types of evidence supporting adoption and contextual factors that might help or hinder implementation.

The approach taken to implementation needs to vary according to the type and scale of the technology being adopted and the level and type of consequential changes it brings about. For example, some technologies can be just purchased and put into service whilst others require strategies such as pilots and phased roll outs. It is worth noting, however, that the overlap between development of an innovation and its implementation into practice can be very blurred when the development takes place at the implementation site. Metcalfe and Pickston[163] describe the development of innovations in hip replacement and intraocular lenses. Common to both is the extent to which implementation is linked to the trialling and experimentation. Like other sectors such as computer software, (see for example Crinnion[43]), it is common to develop and use prototypes with the intention that they will be improved incrementally over time. In cases such as these, less structured approaches to implementation are often the norm. Implementation can take the form of evolutionary prototyping or trialling.

For more complex technologies and for those that require or lead to wider changes such as changes in practice of healthcare staff and changes to a process involving several stakeholders or cutting across departments, or even organisations, or need to be rolled-out across many locations, implementation needs to be treated as a formal process. It needs to draw on project management skills and expertise and make use of the project management methods and techniques.

The end point for successful implementation will normally be the point at which the technology has become integrated into everyday practice. Mair *et al.*[42] have described this in the context of e-health technology as

'normalisation' and said that it can be regarded as the endpoint of implementation when '…health technologies becoming routinely operationalized in everyday work (embedding), and sustained in practice (integration)'p.14. Based on the normalisation process model that May *et al.* proposed[45], four factors have been identified as contributing to normalisation: interactional workability; relational integration; skill-set workability; and contextual integration. Though the development of the model focused on e-health technologies, the key issues raised in relation to the NPM and e-health integration are relevant to other forms of technology adoption, not least because of the pervasive nature of information technology as a component of healthcare technologies.

2.3 Questions guiding research on adoption of NHS-developed technologies

The preceding discussion provides a lens for looking at the adoption of technologies into healthcare systems within the NHS. In comparing the adoption of technologies that were developed within the NHS with those with origins outside the NHS, four guiding questions are important:

1. To what extent has the development process that produced a technological innovation determined specific aspects of the technology that have an impact on its adoption?

2. For a specific adoption context, what are the main factors that mediate the success of adoption and to what extent is this success related to the technology's origin?

3. How do external adoption drivers in combination with an innovation's origin impact on the potential for adoption?

4. Does the adoption process differ for NHS-developed technologies when compared with those that are commercially-developed?

Innovation Characteristics: To what extent has the development process that produced an innovation determined specific aspects of the technology that impact on its adoption?

Adoption Context: For a specific adoption context what are the main factors that mediate the success of adoption and to what extent is this success related to the technology's origin?

Adoption Process: Does the adoption process differ between NHS-developed and commercially-developed innovations?

NHS adoption of technologies

External Adoption Drivers: How do external adoption drivers in combination with its origin impact on the potential for adoption?
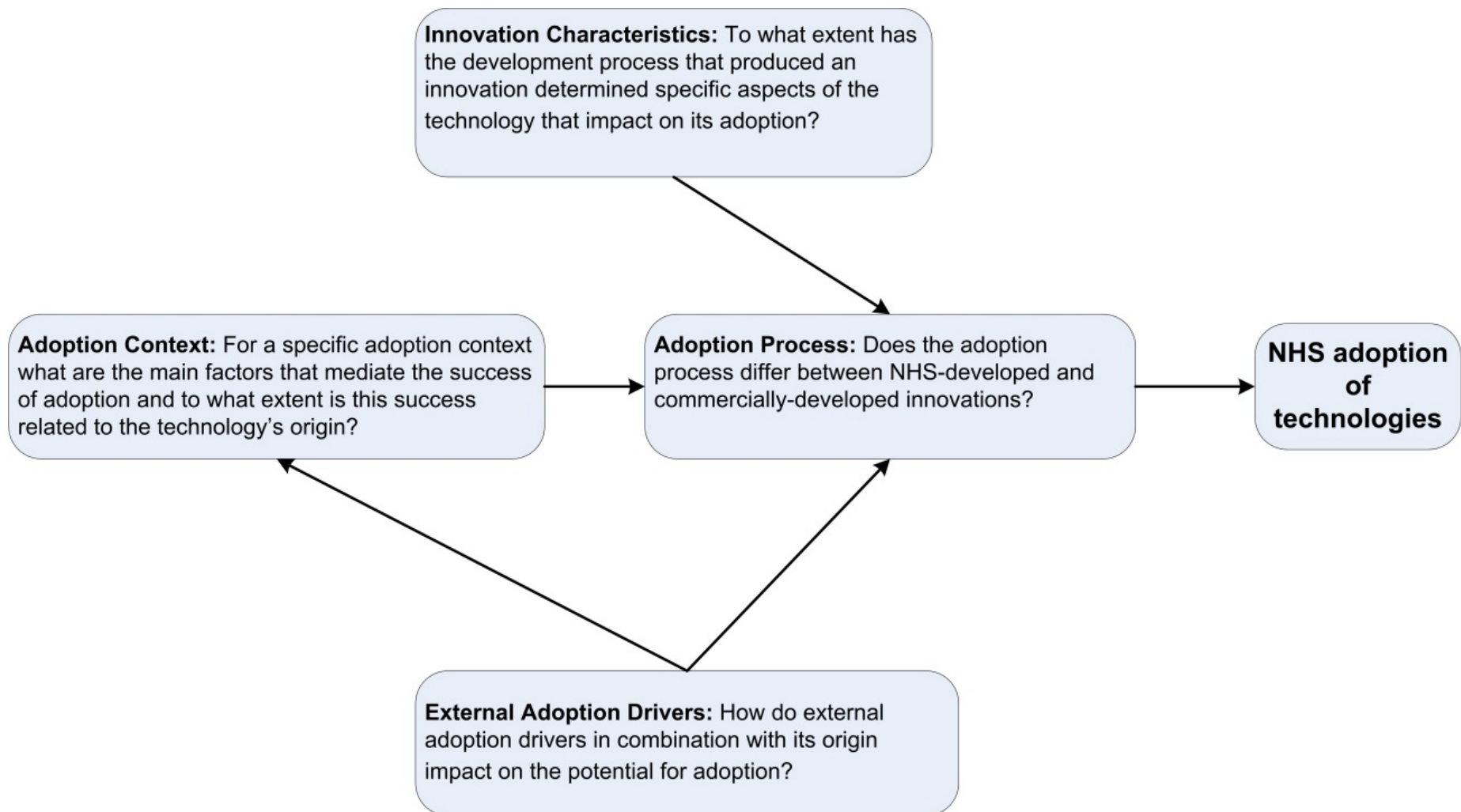
Figure 5. Guiding questions for this research

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3 Methodology

3.1 Methodological Approach

This study set out to explore issues that affected the adoption of technologies into the NHS and how the origin of the technology impacted on the adoption process. The literature review section concluded by setting out a preliminary framework for the study. The framework identifies key issues to which the subsequent fieldwork needed to be sensitive. Yet, it was important that any further issues would also be revealed, recorded and included in the analysis. For this reason the research was designed to be predominantly exploratory and the methodological approach has reflected this requirement.

The general approach taken in designing the methodology was to develop rich descriptions of technologies, their characteristics and adoption in specific context. The research design therefore focused on building detailed narratives of technologies that provided deep insight into a few specific examples, rather than attempting to build statistically significant samples that might allow generalised statements about all NHS-developed technologies, their development and subsequent adoption. The emphasis was therefore on building theory, rather than testing theory.

Case study research is important when the phenomenon cannot be studied out of context for, example through experimental methods[164 p.13]. The research needs to focus on a specific instance of a phenomenon and the various interactive processes that affect it, or for 'sticky, practice-based problems where the experiences of the actors are important and the context of action is critical'[165 p.80]. The case study approach allows the researcher to adopt a holistic view of the context and to '...retain the holistic and meaningful characteristics of real-life events'[164 p.2]. In addition to where the phenomenon is closely coupled to its context, it has been suggested that case research is beneficial where the research and associated theory is exploratory and in its early, formative stages[166]. Eisenhardt makes it clear that case studies are important where research in the area is still exploratory and needs to focus on '...understanding the dynamics present within single settings'[167]. There is now a tradition in using case study methodologies in exploratory research in the fields of information systems and innovation studies, see for example Walsham[168], Suchman[18], Bessant[169], Howells[109], Jones[170], and Leonard[171].

Walsham has emphasised that detailed case study research creates the opportunity to gain a deep understanding of a phenomenon, through the development of thick description that supports understanding of the '...subtleties of changing interpretation'[172 p.103]. This complements Strauss and Corbin's view that taking an approach that is open to the idiosyncrasies

of a particular case, results in an increased scope for emergent issues to arise, grounded in the data collected[173]. In contrast the use of research methods, such as surveys, would yield much less detail of the process to be understood.

A potential strategy for developing a rich understanding of a phenomenon, such as an innovation process, is to adopt a process theory based approach. This emphasises patterns in events, in contrast to variance theory in which explanations are based on causal relationships between independent and dependent variables[174]. Based on this, narrative strategies of qualitative process research[175] can be used to construct from data a story that emphasises the chronology of events, as well as the concepts, understanding and ultimately theory linked to the data collected[176 177]. Such a strategy is potentially problematic due to the fluid characteristics of process phenomena[178], and the difficulty in isolating units of analysis in an unambiguous way[175]. Thus in researching an innovation or adoption process, it is necessary to recognise the relevance of both variables and events. For example, within an innovation process there will be a number of events triggered by actors that are seen as significant, however, contextual variables such as the prevailing norms and values will also impact on the process. Such a strategy does risk what Pettigrew described as 'death by data asphyxiation'[179] due to the large data sets required. This in turn leads to the problem of distinguishing between relevant and irrelevant data, though many techniques have been devised for organising and making sense of such data (see for examples Miles and Huberman[180]). It is also made more complex due to the possible non-linearity of an innovation process[181].

An important part of the development of a rich description is the iteration between theorising and observation. This has been described as an interplay between researcher and data:

> Analysis begins with the first interview and observation, which leads to the next interview or observation, followed by more analysis, more interviews or fieldwork, and so on. It is the analysis that drives the data collection. Therefore, there is an interplay between the researcher and the research act. Because this interplay requires an immersion in the data, by the end of the inquiry, the researcher is shaped by the data, just as the data is shaped by the researcher.[173 p.42]

An important benefit of adopting a multi-case research design is that the development of multiple viewpoints on specific phenomenon are developed. For a research design where all cases share similar context, for example the NHS, the cases provide specific perspectives on common areas of interest. In this way, perspectives on major institutions will yield a range of insights into their inter-relationship. This could be viewed as a form of data triangulation[182] in which multiple sources of data are used to develop a converging line of enquiry[164 p.99]. The use of several data sources within

each case (various informants, documents etc.) allow details of a specific case to be triangulated. This is an important strategy as in developing an understanding of when and why decisions were made, it is useful to be able to compare accounts in both interviews and documentary evidence.

It should be noted however that where a participant's account does not triangulate with another source e.g. an account given in a publication, it does not immediately mean that either account is false. The differences in the accounts of events provided to researchers may be incomplete due to: time constraints in data collection; complexity of events; limits of the research participants' memories; differences between written and oral communication conventions; or participants' reticence to supply a full account. It is also plausible that the perspective of participants changes over time. While triangulation is a useful tool, it is important to recognise its limitations, especially where assessment of a truth is based on repeatability of an observation across several sources.

This suggests that research can adopt an interpretive position on the nature of fact. Stake highlights that while much qualitative research is concerned with using multiple perceptions to clarify meaning and to verify the repeatability of an observation, another important function if to clarify meaning by identifying different ways the phenomenon is being seen[183 p.443]. This is a position advocated in information systems research where Walsham notes that:

> ...I take an interpretive study to mean that multiple perspectives are provided by participants, and thus that the interesting data study cannot be 'triangulated' to provide a 'true' interpretation, since whose truth should be chosen? The interpretive researcher filters participants' statements and actions through a lens of his or her own subjectivity, and then produces a 'story' about the events that have occurred and some reasons for them. The purpose of the story, again, is not to tell 'the truth' about the case study but to tell a 'truth', namely the researcher's own thoughts and ideas concerning the phenomena at issue.[168 p.7]

This shows that the concept of triangulation has been dismissed in interpretive research, as an interpretive approach is based on different assumptions to positivist approaches, making triangulation simply not possible[184 p.67]. The role of multiple cases should therefore be seen as allowing a range of perspectives to be developed, on a range of phenomena, rather than simply as a basis for triangulation data.

An important issue in case study research is the extent to which the findings of a case can be generalised. Case study research does not follow a sampling logic, as in statistical generalisation, where the research seeks to generalise from a sample to the wider population. Instead, case research is concerned with analytic generalisation as distinct from statistical generalisation[164 p.32]. Analytic generalisation represents the process of

generalising from empirical descriptions to theory and has received the attention of several social science and information systems researchers[164] [167 172 173 185-188]. Walsham highlights the potential of four categories of generalisation that may be gained from case studies: development of concepts; generation of theory; drawing of specific implications; and contribution of rich insight[172 p.110].

The area of NHS-developed innovation in the NHS is characterised as novel and an expanding area of research. For this reason, it was important that during the course of the research, the methodology adopted must be adequately flexible and capable of evolution. This study has not set out to prove a specific *a priori* theory or hypothesis established from the start. Instead, the research was concerned with exploring specific research questions and then through analytical generalisation[164 p.32 189 p.120], develop theory that would aid the explanation. This mirrored the concerns of Easterby-Smith *et al.*[190 p.47] when suggesting the use of an inductive or grounded approach; an approach benefiting from flexibility and a potential to provide both explanations and new knowledge.

The research design adopted for this research followed a multiple case study method. This drew on Yin's case study method[164 p.50]. The design was based on three phases concerned with: research definition and design; preparation, data collection and analysis; and finally cross-case analysis and conclusion. In common with Yin's model the research design incorporated feed-forward and feed-back loops that allows the experience gained from each case study to be fed into other parts of the research. The overall design of the research is shown in Figure 6.
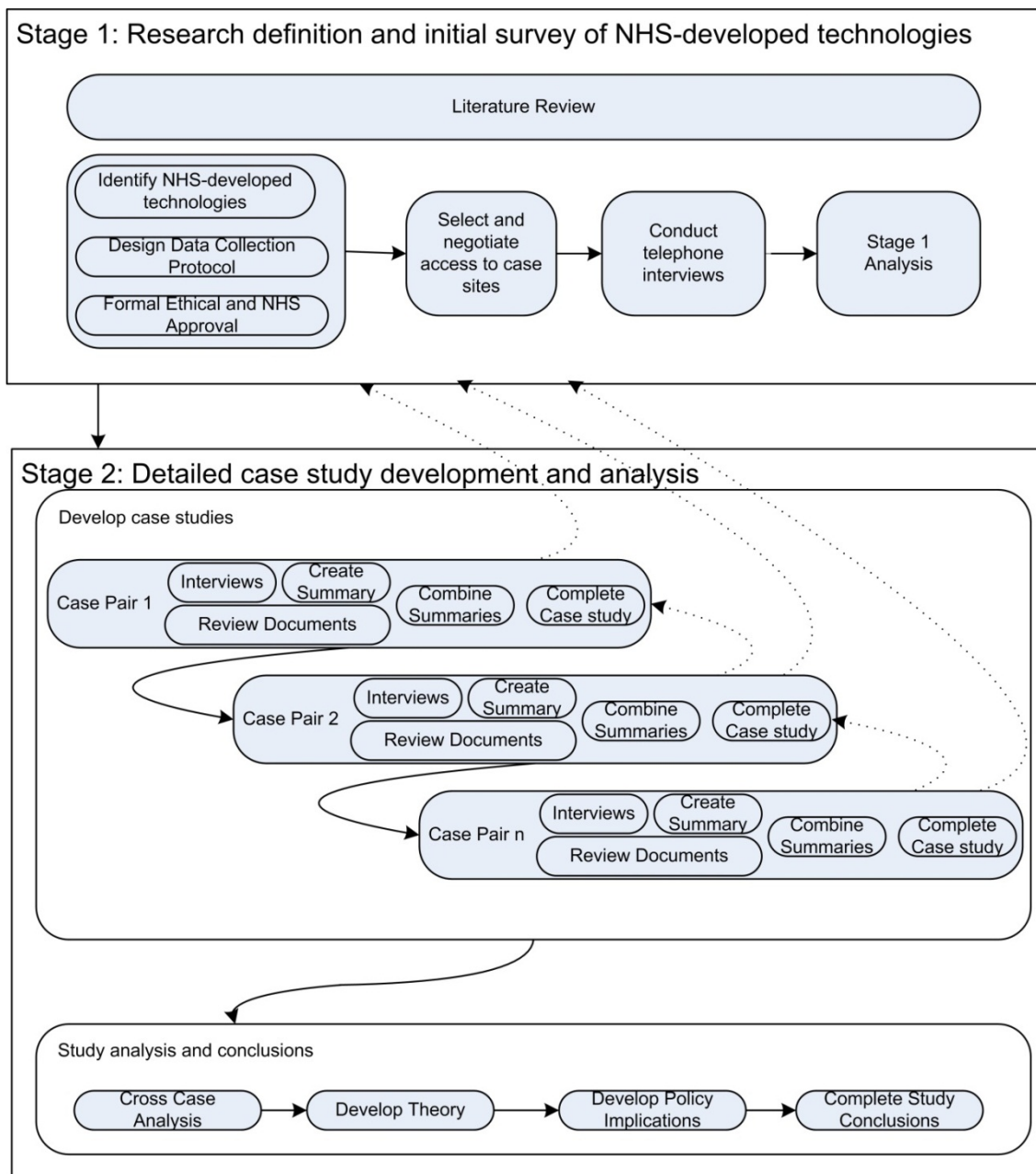
Figure 6. Overall design of the research

An integral part of both Stage 1 and Stage 2 was the gaining of ethical approval and R&D permission for access at individual NHS trusts.

3.1.1 Stage 1

The purpose of Stage 1 of the research was to ascertain the characteristics of a wide a range of NHS-developed technologies so that six theoretically important technologies could be selected for further study in Stage 2 of the research. It was decided that this would be achieved by conducting a series of telephone interviews with the developers of the technologies, their

industrial partners (if any) and adopters and by studying any published information about the technologies that was available.

The first step was to undertake four parallel streams of activity: conduct a literature review to inform the research; identify technologies for inclusion in Stage 1; apply for ethical approval and the permissions needed to undertake the work; and build a database to hold the data gathered. The results of the literature review appear in Section 2 of this report.

The first ports of call to find out about technologies that had been developed within the NHS were NHS innovation hubs, the NHS National Technology Adoption Centre (NTAC) and the NHS National Innovation Centre (NIC). Because the sample had to satisfy particular needs, the snowball sampling technique[191 192], as recommended by Robson[193] was used. This, augmented by use of internet search engines, delivered a list of technologies for further investigation. Further additions were made to this list as Stage 1 proceeded in order to build as large and varied a sample as possible. Application for ethical approval for the research was made via the Integrated Research Application System (IRAS). A protocol was developed and participant information sheets and consent forms were drawn up. (see Appendix 1)

Figure 7. Research protocol

A database to hold the Stage **1** data was built and housed on a secure server. It allowed the following to be stored for each of the technologies that were considered for inclusion:

- information such as job role and contact details of the people involved with the technology

- the NHS trust(s) associated with the development or adoption of the technology

- any industrial partner(s) involved in manufacturing and/or marketing the technology

- anonymised data gathered during Stage 1 of the research

A set of selection criteria for including a technology in Stage 1 was drawn up to ensure that only technologies that could be classed as 'NHS-developed' and 'currently at the stage of being marketed to the NHS' were included in the sample. The criteria used were as follows:

1. Meets the definition of 'healthcare technology' as set out in the introduction of this report.

2. Being marketed to the NHS at the time the survey was undertaken.

3. A member of staff of the NHS in England developed the technology or played a very large part in its development.

4. The function of the technology was linked to the job role of the NHS developer.

5. Sufficient respondents willing to take part in telephone interviews so that their responses, when taken together with information from other sources, would allow the characteristics of the technology to be ascertained.

Consideration was given to adding a criterion related to the ownership of intellectual property associated with the technology to this list. The proposed form for this criterion was 'Where intellectual property (IP) had been protected it should be owned, wholly or in part, by the NHS'. In the end it was decided not to apply this criterion rigorously because a number of technologies were identified, especially those developed prior to 2000, that were very much NHS-developed even though the NHS has no rights to the IP.

Some technologies were ruled out very soon after their initial identification but for others it was not until much later in Stage 1 when one or more interviews had been conducted that it became clear that they did not meet all the inclusion criteria.

The next step of Stage 1 was to build schedules for telephone interviews. Telephone interviews were chosen because they are a very cost effective way of collecting data from a geographically dispersed sample and because

it was felt they would mean less disruption to the very busy health professionals who would be taking part as developers or adopters. Semi-structured interview schedules incorporating closed and open questioning were drawn up to maximise uniformity across researchers and to ensure comparable data was collected across the range of technologies whilst allowing sufficient flexibility to capture as much insight as possible across the widely differing technologies. Interviews were recorded using a digital recorder if interviewees had given permission. Recordings were stored on a secure server and identified only by the unique number known only to the researchers. Responses were then transferred onto a written record for each interview. Once again the numbering system was used to identify these. Where appropriate, responses were coded and free text used for the remaining responses.

Although there was substantial overlap between the questions put to all respondents there were questions that were aimed specifically at developers, adopters and partners so three versions of the semi-structured interview schedule were drawn up. Between them they explored the following topics:

1. Background to the development of the technology

2. The development 'story'

3. The purpose of the technology and the way it is used

4. Costs and benefits

5. Any evaluations that have taken place

6. Commercialisation, including the role of collaborative partners

7. Protection and ownership of intellectual property

8. Adoption decision making

9. The adoption and implementation process and the support available

10. Potential and actual adoption sites and the extent of adoption within them

11. Results of adoption and any consequential changes associated with it

12. Reflection on the development and/or adoption process

Framework for analysis of Stage 1

A condition of the permissions that allowed this research to take place is that neither the technologies investigated nor the individuals who participated will be identified by name. The first step in the analysis was therefore to classify each technology and allocate it a code that could be used to identify it. For Stage 1 the unit of the analysis was the individual technology, so data from developers, adopters, partners and written sources was brought together for each technology. It was then used in two

ways: to populate a spreadsheet; and to write 'stories'. Essentially, the spreadsheet provides a data set that makes it easy to look across all 36 technologies or across technologies in the same class. It provides a snapshot of the characteristics of the technologies with some indication of the level of adoption each had achieved at the time the survey was undertaken.

The second form of analysis consisted of interpreting the data relating to each technology so that it, in effect, told the story of the technology and drew out its important characteristics. Each story provides a concise narrative of each technology's significant characteristics and its development within the NHS. As in much qualitative research, the emphasis here was on interpretation[194]. It should be noted that particular regard was paid to 'contextuality'[195 p.16]. This was because the purpose of Stage 1 was to select technologies that would become the cases for Stage 2 of the research and, as Yin[164 p.13] says, a case study is 'an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident'.

The whole set of technologies were then viewed alongside each other so that important themes and sets of characteristics could be identified that would allow judgements could be made about which technologies to investigate further in Stage 2. This activity was informed by the literature review and provided five dimensions against which each technology could be mapped. The results of this mapping exercise allowed theoretical sampling to take place[167 196 p.519] where each of the six technologies to be taken forward to Stage 2 represented either a theoretical category or a polar type.

3.1.2 Stage 2

The purpose of Stage 2 of the research was to compare the adoption of NHS-developed technologies with the adoption of equivalent commercially-developed technologies. The first task, therefore, was to identify a competing or equivalent technology for each of the six technologies selected at the end of Stage 1. When this had been done, primary and secondary research started in order to gather data that would allow six pairs of comparative case studies to be developed which in turn would allow similarities and differences between and across pairs could be identified. A variety of methods were used to gather this data. These included visits to adoption sites to interview adopters, telephone interviews with adopters and other stakeholders and study of secondary sources such as refereed journal articles, government-backed reports and other items of grey literature such as newspaper and magazine articles and sales catalogues and brochures. In recognition of the substantial differences in nature, scale and scope between the six cases, unstructured and semi-structured interviews were used so as to allow questions appropriate to the individual

pair of cases to be asked whilst at the same time covering some specific topics such as adoption decision making, implementation processes and reactions to the adoption across all cases. Notes were taken during each interview and a summary sent to the interviewee who was asked to confirm in writing that the summary was accurate and authorise inclusion of the data within any publications associated with the research.

The methods used to draw lessons from the cases varied a little across cases depending upon the nature of the pair of technologies being studied and the extent to which adoption had taken place. In all cases, however, the emphasis was on:

- Answering the question: Is the adoptability of the NHS-developed technology greater, less or no different from than that of the competing or equivalent commercially-developed technology?

- Shedding light on the much wider topic of healthcare technology adoption within the NHS.

Although the emphasis of the research was on technology adoption into the NHS, understanding the broader context NHS policy was also critical. For this reason, two higher levels of data collection took place. All three levels are shown in Figure 8. Level 1 is concerned with NHS policy and is, of course, tightly coupled to government policy more generally. Data sources included NHS and government documents such as policy papers but also care guidelines and recommendations from various agencies. Level 2 is related to the management of technology adoption within the NHS and includes the innovation and adoption management services that are made available to managers and clinicians. These services may be provided from within the NHS (for example, the NHS-based innovation hubs) or by commercial companies offering management services. Level 3, where the primary research was undertaken, is concerned with the specific adoption projects carried out within the NHS.
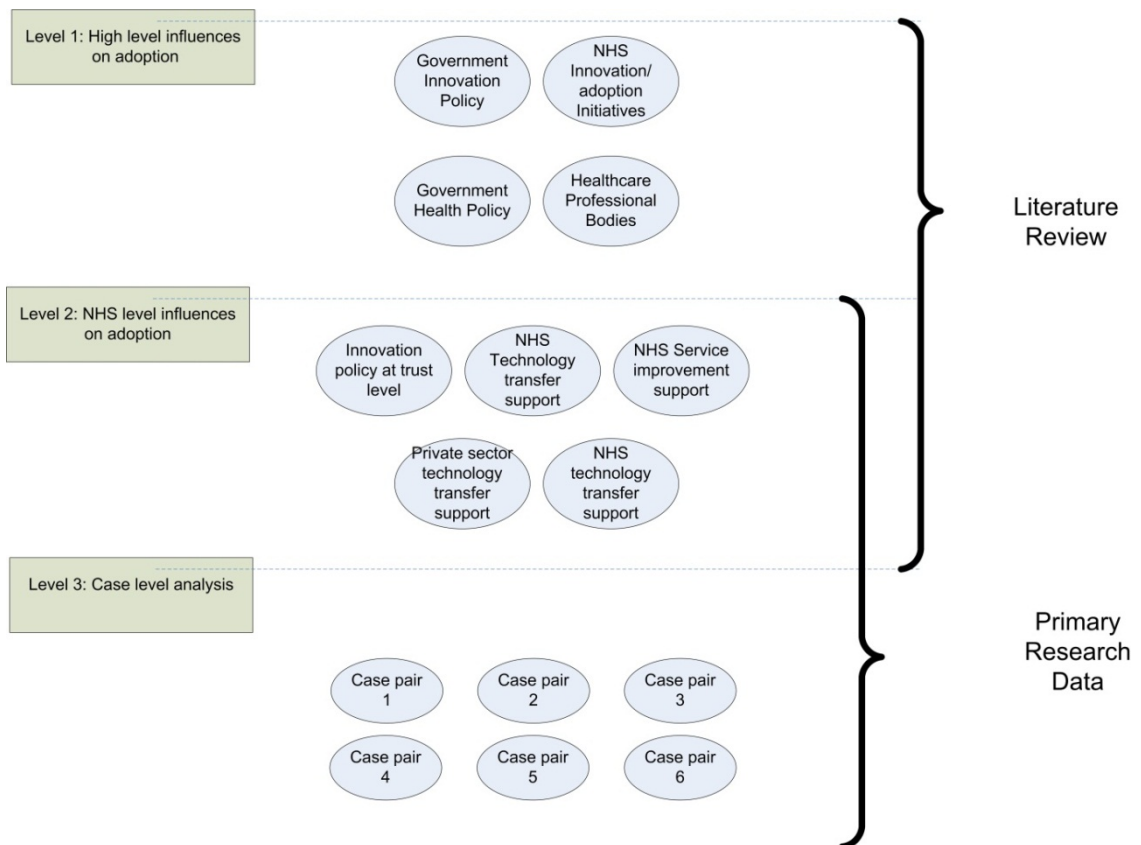
Figure 8. The three levels of Stage 2 data collection

The research was therefore based on a multiple case study design, with the individual cases contributing an understanding of processes in the NHS. For each case, the unit of analysis is the adoption of technology into the NHS, however for the overall study the unit of analysis is adoption processes more generally across the NHS.

Framework for analysis of Stage 2

Data from the case study interviews was analysed using a framework that comprised three stages. The purpose of the stages was to analyse data systematically, starting with individual interviews, then through the development of themes and issues, backed up where necessary with verbatim quotations, before aggregating all the information gathered for an individual case. This framework is shown in Figure 9.
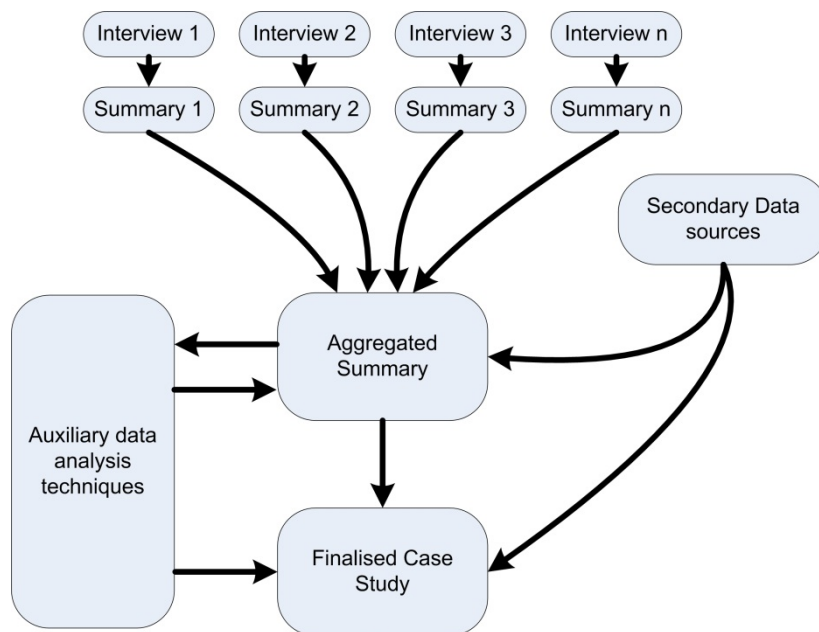
Figure 9. The Stage 2 framework

The first stage was to convert data held in interview notes or recordings into an initial summary. The interview summary provided a written account of the content of the interview that presented only the views and perspectives of the participant to which it related. No additional analysis was included although the order of the content of the summary was not necessarily the same order in which it emerged during the interview. This re-ordering was carried out to group together data related to themes and issues raised in the interview or of particular interest to the researcher. Any queries or additional questions raised in reviewing the interview were also added to the summary. The summary was not therefore a transcript of the interview; it represented the data that was perceived as being useful to the research. Once the summary had been produced, it was sent to the interviewee to give him or her the opportunity to add, amend or remove material from the summary before authorizing its inclusion in the analysis.

The second stage of the analysis process involved aggregating all the interview summaries into a single case. This allowed data relating to common themes to be combined, while maintaining any multiple perspectives identified within the case. Some quotations from participant interviews were retained to provide a link with base data and introduce the voice of the research participant into the final case study[197]. The report also incorporated material from secondary data sources, such as published articles about aspects of the case. An important part of the aggregation of the summaries was the use of various analysis techniques that allowed the ordering of concepts and viewpoints emerging from the analysis.

The final stage of the analysis was to develop a completed case study of the adoption. The final case study thus provided a comprehensive account of the adoption process. An intended consequence of the research design

was that the six pairs of cases were not similar in terms of length and complexity so it was not appropriate to force them into the same presentation format. Instead, each case was structured in such a way as to allow its contribution to the research to be maximised. Nevertheless, there are certain topics that are common to all of the case reports. These include:

- background and context

- overview of the technology

- key emergent themes and issues raised by the adoption

As each study was completed it was fed into the cross-case analysis.

The cross case analysis used a similar analytical framework to the analysis of the individual cases. Figure 10 summarises the way three streams of analysis contributed to the research.
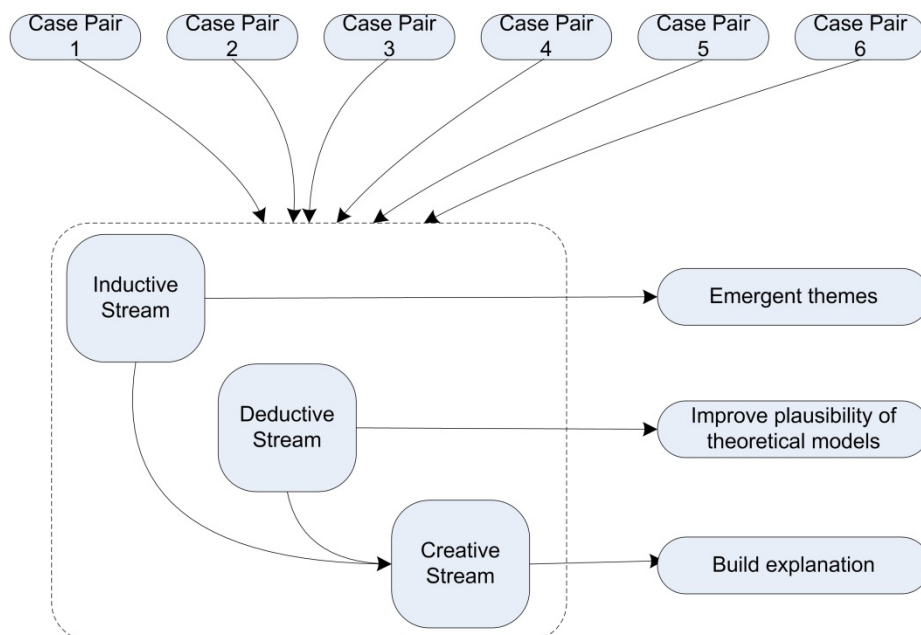
Figure 10. **The cross case analysis**

4 Stage 1 Results and findings

4.1 The technologies surveyed

The search for technologies that met the five criteria set out in Section 3 revealed the first point of note emerging from this research. During this search a substantial number, though meeting most of the criteria defining NHS-developed, had to be excluded from the study on the grounds that they were yet being marketed back into the NHS.

Some technologies that had been developed within the NHS and featured on various websites linked to the NHS, often in connection with the award of some form of innovation prize, had not been brought to market even though the website gave the impression that they were, or had been about to become, available some time ago. Initial investigations of other technologies found that they appeared to have no adopters beyond the developing site. For example, where one monitoring technology was concerned, IP had been protected and a license agreement made with a commercial partner in 2006 and it had won an Innovation Award in 2008, but when the commercial partner was asked in August 2010 to identify adopters he was only able to express hope that the technology would be available by 2011. An assistive technology that was a finalist in the same innovation competition in 2008 was also not on the market two years later. When contacted in September 2010 the developer explained that attempts were still being made to attract the funding needed 'to conduct testing to prove that it works'. Yet another assistive technology was awarded an NHS innovation prize in 2005 but by 2012 was still being flagged as 'available to license' by its local innovation hub.

Obviously, the long period of time between invention and development into a marketable product, is a normal part of healthcare technology development and it is likely that many technologies excluded from Stage 1 will eventually come to market. Stage 1 therefore only provides a 'snapshot' view of the development of a number of technologies. However, several other important factors seemed to be at play including:

- Delays caused by slow or inadequate evaluation

- Technology was not really suitable for commercial development and so the intention to exploit was over-optimistic.

- Technology fitted a very narrow niche for which there was only a very small market in the NHS or the wider healthcare sector.

- Technology was novel and useful but required more significant investment than was available and required integration with other technologies in order to develop a commercially viable system.

- A technology, though effective, lacked a viable business model.

- Development stalled due to difficulties in gaining interest from funders or industrial partners.

A further issue in identifying technologies was the extent to which some technological innovations, though developed by NHS staff, are never recognised as developed within the NHS. One example is cases where NHS staff have worked on projects in their own spare time and have licensed or are selling the technologies themselves. For these innovations, trusts may even be unaware of their existence and so normal NHS innovation management processes are bypassed. It is unclear whether this group of innovations is substantial or comprises just a small number of innovations. It also varies according to the time at which they were developed. Until 2002 there were few mechanisms available within the NHS to support innovation and exploit IP.

The number of technologies that did meet all of the five criteria and therefore could be included in the survey was 33. These are shown in Table 2 where they have been classified into eight types. The numbers of interviews generating data used in the analysis are shown in Table 3 Almost all interviews were conducted over the telephone and lasted between 14 and 83 minutes.

Type of technology	Number included	Codes allocated
Assistive	1	A1
Clinical IS/Decision making	6	C1-C6
Infrastructure	5	I1-I5
Learning/Training/Teaching	3	L1- L3
Measuring/Monitoring	3	M1-M3
Security/Quality assurance	4	Q1-Q4
Medical/Surgical instrument	6	S1-S6
Therapeutic	5	T1-T5
TOTAL	33	

Table 2. Technologies included in survey classified by type

	Number of interviews
Developers	22
Adopters	15
Partners	16
Total	53

Table 3.   Number of interviews included in analysis

The data gathered from interviews and other sources for each of these 33 technologies is presented in one of two ways. Appendix 2 provides a data set that covers:

- The originating organisation (usually an NHS trust) and the job role of the developer(s)

- Who else assisted the development and/or is now supplying it

- Trigger for the start of the development process

- Clinical or operational need(s) addressed

- Perceived degree of novelty of the innovation

- Form any evaluation took

- Benefits claimed

- Adoption triggers

- Whether adopters were aware the technology was NHS-developed

- Adoption guidance available

- Financial and other costs of adoption

- Consequential changes brought about by adoption

- Potential size of market(s)

- Amount of adoption and discontinuance (if any)

- Other information about the development of the technology

Empty cells in this data set signify that the information was not available or there was no consensus between different data sources.

Appendix 3 contains a narrative for each technology that adds greater depth to the data included in Appendix 2. Each narrative emphasises those aspects that are important in relation to the adoption of that particular technology and provides background information that helps to explain why the characteristics of the technology are as they are.

4.2 Categorising the Stage 1 technologies

The purpose of the Stage 1 survey of technologies was exploratory and aimed to ascertain the characteristics of the technologies. Within the technology literature several attempts have been made to describe configurations of healthcare technology. (See, for example, Adams *et al.*[198] p.367-369.

- Novelty

- Departure

- Disruption

- Risk Ideation

- Uncertainty

- Scope

- Complexity

- Adaptabilty

- Relative advantage

- Actual operation

- Observability

- Profile

However, for many dimensions of configurations such as those suggested by Adams it is not easy to collect data to allow the dimension to be used reliably. For example, novelty, disruption, uncertainty and relative advantage of a technology can be perceived and assessed very differently by different observers. For example, in this survey a pattern was seen across a number of technologies where the developer believed the technology lay at the higher end of the novelty spectrum but adopters and the commercial partners rated the technology as lower down the scale where novelty was concerned.

4.3 Selection of the cases for Stage 2

Based on the Stage 1 survey a number of candidate dimensions were considered and five chosen that would allow six theoretically interesting case studies to be selected. The basis for selecting the five dimensions is that they represented important characteristics of the technologies where adoption is concerned and each one covered a range of values/categories that discriminated between technologies. They were also five dimensions where substantial amounts of data were available. The five chosen dimensions were:

- Balance of Control

- Complexity of technology

- Complexity of the adoption process

- Potential benefits

- Supporting evidence

Balance of control

The first dimension used for categorising the Stage 1 technologies was the balance of control maintained between NHS staff and commercial technology suppliers during the innovation process. For some technologies the amount of control maintained by an NHS inventor was minimal, whereas for others NHS staff continued to play a significant role even after the product was launched on the market. Each technology was placed into one of five categories:

- *Insular with no support:* technologies where the whole of development was done within the NHS with minimal support from outside.

- *Contract in support from wider NHS:* development was controlled mainly by NHS staff, though some extra support was co-opted into the project from other parts of the NHS.

- *Contract in support from outside NHS:* development was controlled mainly by NHS staff, though some extra support was co-opted into the project from outside the NHS.

- *Licence to commercial partner:* development controlled in its early stages by NHS staff until the technology reached a point where IP was licenced to a commercial partner, who then assumed control.

- *NHS staff as lead users:* NHS staff took important development roles and their input was significant, but the balance of control was overwhelmingly towards a technology supplier. The staff or NHS trust involved maintained rights to the IP developed. In these projects the NHS took on the role of lead users.
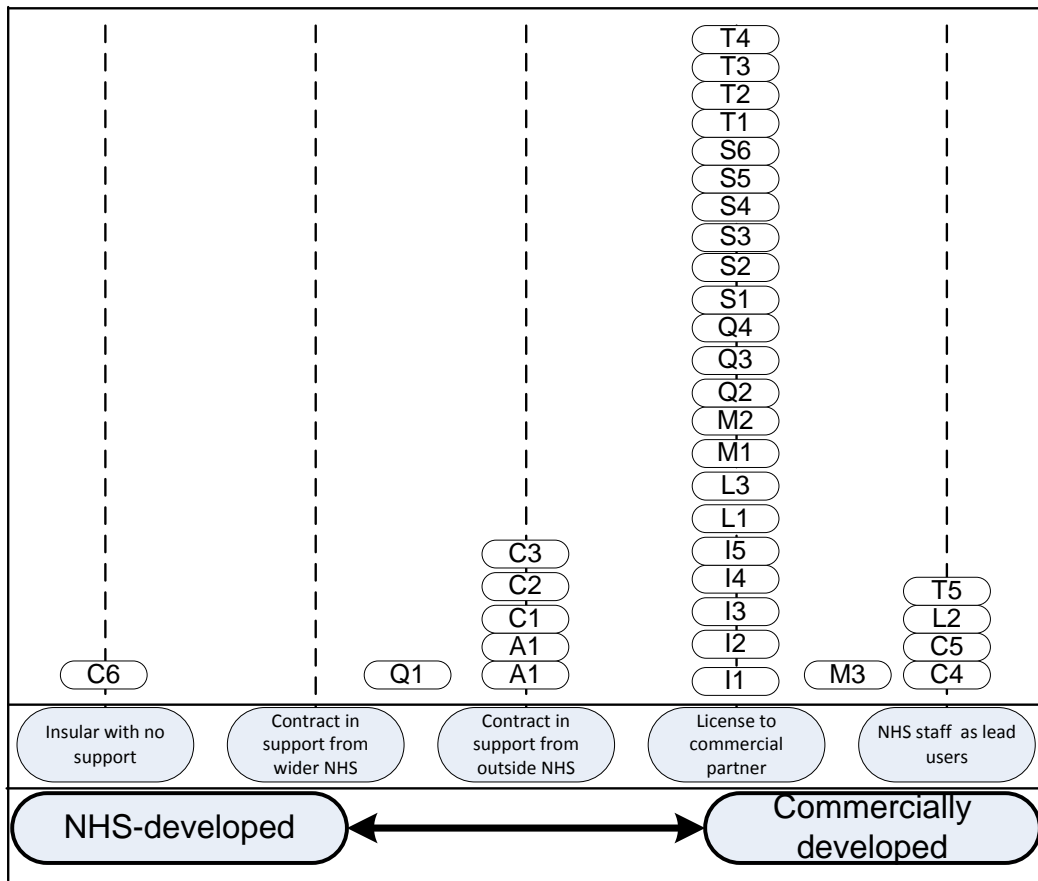
Figure 11. **Balance of control during development**

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Complexity of technology

The range of technologies included in Stage 1 was very broad. An important dimension on which to categorise them was their complexity. Technologies were ranked from low to high in accordance with their relative complexity.
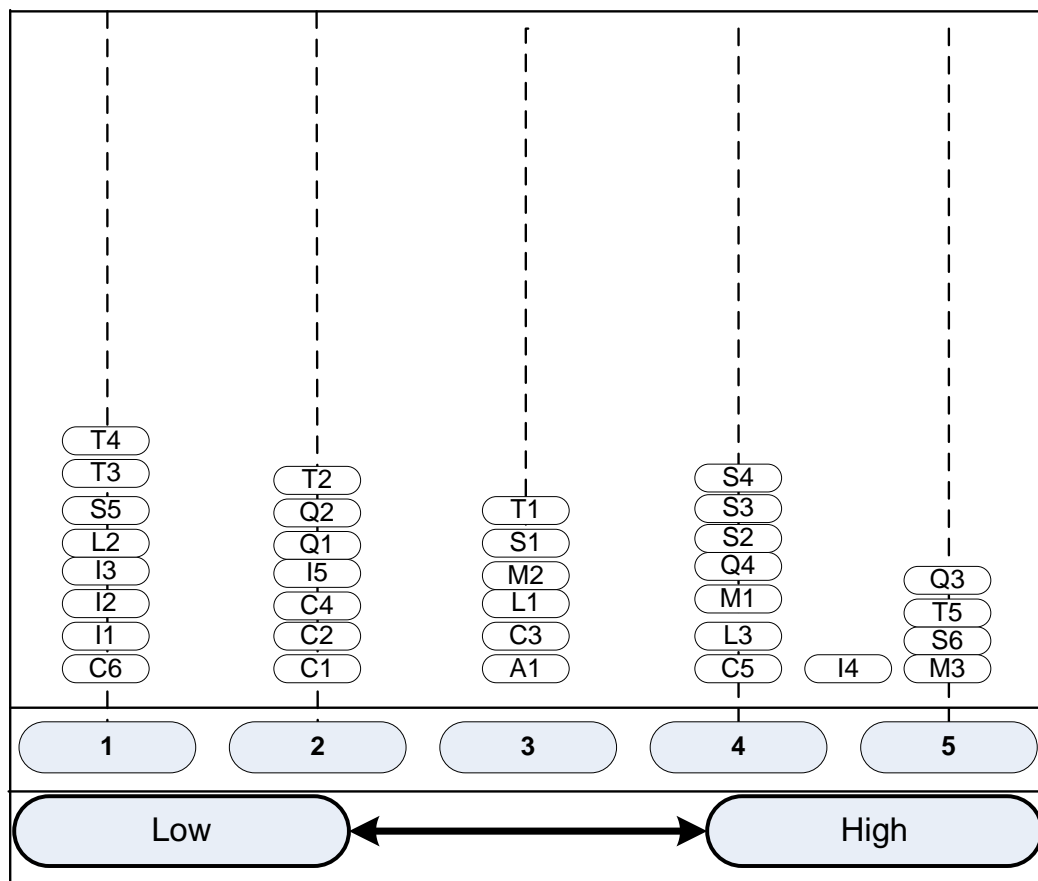
Figure 12. **Complexity of technology**

Complexity of adoption process

The extent to which adoption of technology represented a complex process was a defining feature of the Stage 1 technologies. Technologies in Stage 1 were ranked from low to high according to the relative complexity of adoption, taking into account factors including: levels of training, changes required to infrastructure, service re-design etc.
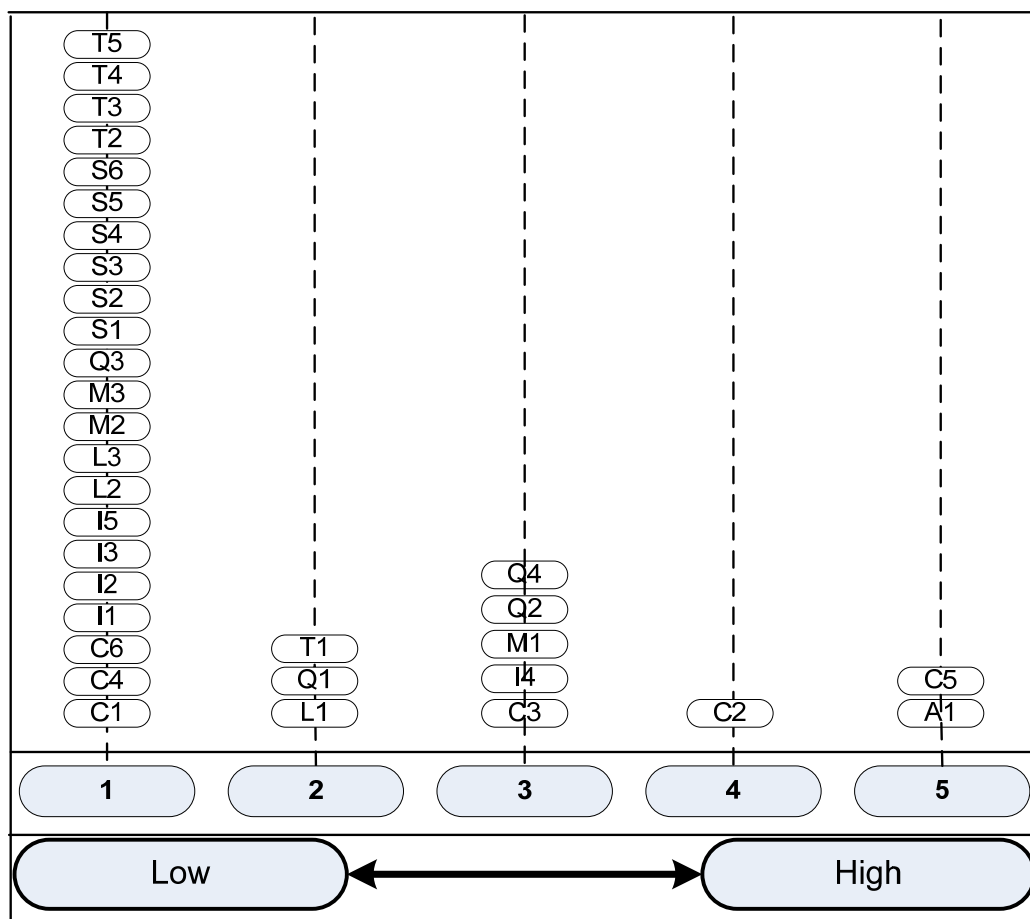
Figure 13.　　　**Complexity of the adoption process**

Potential benefits

The benefits of an innovation can include improved services and financial savings. However, perception of potential benefits is inconsistent between stakeholders so it was decided to categorise potential benefits on the basis of relative improvement in services and/or efficiency.

- *Improved patient or staff experience with little or no financial benefit:* These benefits were mainly based on improvements to experience of patients or staff. Reduced distress, discomfort, risk or inconvenience, were the principal benefits.

- *Improved outcomes with little or no financial benefit:* Implementation results in improved patient outcomes.

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- *Improvements and some financial benefit:* Implementation results in improved service provision and limited financial savings.

- *Improvements and mid-range financial benefits:* Implementation results in improved service provision and financial savings.

- *Improvements and substantial financial benefits:* Implementation results in improved service provision, with significantly improved service design, accompanied with significant financial savings.
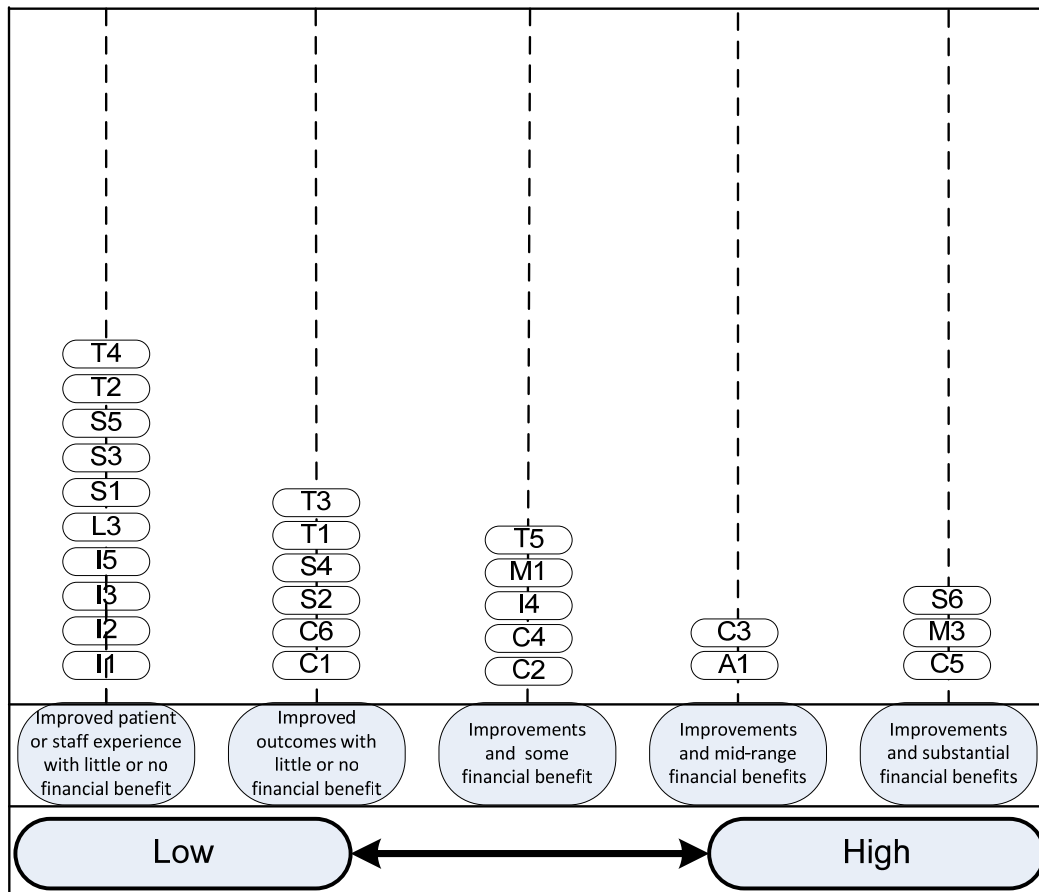
Figure 14.   Potential benefits

It was difficult to collect sufficient reliable data to categorise some technologies and so the following were omitted from this categorisation: L1, L2, M2, Q1, Q2, Q3, and Q4.

Supporting evidence

The extent and type of evaluation carried out on the Stage 1 technologies varied considerably. Existence of supporting evidence is a factor in adoption and so technologies were categorised by the level and type of evaluation and the rigour with which supporting evidence to support adoption was gathered.

- *Purely subjective/anecdotal:* Very little or no evaluation has been undertaken, though subjective judgements by staff/patients suggest some benefits exist.

- *Some data:* Though not systematically evaluated, some data (for example operational performance) has been produced that suggests benefits exist.

- *Systematic evaluation:* A systematic evaluation of some kind has produced evidence suggesting benefits, though the evaluation falls short of a rigorous clinical trial.

- *At least one rigorous trial:* At least one formal clinical trial completed that supports adoption of the innovation.

- *Substantial clinical trial data:* A substantial amount of clinical trial data has been produced that supports adoption of the innovation.
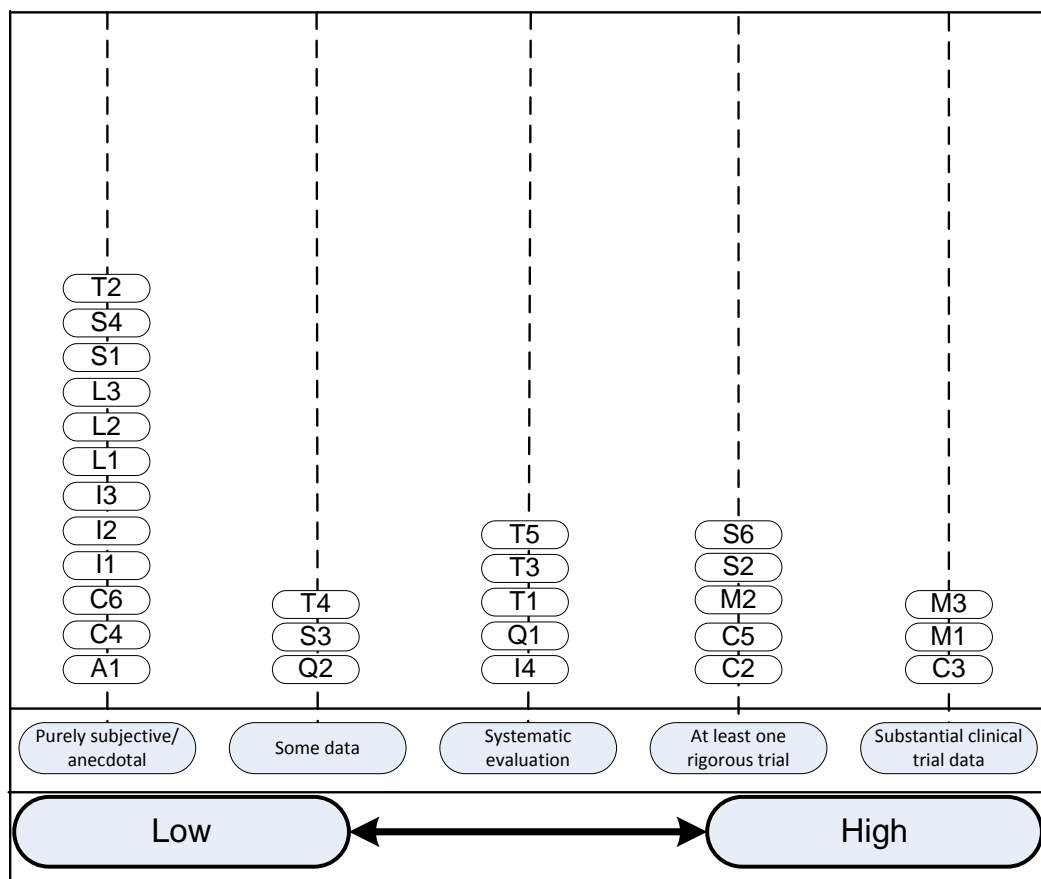
Figure 15.   **Supporting evidence**

This dimension is not meaningful for technologies C1, I5, Q3, Q4 and S5 so they have been omitted.

4.4 Stage 1 analysis

Each of the Stage 1 technologies were ranked on each of the five dimensions and a polar diagram produced. These are included in Appendix 3. By looking across the range of technologies it was possible to identify technologies that would provide six theoretically interesting case studies. Figure 16 shows the results of this analysis. The six technologies that were identified for investigation in Stage 2 have been shaded on each figure and are:

- C3: a telehealth system

- I2: a basic item of equipment

- M1: a technology for informing diagnosis

- M3: a technology for monitoring during surgery

- Q1: a clinical assurance technology

- S3: an engineered component
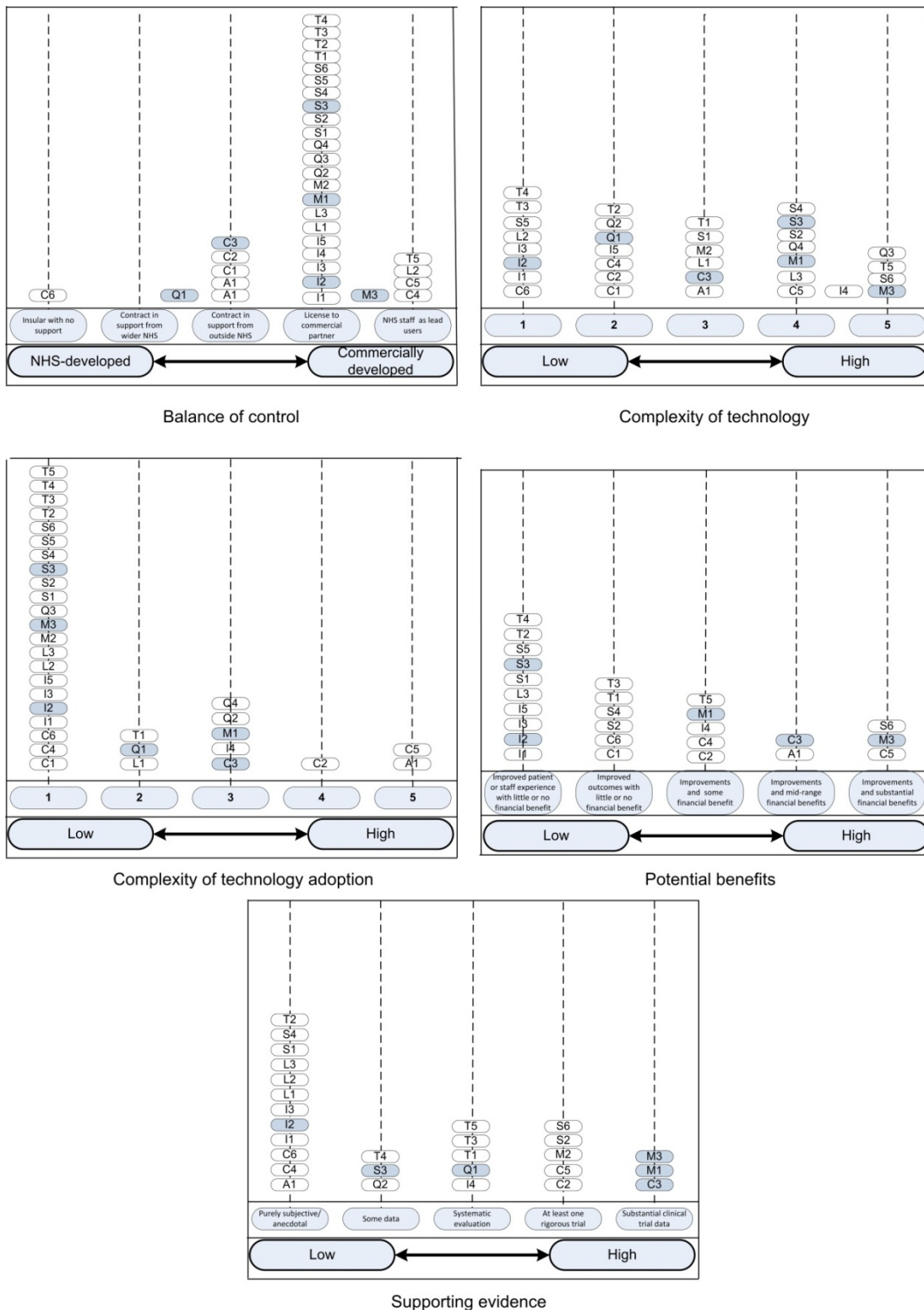
Figure 16. **The six selected technologies**

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5 C3: a telehealth system

C3 and C3a are both telehealth technologies that provide the means of remotely collecting health information from patients. C3 collects data on patients' self assessments of their symptoms and quality of life. It uses an electronic questionnaire to conduct an initial assessment prior to a clinical consultation and can then be used again after treatment to determine outcomes. C3a uses various diagnostic devices to undertake population screening or help to deliver long-term management of conditions. Though not addressing the same clinical areas, these two technologies form a theoretically interesting pair. Together they represent telehealth applications that are used in a range of settings including: outpatient clinics; GP surgeries; pharmacies; and patients' own homes.

5.1 Data collection for the cases

Both cases draw on the experiences of staff in early adopting sites and at sites where adoption occurred when the technologies were more mature. C3 case research was carried out at five adoption sites. Interview data gathered from the main stakeholders at each site was collected and has been complemented with additional data from published sources. The clinician responsible for developing C3 also provided additional insights into the technology's adoption.

Case research for C3a was conducted on five implementation sites through interviews with stakeholders and additional data from published sources. These were:

1. a GP surgery that had piloted C3a

2. a GP practice that was an early adopting site

3. a pharmacy group that adopted C3a into its chain of pharmacies

4. a primary care providers based in an urban area of the UK

5. a primary care provider in a rural area of the UK

In the GP practices the adoption decisions were made by practice staff but for the primary care providers the decisions were made primarily by commissioning staff based outside the organisations.

5.2 C3 and its development

C3 comprises a clinical questionnaire builder and a system for administering the questionnaires to patients. The questionnaire builder includes a facility to define complex routing rules so as to allow patients to answer questions faster and more easily. The answers are inputted using either touch-screen

computers located in a clinic or from home using a web interface. Once a questionnaire has been completed the system produces an analysis of the data entered that can be added to patients' notes. Typically the results from a questionnaire are supplemented by information gathered during a clinical interview and then used by a clinician to inform clinical decisions. Since its initial development, variants of C3 has been developed to support a range of questionnaires. The original questionnaire is the one that has been adopted most widely by NHS trusts and is the focus of this case.

The system uses anonymised codes to hold the data so minimising the risks of holding patient data. The range of benefits delivered by C3 include: increased throughput of patients in clinics; improvements to the effectiveness of clinical interviews; better triage of patients to appropriate pathways; more objective assessment of treatment outcomes; and clinicians being able to carry out consultations remotely, for example by phone.

The idea for C3 came from a hospital consultant who subsequently assembled a team to develop a prototype system. This team included clinical staff, technical staff from the hospital's medical physics department, and academic staff.

The first questionnaire designed for use on C3 assessed elderly patients and so design focused on ease of use in order to minimise the level of support needed from healthcare staff. Because the questionnaire addressed symptoms that were potentially difficult or embarrassing for patients to discuss they welcomed being able to communicate via a questionnaire rather than face-to-face. It reduced their anxiety and embarrassment and this in turn led to improvements in the quality of information received by the clinician.

Over several years the team iteratively improved a working prototype, implementing the various versions into clinical use in the hospital and local community and modifying existing service designs as they went along in order to accommodate the system more effectively. The cycle of iterative implementation and revision incorporated several clinical trials. Some of these focused on reliability and validity of the questionnaire instrument whilst others considered the system more broadly in terms of the acceptability of the questionnaire system to patients and its organisational fit. A number of peer-reviewed papers reported the findings from these trials.

In collaboration with the local NHS innovation hub the IP associated with C3 was protected and a spin-out company formed to commercialise the technology. This spin-out company was a partnership with a small, local software house with previous experience of developing healthcare information systems. It led to two important developments. First, it completely reverse-engineered the system and rewrote the software to a commercial standard. Secondly, it developed the system into a web-based

service. The company now licenses the system as a hosted service that includes user support. Adopting trusts purchase an annual licence to use the technology.

5.3 Adoption of C3

The clinician who developed C3 works in a specialist area that has only been regarded as a distinct professional speciality for about the last fifteen years. He is therefore part of a relatively small professional group and perhaps as a consequence the group forms a close-knit network of clinicians across the country. It is this professional network that has been most important in encouraging adoption of C3. It is the case, however, that although C3 is valued by clinicians, it does not provide large-scale improvements in outcomes or savings to the NHS so it has not been identified as strategically important by individual NHS trusts.

The professional group using C3 is supported by regular programmes of workshops and conferences that create plenty of opportunities for joint research and exchange of ideas. Clinicians in the group are generally well informed about developments in treatment at other trusts. It is this network of relationships that has been most important in creating awareness of C3. In some cases there is a long-term, collaborative relationship between C3's developer and clinicians at adopting sites. At others adopters had more distant relationships with the developer and became aware of C3 from presentations he made. Whichever was the case, across all sites investigated for this research C3's developer has provided significant support to adopters both prior to the adoption decision and during implementation. Adopters feel that this support has only been possible due to the developer's own role as a practicing clinician. One clinician reflected that in comparison with a commercially developed system, C3 was viewed less suspiciously, and that clinicians sensed that they were not just dealing with a 'rep'.

5.3.1 Evidence

Adoption of C3 was found to be heavily influenced by three forms of evidence. The first, relating to clinical validation of C3, was drawn from the published trials carried out at the developer's trust. This validation was crucial to adopters recognising the feasibility of using C3. Without it, it seems unlikely that any centres would have adopted C3 so this evidence can be seen as 'qualifying' C3 for potential adoption, though on its own the evidence was unlikely to guarantee adoption. The second was witnessing demonstrations by C3's developer. It was these demonstrations that convinced clinicians that the system would work within their own context. In contrast to published trial data, this less formal contact with the developer was often critical in 'winning' the confidence of clinicians and making them enthusiastic to adopt C3 into their own trusts. Finally, the

internal hurdle faced by adopters was often the development of a business plan setting out the adoption case. This task was eased because the developer was able to provide a comprehensive set of data to support adoption in a format that allowed it to be easily assimilated into a business case. This data also went some way to providing information on wider benefits.

5.3.2 Adoption and funding decision-making

In general, the adoption of C3 has been championed by senior clinicians with little ownership of the adoption decision by senior trust management. The lack of strategic significance given to C3 by trusts has meant that funding of the C3's implementation was generally ad hoc, with little formal strategic investment funding made available by trusts to purchase either hardware or software licences. Instead, implementations of C3 were commonly funded from a clinician's own research project, surpluses from department budgets or charitable sources. For example, at one trust the adoption decision was driven by a consultant. Central to this decision was an informal, reciprocal agreement between the consultant and his department to use money from his research budget to fund the hardware, with the department paying for the annual licence fee. This arrangement was not without complications, however. Because the installation of the hardware was delayed the cost of the annual licence had risen significantly by the time it was in place so the department decided not to fund the licence after all. It was only the consultant's ability to negotiate a licence fee reduction that prevented the project being abandoned. Overall, trusts seemed to focus on the costs associated with C3 rather than its benefits. One trust did use regional innovation funding to finance the implementation of the system but where the others are concerned, without the entrepreneurial action of individual clinicians, funding would not have been obtained.

At another trust the adoption decision followed a rather different path. Adoption of C3 into a particular department was suggested by a clinician in an allied department. This clinician was not a consultant but had taken opportunity of a free trial of the system to see how it would work with patients. As a result of this experience the clinician arranged for C3's developer to present to a group of consultants in the main department. In addition, the clinician presented the results of her own pilot and produced a business plan for its implementation. The decision to adopt C3 was based on a consensus decision by consultants in the main department and the departmental manager. It was also agreed that the project would be led by the clinician from the allied department. Unfortunately, partly due to being based outside the main department, and partly because she did not have the seniority and power to drive the project forward, the clinician found it very difficult to maintain C3's implementation as a priority when priorities changed in the main department. As a result the implementation eventually

stalled. At all but one of the other sites in this case study, implementation was led by a consultant clinician. At the remaining site the implementation was seen as a nurse-led project.

The advantage of consultant-led implementation is that consultants usually have the organisational power to arrange funding and to bring about changes to services that are required as a consequence of adoption. An important feature of the consultant-led implementations, however, was the extent to which they had the time needed to manage day-to-day implementation issues. In some instances it was clear that the amount of effort required had been underestimated by the consultants and they were surprised by the scale and range of operational issues they had to deal with. Perhaps as a result, implementations were managed in a relatively ad hoc fashion. For example, one consultant characterised the approach he took as being based on "Let's do it and trouble shoot as we go along". He did not consider it to be a project that required a sophisticated approach. He saw his role to be directing staff to sources of information, negotiation and troubleshooting. However, during the implementation he found he had to personally intervene to test the system, train staff, solve technical problems and even counter staff resistance to the project. These interventions undoubtedly delayed the full implementation of C3.It was the case, however, that the clinician had little option other than to take control of the project. The work of managers in the department was focused predominantly on more general operational issues so they were unlikely to have sufficient time to spend on implementing new technology. Though C3 was eventually implemented successfully, the consultant was aware that no formal evaluation of it was ever undertaken due to lack of time and the pressure to focus on the delivery of care to patients.

The experiences of other trusts in this study illustrate how the success of implementation also depends upon other factors beyond project management style and ownership of the project by a senior champion. Despite C3's design as a managed service, coordination of effective IT support was seen as a major risk to implementation and was cited as a major source of problems. These included problems associated with installation of hardware and the availability of technical support. Issues around information governance were also found to be major obstacles to implementation and slow to resolve. In one trust, responsibility for introducing the hardware was given to the trust's IT department but they regarded it as low priority. As a consequence, IT problems were only resolved slowly. The lack of responsive IT support meant that the consultants who had taken the decision to adopt had to handle day-to-day implementation problems themselves, a task for which they were ill-prepared and to which they were unable to devote sufficient time. Frustration with the situation was exacerbated because the hardware problems inhibited use of the system whilst at the same time they were wasting money on the licence fee. As a result, use of the system in clinical practice was abandoned.

In one trust, adoption involved a large teaching hospital and a smaller general hospital. Research at this site showed that the size of an adopting site can affect implementation. Significant differences in the extent of adoption were still apparent three years after adoption began. Use of C3 at the smaller hospital was far more extensive and sophisticated than at the larger hospital. The key reason cited for this difference was better communication and a high degree of cooperation between various departments in the smaller hospital. In the larger hospital adoption was impeded by more clearly defined (and possibly more rigid) job roles combined with more distanced communications between departments.

At one trust investigated for this case (a District Hospital), C3 was adopted much more recently than at the other four sites. Their adoption was swift and smooth with minimal problems. It was driven by a consultant and undertaken by an enthusiastic team made up mainly of nursing staff but also including a representative from the IT department. Inclusion of the IT representative was seen as critical to successful implementation of system because it meant they avoided IT failures that would have upset staff and patients. Success was also attributed to the full support of the project that was given by the nursing team. This support was in turn attributed to their direct involvement in decision-making and provision of the opportunity to contribute to the development of operating procedures.

The range of adoption experiences across sites suggests that though robust project management processes contribute to successful adoption, commitment, cooperation and enthusiasm from staff is also essential.

5.3.3 Role change and workload

A consequence of adoption is that changes to the patient consultation process require a change in the role of nursing staff. Introduction of C3 requires nurses to provide additional support to patients and thus to have a sufficient level of IT literacy to be able to guide patients, some of whom are elderly and very infirm, in the use of the system. Willingness to embrace this role change was a critical factor in effective adoption. A relatively small number of nurses reacted negatively to C3 on the basis that they felt that it increased their workload and it was not part of their job role to operate computer systems. This resistance was overcome over time but where it occurred it represented a significant barrier to adoption. Furthermore, resistance was not necessarily limited to nursing staff. At one site, the project champion felt the technology might have been perceived as threatening to consultants because they saw it as diluting, or even removing, some aspects of their role. More generally, staff may harbour concerns that use of C3 in a patient pathway may not actually increase quality. At a site where implementation stalled, the satisfaction of department staff with the status quo was cited as a reason for the lack of motivation or 'tension for change', despite the benefits formally identified in the business plan.

5.4 Adoption of C3 into other specialisms

C3 is a combination of two elements: a validated questionnaire and a questionnaire generator. Though the focus of this case has been on the adoption of the first questionnaire developed through relatively strong professional linkages of the inventor, it is also worth noting the extent to which adoption of the questionnaire generator has progressed. At the time of writing no further questionnaires have been developed and adopted on anything like the same scale as the original questionnaire. However, several questionnaires have been developed in separate and unrelated specialisms. This diffusion of the original questionnaire concept to new specialist areas represents a second dimension of adoption. In common with the adoption of the original questionnaire, the diffusion is based primarily on personal and professional relationships of C3's inventor but the specialist areas for which questionnaires have been developed are un-related and diverse. They therefore represent an organic abstraction of the original concept to new domains that have relatively weak linkages with C3's inventor.

5.5 The C3a Technology

C3a is a telehealth technology used to support patients with a variety of long term conditions that can also be used to carry out routine health-checks. Variants of C3a have been developed to allow regular use by patients in their own home and on a self-service basis in GP surgeries, pharmacies and other community settings. All versions of the system are designed to be simple to use so that patients need minimal intervention or support from healthcare staff.

C3a integrates with a number of standard patient record systems used as part of GP practice management systems. Providing appropriate communication infrastructure is in place (e.g. broadband), it can transfer readings taken remotely directly to a patient's own electronic record, This integration with other NHS systems does, of course, require conformance to information governance requirements.

C3a can be configured for tests using a range of interfaced diagnostic devices. Each configuration supports either the management of a long-term condition or a standardised health check. In addition to interfaced devices, C3a enables administration of a range of electronic questionnaires adapted from paper-based versions of clinically validated questionnaires in common use by GPs.

5.6 Development of C3a

Development of C3a was led by the Chairman of a commercial company. He had been involved in the commercial development of various healthcare information and telehealth applications since the 1980s. These included a clinical decision support system (CDSS) that has been widely adopted by

clinicians in the NHS. The experience he gained from developing and commercialising the CDSS informed the approach he took when developing C3a, especially with respect to the importance he placed on gaining extensive clinical support and his recognition of the value of using direct feedback from clinicians to inform decisions about functionality and interface design.

Development of C3a followed a strongly user-focused, incremental process. Several NHS sites were used as pilot sites to develop the various versions of C3a. User feedback was collected systematically used to identify potential improvements to functionality and interface design. This approach to development continued beyond the initial development phase and even now C3a is relatively mature the supplier works with customers to adapt the system to meet new requirements.

5.7 Adoption

C3a has now been adopted widely in the NHS. There are several hundred C3a installations in a range of settings that includes: GP surgeries; patients' homes; pharmacies; and mobile use by community staff. The adoption has been driven through several mechanisms. In some cases individual GP surgeries and pharmacies have invested in the technology. In others the implementation has been organised by local primary care groups. A number of other similar, commercially-developed systems are available; competition from major healthcare IT providers and other smaller more specialised suppliers is significant.

5.7.1 Awareness

One of the GP practices looked at, and the pharmacy group, were both geographically close to the developer and, perhaps more significantly, staff within them had long standing relationships with the developer. As a consequence of this the GP practice agreed to act as a trial site and in return, the developer supplied equipment free of charge. The pharmacy was an early adopter. The second GP practice was also a relatively early adopter. It became aware of the C3a by chance when one of its GPs and the Practice Manager attended a conference. They were both already enthusiastic about the potential application of new diagnostic technologies in their practice and each had a strong interest in healthcare IT. Indeed, the GP was the local commissioning group's clinical lead for IT. As a result of meeting the suppliers of C3a at the event they arranged for a demonstration of the technology to be given to the other GPs in the practice. The demonstration persuaded them that C3a would be robust and they agreed to go ahead with a local trial. (They are happy to say that this decision was based more on personal preference than a strictly evidence-based assessment.)

Both primary care groups included in this case study became aware of C3a by conventional market scanning processes. The decision to commission C3a was based on a combination of both awareness gained through existing relationships and more formal tendering processes. In the case of the urban group, the commissioner had initially considered an alternative technology with which he was familiar from a previous role. However, problems in gaining agreement as to how the candidate technology would be integrated with other technologies meant that it was dismissed as an option. The commissioner then widened the search to other preferred technology suppliers but after a tendering process the other options were judged as over-specified and uneconomic. A decision was therefore made not to use preferred suppliers and, based on a recommendation by a commissioner in another trust, C3a was evaluated and then selected.

When the rural primary care group was deciding which technology to adopt it invited a number of telehealth providers to tender, including the developer of C3a who had been very active in developing relationships with thought-leaders and decision makers in the region concerned. As a result of this process, C3a was selected. The developer believes that the company's success was based on being able to show previous success, demonstrating understanding of the user's requirements, ability to deliver, and competitive pricing.

5.7.2 Drivers for adoption

In terms of motivation to adopt, several factors were evident at the sites. These include internal and external concerns and are summarised in Figure 17.
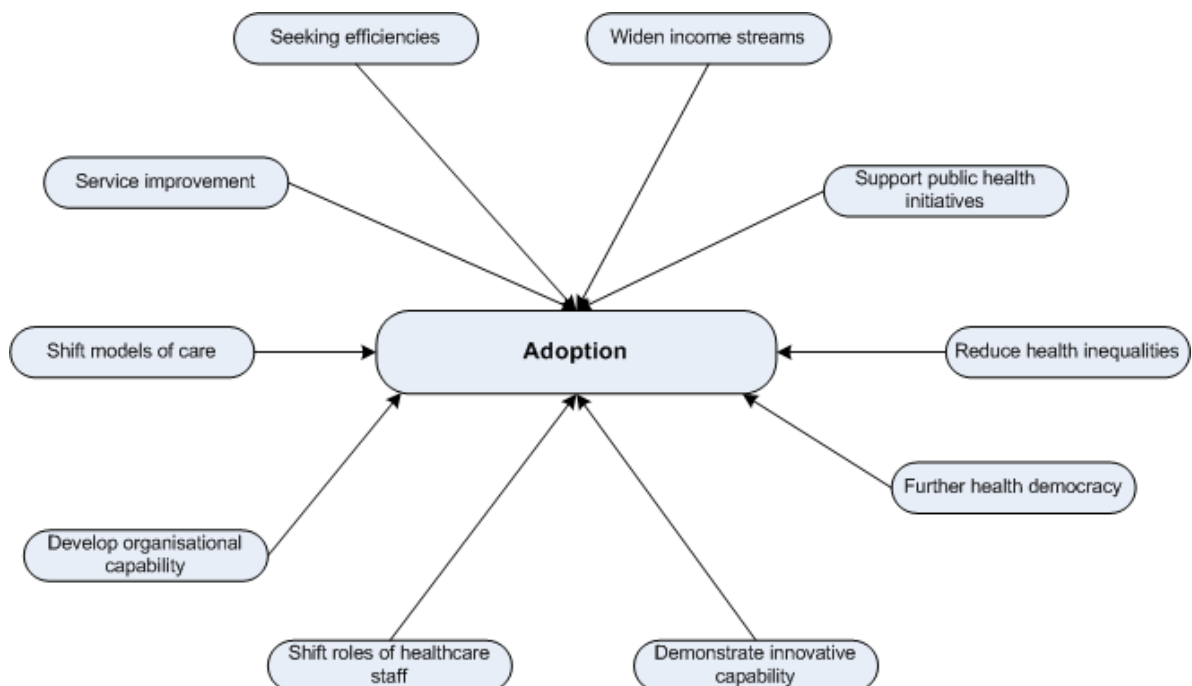
Figure 17. **Motivating factors in adoption of C3a**

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The predominant concern for the GP practices was to reduce time spent on routine patient assessments by GPs, nurses and other practice staff. The potential to enable patients to undertake their own assessments on a self-service basis made C3a an attractive option. A second significant motivating factor, shared by GP practices and the pharmacy group, was the opportunity to generate extra revenue by offering additional services.

Aspirations to improve health democracy were identified as an important driver for adoption. A Pharmacy Manager believed tackling men's health inequality should be a key concern and was aware of research showing that men were more likely to engage with pharmacists than GPs. Consequently, he saw C3a as a way of providing NHS health checks efficiently whilst at the same time improving men's access to healthcare. The pharmacy's shift towards use of C3 was also a way of improving services to patients. Some of these were small improvements in the flexibility of routine services through the provision of self-service elements, such as the processing of repeat prescriptions. Others were more significant improvements such as relocating population screening programmes and support for long-term management of conditions from hospital outpatient clinics to community-based sites. The pharmacy group was also keen to start to provide novel diagnostic tests such as those for diabetes. The Pharmacy Manager saw that adoption of M3a would, therefore, provide a means of meeting objectives related to both the QIPP and the health–inequality agendas.

The primary care groups' decisions to adopt telehealth were strongly linked to central policy initiatives and priorities. For example, in the urban group, policy initiatives developing from Lord Darzi's 2008 'Next Stage Review'[9] drove the search for suitable technologies that would enable the group to achieve policy objectives. Telehealth technology was seen as capable of supporting the QIPP agenda, particularly in relation to prevention initiatives (see for example 'Putting prevention first'[199]). Significant funding accompanied these central initiatives and so reduced the financial barriers to implementation of C3a and other telehealth technologies. Similarly, the rural primary care group's implementation of a small pilot study extended previous telehealth initiatives in remote rural areas of the UK. While this mirrored the urban primary care group's motives, the pilot study had several additional specific purposes. First of all the project sought to explore how C3a could extend the support given to patients living in rural areas who suffered from long-term conditions. Within this, reduction of unplanned hospital admissions was a specific objective. Other aims were more focused developing staff expertise and wider organisational capability. Finally, the primary care group was keen to present an external view of itself as being innovative in its use of telehealth technology.

5.7.3 Trialling, evidence and evaluation

An issue that was raised by the adopters who were interviewed was the difficulty of gathering evaluation data to support the initial adoption

decision or review implementation. Part of this difficulty was the limited availability of formal clinical trial data that would allow generalisable evaluation of C3a. This lack of data was exacerbated because the adoption sites did not have sufficient time and resources to carry out long-term evaluations of their own implementations. This meant that the evidence base underpinning C3a could only grow slowly.

The technology supplier has been proactive in evaluating C3a. By maintaining close relationships with key staff in early adopting sites he has been able to gather feedback to inform modifications and extensions to the technology. Through the use of automatic logging he has also built a significant store of usage and used it to calculate key performance indicators and generate comprehensive reports at individual installation or groups of installations level. Further refinements of the data logging mechanisms have also allowed feedback from peripheral devices to be collected. The information generated is important to the technology supplier and the early adopting sites but it also informs potential adopters about the potential for cost savings and the like.

Unfortunately, in common with many telehealth technologies, lack of formal clinical trial data or published evaluations of specific implementations have made it difficult to satisfy the information needs of potential adopters, especially commissioners. Central to this problem is the extent to which each adopter prioritises performance indicators according to their own aims and context. Hence the perceived generalisability of data from evaluations between contexts can be poor. This was also exacerbated by the extent to which all the adoption sites implemented C3a as an evolving technology, for which features were still being added or changed. This meant that evaluations were done on a system with no fixed specification. Similarly, all the sites presented distinct contexts in which C3a was implemented.

A final problem with the available evaluation data is its quality. One commissioner highlighted the fact that that commissioning decisions rely heavily on projections of potential performance that can be presented within business plans. Precise forecasts for C3a cannot be provided due to the poor quality of data that is available, especially where data collected from primary care providers and GPs is concerned because it is often imprecisely recorded and/or poorly coded. Furthermore, poor data quality problems are sometimes compounded by a lack of ability within commissioning organisations to apply health economic techniques when evaluating technologies.

Some of the adoption sites have sought to address the above problems. Within the GP practices evaluation has drawn on existing evidence where available but has found that this is frequently oriented towards local trials that are limited in duration, scope and size and which often combine systematic assessments with subjective judgements of the technology's performance. For example, at the GP practice where the early pilot was conducted a formal evaluation of C3a was not carried out by the practice.

Based on their experience though the practice staff believed there had been a very positive response from patients, to the extent that discontinuing the use of C3a would have prompted patients to complain. C3a was also perceived by practice staff as more efficient. In contrast, the early adopting practice's approach to evaluation involved a short but intense single day trial in one of the practice's clinics. The subsequent decision to install C3a into routine use relied on the staff's belief that that C3a had been shown to be stable and usable by patients. However, no subsequent evaluation of C3a was conducted in the practice to assess either the impact on patient outcomes or efficiency. Overall, evaluation has relied mainly on anecdotal evidence that patients and staff have welcomed C3a.

There was less scope for trialling C3a within the urban primary care group prior to making an adoption decision and so instead, the commissioner used a constrained range of criteria to evaluate candidate telehealth technologies. It was challenging to identify unequivocal evidence, acceptable to all stakeholders. For this reason the main evaluation strategy was based on ensuring, with a reasonable amount of confidence, that C3a was robust, safe and met information governance requirements. In addition, ease of use by practice staff and interoperability with existing GP information systems was an important criterion, especially as telehealth systems need to be able to operate alongside and in conjunction with technical and organisational systems within GP practices. Acceptability to GPs is therefore an important criteria, especially if one accepts the view expressed by a commissioner that it is more difficult to change clinicians' attitudes and behaviours towards telehealth technologies than it is to alter those of patients.

Evaluation was an integral part of the formal pilot study run by the rural primary care group. Quantitative evaluation used data generated by C3a and satisfaction surveys of patients and service staff. Qualitative evaluation of C3a was also carried out through interviews with staff, focusing on the extent to which implementation into routine practice had been successful. However, this evaluation also had limitations. The small size of the pilot study limited the statistical significance of the results and problems with delays and variation in implementation undermined the external validity of the findings. Despite its limited size, however, the evaluation was able to identify key adoption issues. These were associated with: rural settings and communication infrastructure; changes to responsibilities; roles and knowledge requirements that are brought about by adoption; and other changes to working practices. Despite their lack of statistical significance, these issues were regarded as insightful and of relevance to other potential adopters of C3a. This suggests that even small scale pilot studies may have a role to play in supporting widespread adoption of technologies, though the drawback remains that potential adopters are often only willing to accept data from large, rigorous trials.

5.7.4 Implementation, context and partnership

There were differences in the way in which sites included in this case implemented C3a. These variations were not only due to differences in context. They also reflected the types of partnership involved in the adoption process. The most straightforward implementation was probably the early adopting GP practice. The implementation was wholly driven by the practice staff, with no involvement of the local PCT or commissioning groups. Looked at four years afterwards, C3a was well established and integrated into routine processes within the practice.

The GP practice where the early pilot was conducted and the local pharmacy group were each implementing more complex configurations. After separate initial adoptions of C3a, they agreed to collaborate and integrate their systems. The intention was for assessments completed in the pharmacy to be transferred directly into a patient's notes at the GP practice and if the results raised concerns an appointment with the GP would be arranged automatically. The implementation of the combined system was thus dependent upon a three-way relationship between GP practice, pharmacy and the local PCT. Critical to its success was agreement by the local PCT that it would manage the necessary IT infrastructure and various governance issues. This agreement was never fully achieved and progress in resolving issues was slow. Both the GP practice and the pharmacy found the PCT's involvement impeded progress and both perceived the local PCT as overly cautious and too risk-averse. Further delays were caused by disagreements about responsibility for funding the equipment though this was ameliorated when the technology supplier offered some equipment free of charge. In addition, the practice's patient group were not enthusiastic about the technology being located in the pharmacy as they felt a GP surgery environment was more commercially neutral than that of a pharmacy. Unfortunately, these issues were never properly resolved and so the integration stalled, though C3a continued to be used independently by the GP practice and pharmacy.

The urban primary care group were very successful in achieving adoption of C3a. In part this was due to the policy initiatives on prevention and management of long-term condition that created a very positive climate for telehealth adoption. They implemented more than thirty systems into GP surgeries, pharmacies and other community-based settings at a total cost of several million pounds. A critical success factor was the support given by clinicians in acute trusts to the initiative, possibly as a result of the initiative being jointly managed by public health commissioners in the PCT and clinicians in the acute hospital. The commissioner believed that the initiative would have been less successful if specialist clinicians had resisted the shift in services from hospital out-patients clinics to community-based settings.

5.8 Findings and conclusions

Several themes run through this pair of cases. A prominent feature of the C3 case the way a process of evolutionary prototyping allowed it to develop from an initial idea into a commercially robust product. Development expertise and committed application by clinicians resulted in a validated technology that met the needs of clinicians and was acceptable to patients. Despite the resulting prototype having to be reverse-engineered and then rewritten, the key functionality and interface design was well defined. This case therefore demonstrates the effectiveness of the prototyping approach in capturing and responding to clinical requirements. Similarly for C3a, development was based on a user-centred organic approach that allowed the supplier to develop the technology to meet the needs of adopting sites and also helped engender trust from potential adopters. The willingness of the supplier to collaborate with adopting organisations to refine the technology was seen as a significant factor in adoption decisions. Adopting organisations were able to request modifications and additions that allowed them to implement C3a more effectively and with greater success.

A challenge for any computer-based information system is the extent to which the technology can be developed to reflect situated knowledge of potential users. To a large degree it is the extent to which situated knowledge is embedded within technology designs that determines how successfully the technology fits into a specific context. At the start of this research, it was hypothesised that one of the potential benefits of NHS-developed technologies is that it will fit better into NHS organisations because of the direct involvement of NHS staff in the development process. Both C3 and C3a demonstrate that an explicitly user-centred approach to their development and refinement was highly beneficial and allowed the situated knowledge of NHS users to be taken into account when defining the purpose and user requirements of the technology. In both cases the NHS and its staff were prominent lead users of the technology being developed. Taken together this pair of cases suggest that NHS-developed and commercially developed technologies can derive significant advantage by formally recognising NHS staff as lead users.

C3 also shed light on the complex trajectories of development NHS-developed innovations can follow. Two dimensions of this were observed: development within a specific domain; and abstraction of the technology for application in a different domain. Much of the development effort for C3 remained in the original clinical speciality but subsequently, the development of new applications of the technology in completely different clinical areas has required the core characteristics of C3 to be abstracted and reapplied. Abstraction of the technology to new domains is perhaps the more powerful mode of development. If successful it opens up significantly broader markets. Unfortunately, this in turn creates new challenges in development. First, new specialist teams are required to undertake the development in new application areas. The original development of C3 took

place in a team that possessed a well-balanced set of skills. In order to successfully develop new domain areas it is necessary to not only identify relevant new domains but also build committed teams to work on the new application. C3a also illustrated the challenge of managing technology trajectories into new areas, in this case in response to a new policy initiative or service priority. In contrast to an NHS-developed technology where the development team are very likely to be highly skilled and focused on one single speciality, commercial developers might be seen as less entrenched in a single specialism and so is more 'nimble' in forming new relationships to support application in new domains.

There was little evidence that adoption of C3 was based on the high-level, strategic decisions of NHS trusts. Instead, decisions were usually taken by specialist NHS staff, predominantly consultants. One implication of this is that the responsibility to champion the adoption decision falls on an individual member of staff who might be remote from high-level trust support. This gives staff the autonomy to act but can also leave them relatively isolated during the adoption process. Even when potentially important benefits to a trust existed, not least in terms of improved efficiency or effectiveness, it was common for the adoption C3 to take place 'under the radar' of senior trust management.

The role assumed in leading an adoption project is varied and requires not just clinical but managerial skills. These include the ability to develop a business plan, negotiate funding and perhaps most importantly, those required for effective project management. For the sites adopting C3 there was little support from trust managers who do have the specialist skills required. This raises a question as to the types of management support that clinicians need when implementing technologies and how this support should be made available. Without such support failure is much more likely. The need for project-related skills is also highlighted in the C3a case. While the implementation of the C3a was generally unproblematic, it is notable that the two adopting GP practices undertook very little evaluation as part of their respective implementations, primarily due to lack of time and resource. This again suggests that provision of greater support for adoption projects may be a more general issue in the NHS.

C3 and C3a illustrate how technology adoption is driven by the need to fulfil a specific clinical function whilst at the same time serving wider purposes. However, each case illustrates a very different way in which the wider purposes of a technology can impact upon adoption.

The adoption of C3 was ostensibly driven by the primary need of adopters to gain clinical benefits, such as improved throughput, better patient experience and the ability to systematically assess the outcomes of treatment. However, there was also a less clearly articulated purpose behind the adoption of C3 that lay within the closely-bound professional network of clinicians interested in the emerging specialism. This was C3's potential as a research tool that would allow the specialist area to build its

own knowledge base and thus form part of the specialism's research infrastructure. In contrast, adoption of the C3a fitted different wider purposes such as concerns to improve health inequalities, and capacity building in the use of telehealth technology. Although the wider motives behind adoption of C3 and C3a are very different it is clear that such broader purposes need to be taken into account when encouraging or providing support for adoption.

A common theme for both C3 and C3a adopters was the extent to which specific evidence of effectiveness was used. Both C3 and C3a present challenges in terms of providing comprehensive evidence to support adoption. The developer of C3 was extremely careful to follow a publishing strategy to show the technology's effectiveness in clinical trials. However, the extent to which this evidence was instrumental in triggering adoption at other sites seems limited. For many adopters it was the direct communication with the developer that was most influential than the existence of the published evidence on its own. At best the published evidence 'qualified' the technology for consideration, but it seems likely that for some adopters it had minimal impact in the adoption decision. Similarly, there was a lack of definitive evidence that proved benefits of adoption of C3a. As with C3, the deciding factor affecting most adoption decisions was the outcomes of direct communications with the technology's supplier. Though there was evidence relating to use of telehealth, much of this was linked to specific contexts and so its applicability to each adopter's context was often equivocal. This suggests that decisions were based on adopters recognising how the technology would fit into the organisational context and work effectively. Published evidence played a part in decisions but the extent to which each adopter's organisation was receptive to a technology was based on whether the technology is perceived as fit for purpose and adoption makes sense to the decision-makers.

6 I2: a basic item of equipment

This pair of cases looks at two forms of portable drip stand, I2 and I2a. Compared with most technologies used in healthcare, drip stands are very simple, inexpensive products and on the face of it one might assume that over the years their designs have evolved to the point where there is very little to choose between different brands and models in terms of functionality and price. However, this is not entirely the case. Over time, requirements change and opportunities for innovation emerge. I2 represents just such a departure from the established brands. It is a portable drip stands that originates from a care team working within a primary care trust. They used their own experiences of delivering care in the community, in particular their awareness of the difficulties of working in patients' homes with heavyweight equipment, to devise a piece of equipment that is specifically designed for use during treatment in patients' own homes. I2a is a commercially-developed competing product, also targeted at the home market. It is manufactured by a company based in mainland Europe and available from a number of suppliers in the UK and elsewhere.

The main requirements for I2 and I2a are:

- portability so that community nurses can easily transport them to patients' homes

- low intrusiveness so that patients are happy to accommodate them in their homes

- competitive price

- effective at fulfilling the care purpose for which they are intended

- sufficiently robust to withstand everyday use and transportation

These requirements mean that the drip stands designed for use in hospital wards are not particularly suitable for use in the community, especially where their weight and size are concerned. Equipment designed for hospital use is often over-engineered and thus heavier in weight and more costly to manufacture than is necessary for domestic use.

The amount of care delivered in domestic homes and care homes is expanding rapidly and becoming more sophisticated so there is an increasing market for products such as I2 and I2a. There is a problem, however, in that many cases where products such as I2 and I2a would be very useful, improvised domestic equipment is often regarded as adequate. In some quarters there is no perceived need to invest in the healthcare technology even though the cost is relatively modest and the technology

offers real benefits in terms of eliminating potential hazards. Community nurses feel this attitude represents a less than professional approach.

6.1 Data collection

Data for this pair of cases was collected by interviewing NHS staff who were: supporting or delivering care in the community; had worked on the development of the technology; or had direct involvement in purchasing. Interviews were also conducted with people involved in the manufacture of I2. Some of the interviews were conducted over the telephone and the remainder were face-to-face.

6.2 Development of I2

I2 was developed during the period when the NHS was becoming much more proactive in exploiting IP developed by its staff. Initiatives set by national policy were being complemented by local initiatives, particularly in certain regions of the country such as the one where I2 was developed. The local trust had been proactive in setting up an innovation unit dedicated to the exploitation of IP created within the trust. This unit played a significant part in supporting the commercialisation of I2 and a range of other innovations. I2 is an early entry into the community practice area, but the trust hopes it may be the start of greater involvement in this area if I2 continues to be successful.

At present, the trust's approach to innovation is reactive rather than proactive. Staff are encouraged to bring ideas to the attention of the innovation unit and are rewarded with a small share of any royalties. The composition of the portfolio of innovations sponsored by the trust is thus essentially determined by the ideas presented to the trust and there is little overall coherence to the innovation strategy.

The unit has a policy of working with local SMEs to cover the detailed design, manufacturing and sales and marketing aspects of the innovation process. The reason for this is that although the trust is keen to see a return from its innovation activities, it does not wish to be directly involved in manufacture, sales, or support. In particular, it regards the risks involved in product liability to be incompatible with the mission of the trust. It is also the case that trust staff working in the innovation unit perceive their skills to be heavily oriented to development and design rather than marketing and sales. In accordance with usual practise, the SME for this particular project was chosen by the type of selection process that is sometimes referred to as a 'beauty contest'.

Approximately two years elapsed between the initial presentation of the care team's ideas to the NHS development unit and I2 becoming available commercially and marketed to the NHS. During this time all the parties worked together to enhance product design, establish intellectual property

rights, gain regulatory approvals and to make sure appropriate arrangements were in place for manufacturing and marketing. Although it was not appropriate to patent the technology, design right applies, and the registered design is owned by the trust. Clearly, this gives very limited protection, but the relationship with the manufacturer is based more on mutual trust than rights. Other commercial manufacturers already produce very similar items, and could quite easily incorporate the improvements this exhibits into their own products.

After I2 had been on sale for six months a decision was made to replace some steel components with ones made from rigid thermoset plastics. This was an important change which increased fitness for purpose and lowered costs. The design is now essentially stable and performing well, although some of the providers of care who were interviewed said they would like to have a similar but heavier duty version available to cater for a wider range of applications. Its manufacturer's web site currently lists 40 NHS customers for the product. These are a mix of hospitals, PCTs, clinics and health centres.

6.3 Alternatives to I2

At the time I2 was developed, the alternatives available were heavier and more expensive but now there are a number of very similar commercial products. As a direct competitor, this case identified I2a. Interestingly, I2a is the 'hit' that appears when searching for 'portable drip stand' in *NHS Cat from NHS Supply Chain* (https://my.supplychain.nhs.uk/catalogue). Like I2, I2a is aimed at the homecare and emergency market and supplied with a carry bag. I2a costs a little over £100, which is roughly £30 less than I2. Companies selling I2a emphasise its ergonomic design, the speed with which it can be set up, its low weight and portability, and the small space it occupies when not in use.

6.4 Adoption compared

Adopters of I2 reported satisfaction with it and felt that it fitted its purpose slightly better than the other wholly commercial equivalents because it was marginally ahead on detailed design. Particular features mentioned in relation to this were ease of use and ease of cleaning, the latter being particularly important where infection control is concerned. They said they would not replace similar commercial items already in use but would purchase I2 if additional items were needed.

The manufacturer of I2 reports some difficulty in NHS adoption due to it being a relatively ordinary product, for which most trusts have established suppliers, including the suppliers of I2a. It is also a disadvantage for I2's manufacturer that I2a's manufacturer offers a very wide range of equipment of this type and the less expensive items like I2a are often bundled in with more expensive equipment. In interviews, front-line staff

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and the manufacturer of I2 both suggested that staff involved in authorising purchasing tend to favour existing suppliers rather than exploring new possibilities.

Because this category of product is relatively inexpensive, NHS purchasers often do not spend a lot of time on its selection. Adopters of both technologies observed that in past years I2 and I2a would be the sort of products they might become aware of at conferences, either from manufacturers presentations, or recommendation from colleagues, but with tighter budgets there are fewer opportunities to attend this type of event. Therefore, this awareness/marketing opportunity is no longer available. 'Searching the web' was the approach mentioned to identify products of this type and compare them with similar ones. As noted above, searching within the *NHS Cat from NHS Supply Chain* only reveals I2a. Users said that they did not regard endorsement by other NHS units as very significant, but all users of I2 also said they were aware that it was developed in the NHS.

6.5 Discussion

The I2 case demonstrates how development activities by staff within the NHS can lead to good design as a consequence of the opportunity this brings to engage in a collaborative design process. It also illustrates that staff within the community nursing sector are very adept at identifying particular needs in this rapidly expanding sector where many gaps remain in terms of the technology available to meet sector-specific needs. This is particularly true for very basic items where community nurses in the field are still having to improve suboptimal solutions from domestic or general purpose equipment even though simple, well designed, equipment could improve patient experience and ease the work of community nurses. This would suggest that the provision of support for turning ideas into products through collaboration between NHS staff and the healthcare technology industry can have potential benefits for the NHS.

However, it does not follow that the NHS necessarily needs to be involved beyond the identification of need and guidance on what properties an effective solution needs to possess. As I2a shows, commercial developers are very happy to make such solutions available providing they believe there will be sufficient demand to justify their investment. It is essential for the NHS to evaluate the overall costs and benefits of involvement in projects of this type. This would require data to be gathered that is not readily available at present, especially where the costs of supporting development are concerned. Another linked issue is the choice of manufacturer. 'Local' was an important factor in the I2 decision but the choice of partner has meant that I2 is not part of a coherent range of products. Information gathered for this case has shown that this lack of coherence is damaging in terms of sales in a situation where high sales volumes are needed to generate a profit because the unit price is relatively low. The extent of this problem is hidden to a degree because I2's

manufacturer is supported by development grant aid as well as commercial activity but complications such as this do need to be considered when evaluating costs and benefits to the NHS of 'NHS-developed' versus 'commercial based on need identified by staff within the NHS'. If such an evaluation shows that the former does not enjoy a reasonably strong advantage over the latter then other mechanisms such as those based on the concept of 'lead user' or 'preferred customer' should be brought to the fore. Indeed, this case, looking at very simple products, highlights the extent to which the existing initiatives in the NHS to improve procurement are probably well-founded. The role of effective procurement processes seems an important factor in gaining adoption. Initiatives such as pre-commercial procurement activities, in which unmet clinical needs are identified and then the NHS actively seeks commercial partners that can develop appropriate solutions seem vital to an evolving NHS.

Another question raised by this pair of cases is how best to organise purchasing. Adoption decisions of commodity items are relatively unstructured and are often based on minimal investigation of options with little effort put into the decision process. This is in part due to the relatively low cost of the technology when considered on a per item basis, but also because the differences between candidate products are relatively small. It is also exacerbated by the fact that purchasing of the technologies is frequently done on an *ad hoc* basis, for example when single items are needed to replacing broken one. It is also clear that staff have significant autonomy in the decision-making process and so have the authority to select technologies that they consider the best. However, lack of time can mean that they take the route of least resistance and make decisions based on satisficing rather than continuing to search and negotiate with colleagues until the optimal solution is found.

The implications of understanding how adoption decisions for low-cost commodity items are made are potentially significant. The extent to which purchasers have a full knowledge of the range of technologies is likely to be limited, especially as staff might have little opportunity and/or motivation to carry out systematic searches. As a consequence, for some classes of technologies, especially commodity technologies, the most effective way of promoting adoption might be the centralised provision of approved products. This would allow them to be purchased based on systematic selection criteria. It would also allow NHS staff to be made aware of new technologies that meet the changing requirements of the NHS. It seems likely that for most NHS staff this would remove a significant burden from the decision-making process, while at the same time improving purchasing decision quality. Of course the implication of shifting procurement decisions to the centre is that an appropriate and systematic methodology is needed for assessing the commodity technologies.

The cases also raise one more final point. Although this product is related to the need of the community nursing sector, there may well be similar

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needs in other specialist sectors. The community sector is currently important because of its current rapid expansion, but is unlikely to be unique in having specialist needs which are best identified from the knowledge of front-line staff.

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7 M1: a technology for informing diagnosis

M1 and M1a are diagnostic technologies used to inform clinical decision-making. Efficient use of novel diagnostic technologies has potential to improve clinical decision-making, in turn improving care and potentially reducing costs, and so these are examples of an important set of technologies.

The pair of technologies do not address the same clinical need but they have several important characteristics in common that make them capable of being regarded as a theoretically important pair. They both potentially address a prevention agenda but one does this by screening for a specific medical problem whereas the other does it through improved decision-making about choice of care pathways. Both technologies have the potential to reduce the level of variation in how well diagnosis is carried out and both allow testing to be carried out in a less specialised setting, when compared to the existing diagnostic tests they replace or augment. They also reduce the need for specialist staff to be involved in clinical decision-making. Each technology can also be used away from specialist centres in, for example, satellite or community-based clinics and GP surgeries. Finally, both technologies have potential for delivering a reduction in cost to the NHS through the replacement of more expensive diagnostic procedures and the avoidance of unnecessary procedures.

7.1 Data Collection

Data for this pair of cases was collected from a variety of sources. Face to face and telephone interviews were conducted with clinicians, technologists and managers in a number of trusts. For the M1 case interviewees were based in five acute trusts, one of which was the trust where it was developed. All of these trusts had established clinical departments and had adopted M1 to some extent. For the M1a case interviewees were based in a GP practice or an acute trust. A smaller number of interviews were conducted with suppliers and other stakeholders. Further information was gathered from published sources including refereed journal articles, government-backed reports and other items of grey literature such as newspaper and magazine articles and sales material.

7.2 M1 Case: Non-invasive urological testing

M1 was developed by a team based in the Urology Department of a major NHS teaching hospital. Urology is an area where management of long term conditions is an important characteristic of the discipline. This management might include surgical or other types of interventions but it often consists almost entirely of 'watchful waiting'. Specific care guidelines have been

developed by bodies such as NICE but there is still a significant variation in practice between centres. An important aspect of these guidelines was the use of the then new diagnostic test for measuring and assessing urological symptoms. This 'gold standard' assessment was established during the 1990s and is an invasive test, requiring specialist staff and equipment. Since then several other non-invasive tests that were capable of being carried out by fewer or less specialised staff have been developed but these are not as comprehensive as the invasive test, as they measure a narrower range of indicators. Their advantages were that they could measure some indicators equally well and with less discomfort to the patient. Within the urology community there has been wide variation in the amount of attention paid by Urologists to the emerging, non-invasive tests despite their potential advantages over the 'gold standard' test.

M1 is one of these non-invasive tests and despite substantial clinical trialling, marketing efforts from the supplier, support from the NHS-based development team and national initiatives across the NHS, adoption has been slow. This case will look at reasons for this slow adoption.

7.2.1 The Technology

M1 combines hardware used for taking measurements and software that allows an algorithm to be used to generate information to guide clinical decisions. The equipment has been designed for use in clinics and is either housed on a trolley or fixed to a wall.

Though M1 measures a narrower range of indicators than the corresponding invasive test, M1's algorithm has been shown to give reliable guidance to the clinician in deciding whether to operate, carry out further invasive tests or do nothing. It is its reliability as a predictor of the success of surgical intervention in alleviating symptoms that potentially makes it an important additional diagnostic for Urologists to use. The advantages for the patient are that it involves much less discomfort and has fewer risks than the invasive test procedure. The relative simplicity of M1 means it can in principle be used in clinics remote from a main hospital, as unlike the invasive test a dedicated clinic suite is unnecessary. The equipment capital cost is several thousand pounds but consumable costs are a few pounds per patient.

The technology's supplier emphasises several benefits in its marketing material. Primarily these benefits are related to reducing the number of patients undergoing invasive tests or receiving inappropriate treatment. These benefits are built into an economic case showing potential reductions in NHS costs based on the need for fewer staff, fewer surgical interventions and fewer complications associated with the invasive test procedure. The supplier also highlights improved quality through improved patient experience and increased choice of diagnostic test. M1 is not marketed as a complete replacement for the more sophisticated invasive test but its

diagnostic accuracy in predicting outcomes to surgery is used to emphasise its use as complementary testing device.

7.2.2 Origin of M1

The development of M1 was based on the work of technologists in the medical physics department of a large teaching hospital. The medical physics staff had significant experience in designing clinical measurement devices and M1 was one instance of a range of innovations that the team had produced. An industrial partner was involved early on in the project. The team started the development in response to two triggers. First, an academic paper published in the mid-1990s that suggested a novel approach to non-invasive testing. The second trigger was a national audit report produced by a team that included academic medical staff at the hospital and university. The audit findings highlighted that there was significant variation in methods used for treating patients with a specific urological condition and that the outcomes of treatment were very variable. Previous trials had established a gold-standard surgical treatment, however, the audit highlighted that the outcomes for a significant minority of patients undergoing this procedure were poor (20 to 30 per cent failed to gain substantial symptomatic benefit). The findings from the audit suggested the need for clinical decisions to draw on additional information, including that generated by invasive urodynamic testing, to support diagnosis.

During the 1990s suggestions had been made by the wider urology community in the UK and abroad for improvements to diagnostic technologies. The hospital is a leading centre of urology research and staff at the hospital had been following these developments, testing them and developing their own methods. Through collaboration between clinical and technical staff in the hospital and local university the group were already active in developing novel approaches to treatment and diagnosis. This created a very positive environment for innovation of M1.

Evaluation of M1 has been rigorous. Trials of the technology started on volunteers and then on patients. Using funding from charities, a clinical trial was carried out that assessed the reliability, acceptability and validity of the technology during clinical use over a five year period. A final study based in the hospital was a blind clinical trial. This showed that for certain groups of patients M1 was reliable in predicting the outcome of a surgical intervention. The clinical lead on the project believed that the assessments carried out in the hospital were much more rigorous than those carried out on many other diagnostic devices. Prompted by feedback from a national agency, a further multi-centre trial at six UK hospitals was carried to ensure that the technology's benefits could be generalised to other sites.

A large number of trials on various aspects of the science and technology underpinning M1 have now been completed and published in several dozen

peer-reviewed papers. Unfortunately, the extent to which these studies are accepted by the wider urology community as definitive proof of effectiveness in clinical and economic terms is unclear.

Development of the technology has extended over several years and the technology's patent is nearing its expiry date. This means the technology supplier risks being unable to make substantial profits from the technology.

7.2.3 M1 Adoption

Adoption of M1 has been in limited in the UK NHS, with just a small number of trusts adopting it into routine practice but adoption in the US, where several hundred devices have been sold, and some other countries has been more successful. A possible reason for the greater adoption in the US is the way funding works. The US healthcare system's funding arrangement acts as an incentive for clinicians to provide additional diagnostic tests as they are often remunerated on the basis of tests performed.

The overriding driver affecting adoption in the UK has been involvement in either the development or the trialling of M1. Perhaps taking part in a clinical trial of M1 has served to promote adoption because it has meant the sites involved have had access to loan equipment at low cost, have received significant staff training and support, and been able to trial the technology with relatively low risk.

Several factors have been suggested to account for the limited take up of M1. The technology supplier believes that barriers to adoption are rooted in aspects of the professional context of urology. The professional body associated with the diagnostic test provided support during evaluation of M1 and played a part in communicating findings in its journals and seminars. Unfortunately, the technology supplier was unable to use this support as part of its marketing strategy because the professional body, out of a concern to remain impartial, was unwilling to be seen to recommend specific commercial products.

A further challenge in marketing the technology to clinicians was how to couch the message to clinical Consultants that their current practice often leads to poor outcomes for patients. Though the general culture amongst clinicians is to strive to improve professional practice, building a business case for the adoption of M1 requires an acknowledgement of an existing weakness in current practice at a personal and organisational level. This acknowledgement may be seen simply as part of a professional approach to reflective practice and improvement but in a more politically-charged environment where scarce resources are competed for aggressively, such an admission may represent a significant yet subtle cognitive barrier to adoption.

A small number of trusts have adopted M1, though the extent to which M1 is used in routine practice varies. This variation reflects local differences in

the way services are configured. Adoption essentially adds an extra test into an existing pathway. This might be problematic where there is pressure on reducing time within pathways, perhaps to avoid breaching the 18 week limit. Where clinicians have little faith in the benefits of the test there is little motivation to manage the re-design of an existing pathway.

Four adoption sites with varying degrees of adoption and implementation into routine practice will now be examined separately. These can be summarised as:

M1-SiteA   Full implementation within the developer trust

M1-SiteB   Successful adoption into a trial site

M1-SiteC   Successful adoption into a trial site but later stalled

M1SiteD   Site involved in a trial but subsequently stalled

M1-SiteA: Incorporation of M1 into routine practice is well advanced at the trust where it was developed. The device is now used to provide a non-invasive urodynamic test as an integral part of a care pathway and has replaced an existing, though less sophisticated non-invasive test. The revised pathway has been implemented through the established hub and spoke relationship between the teaching hospital and the other trust hospitals. Assessment clinics are held at the teaching hospital and at several satellite hospitals. Each clinic is equipped with M1 and staffed by nurse practitioners who have been trained in its use and are able to interpret the data it gathers. The research nurse who had been involved in M1's development played a large part in training the team of clinic nurses so that they are able to provide a full service to patients.

The introduction of M1 and the consequences of the new configuration of clinics in the trust has been closely monitored and evaluated. Several benefits have been observed. Patients from a wide geographical area are assessed consistently across all of the clinics and the results made available to the Consultant Urologists. The number of surgical interventions carried out in the trust has been reduced and where they are carried out the proportion of positive outcomes has increased. In addition, fewer invasive urodynamic tests are carried out which reduces costs and the amount of discomfort for patients.

M1-SiteB: Site B is a medium-sized district hospital that is part of a large NHS trust made up of a number of geographically dispersed hospitals. The hospital's Urology Department has had a long-term (more than twenty years) interest in non-invasive methods of assessing patients, in part linked with the interests of the Consultant Urologist in the trust. Full adoption of M1 has followed earlier involvement in studies looking at the acceptability of the technology to patients. At the end of the original trial of M1, the hospital was given the opportunity to purchase the equipment at a significant discount. The Urology Department was able to use charitable funding to take advantage of this offer so the trust did not have to make

any significant financial contribution and no business plan was needed. It is now used routinely alongside invasive and other non-invasive tests and is operated by staff within the diagnostics section of the hospital's Medical Physics Department.

However, after the Consultant Urologist retired, the remaining Consultants working in the trust, and those who subsequently joined the department, each developed their own view of M1 and how it should be used. A technologist from the Medical Physics Department highlighted that this has affected the extent to which Consultants chose to refer patients to be tested using M1. As a result even within a single trust contrasting views of M1 existed. First a positive view that M1 was useful in predicting effectiveness of subsequent interventions. Second, a more negative view that it represented an unsophisticated test and was a poor substitute for an invasive test. A final view was that the detail of urodynamics tests was of little relevance to Urologists and that it was better to devolve the decision about choice of test to technologists. It was common for referrals from these Consultants to be much less specific in their requests for tests, possibly suggesting a lack of awareness in the relative value of various tests.

No evaluation of the implementation process has been completed though an audit of patient data is planned that will review the care pathways used and the outcomes achieved. This will be undertaken once sufficient patient data is available.

M1-SiteC: Site C is a large teaching hospital. It has adopted M1 into routine practice but over time usage has dropped to only occasional use.

Adoption of M1 was led by a Senior Technologist in the clinical testing department. She had already been made aware of several early publications about M1 but it was a specific urgent request from a Consultant Urologist that led to her contacting M1's supplier. The Consultant was treating a patient who was reluctant to undergo an invasive test so made a request to the Technologist to see whether any more acceptable non-invasive tests were available. The Technologist contacted M1's supplier in the hope of borrowing a machine on a trial basis. By chance, this request coincided with the supplier's efforts to recruit sites for a multi-site trial so the hospital joined the trial. The Technologist and the clinical testing department in general, all saw benefits from joining the trial, beyond just gaining access to the equipment. The trial gave the department the opportunity to assess whether the technology worked in its own service. (The Technologist said he was aware that even if devices were underpinned by good science they did not always work well in a clinical environment.) A broader reason for welcoming the trial was that it provided an opportunity to become engaged in some research-based work again and retain skills they were in danger of losing. The trust was able to buy M1 at considerable discount at the end of the study.

The Technologist noted that during the trial, Urologists had started to refer patients specifically for the M1 test, thus showing that they appreciated the additional information that it provided. But since the trial ended, the number of requests for tests has declined to one or two a week. Though one of the original team of Urologists still requests tests regularly, Urologists who have joined the hospital more recently seldom requested tests using M1. The current prevailing attitude amongst the hospital's Urologists is that the invasive test is still the gold standard and therefore they favour it. They do not accept that there is an excellent case for adding M1 into the current pathway so progress towards making greater use of M1 has stalled.

An additional explanation for lack of adoption centres on the 'ownership' of the technology. The Clinical Testing Department have developed the capability and confidence to use M1 in routine clinics but complete implementation into routine practice depends on the Urologists committing to using the M1 test. Thus, the Urology Department has ownership of the decision to use the test and no matter how valuable the Clinical Testing Department regard M1 to be, the Urologists see it as low priority.

M1SiteD: The large teaching hospital at site D provides an example of less successful adoption. This hospital too had been involved in some early trials of M1 but though it had retained the technology when this involvement ended it was no longer used. Over a year later, a Medical Physicist became interested in M1 and decided to use it as a basis for a post-graduate project. The project was supervised jointly by a Senior Technologist and a Consultant at the hospital. This project was, in effect, an audit, conducted over three months, comparing use of M1 with the invasive test. During the process of setting up the project, the technology supplier became involved in it, and subsequently the project became part of a national initiative to support use of the technology. As a result, the hospital received extra funding for the project. However, although M1 was used routinely throughout the 3 months in which the audit data was collected, its use on a routine basis stopped when the study ended. This was despite the trial providing positive evidence to support the validity and use of M1, however, staff shortages meant that it was not possible to use the M1 test.

7.2.4 Adoption issues

A number of issues relating to adoption and especially the slow adoption are raised in this case. Figure 18 summarises some of these issues.
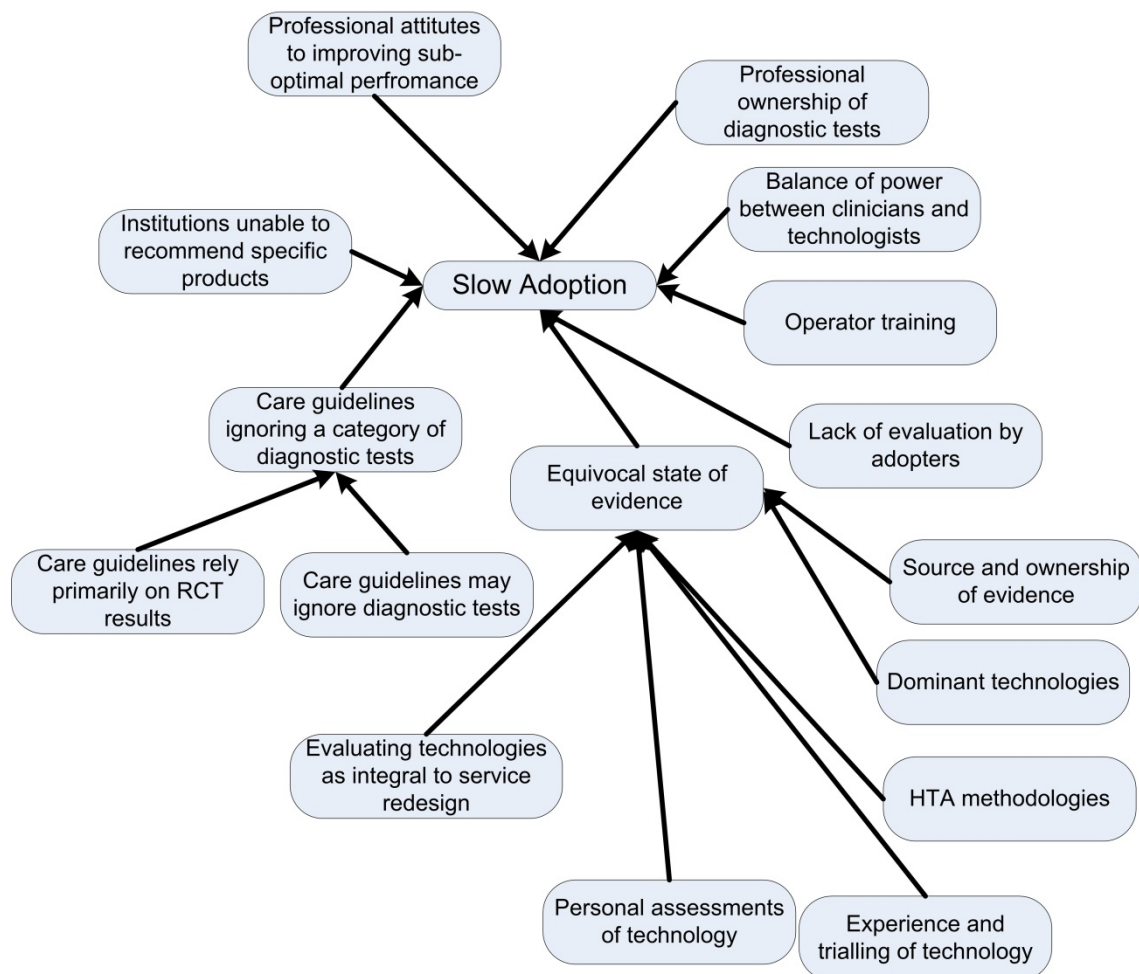
Figure 18.   **Factors affecting the slow adoption of M1**

Evidence

A distinctive feature of M1 is the existence of a significant body of evidence to support its adoption into the NHS. The subsequent slow adoption of M1 has been disappointing and a prominent factor in this has been the extent to which the evidence has been accepted by potential adopters and regulatory organisations. This raises the question of whose and what types of evidence are taken on board when technology adoption decision are made.

A perceived weakness in the existing evidence is that the majority of the studies were conducted within the trust where the development team were based. This has led to criticism that the trials lack independence and fail to demonstrate the extent to which results can be generalised to other trusts. The extent to which this has affected adoption is difficult to assess but has affected the developers of M1s' ability to act as advocates for its adoption and providers of information and support to colleagues in other parts of the NHS. A clinician member of the development team had initially provided training at sites where trials were to take place but over time he had

consciously reduced the amount of support supplied out of a concern to appear impartial. The clinician felt by supporting the adoption of M1 he was undermining his own impartiality when planning and carrying out clinical trials. As a result of this perceived conflict of interest, the clinician believed their ability to influence clinical attitudes had been reduced. The team at the developing trust now see its main role to be the provision of objective evidence through formal publications.

It was frustrating to the technology developers and supplier that the type and quantity of evidence produced to underpin M1 was incompatible with the methodologies used by various HTA agencies. The mode of evaluation used by NICE and other HTA oriented agencies is based predominantly on multi-centre randomised clinical trials. One member of the development team felt that this created confusion about what constituted 'gold-standard' evidence. In the case of M1, building a portfolio of supporting evidence was problematic as conducting a trial that assessed scientific, clinical, organisational and economic factors all together was challenging. Instead, the team had built up evidence by carrying out several individual studies to address factors separately.

The difficulty in developing evidence for use of M1 is rooted in the extent to which its success is dependent upon effective incorporation into care pathways. This was highlighted in a report produced by a technology assessment agency that flagged the significant potential of the technology, yet raised concerns that additional evidence was needed. Its key criticism was that the existing evidence reflected the development and improvements to the technology but gave little validation of the method in a clinical setting. The agency did, however, acknowledge the difficulty in carrying out an economic analysis, especially as care costs varied greatly across the UK. Even across a small number of sites, variation in clinical pathways and practice would make it difficult to separate the impact of M1 from variations in clinical practice. The only way to resolve this would be to change pathways before starting a clinical trial; this was a major hurdle as in order to carry out a coherent multi-site RCT it would be necessary first to affect significant changes in clinical practice across several trusts. This essentially created a 'Catch 22' situation in which the process changes necessary to ensure a reliable RCT, cannot be made without the results of the RCT first being available to prove the change worthwhile.

Marketing

One of the developers described the task of marketing M1 as challenging. At the core of this statement lies acknowledgement that adoption of M1 requires Urologists to adjust their own practices, to accept the use of a new diagnostic test, and perhaps even to accept that their existing practices are sub-optimal. A consequence of this is that the technology supplier needs sales representatives who are capable of addressing detailed queries from clinicians and who possess the ability to use the published evaluation data

to address concerns. Urologists are the main decision-makers when adopting and assimilating M1 so sales representatives needs to be comfortable when engaging directly with senior clinicians.

Ownership of the technology

The ownership of M1 by a specific group of clinicians or technologists varied between sites. Sometimes this ownership was defined by the practical location of M1 within the geographical or organisational structure of the trust. Generally, ownership of the operation of M1 lay sometimes with nurses and sometimes with technologists. But inevitably at all sites the actual operation of the M1 test was controlled by a specific professional discipline. In contrast, the ownership of the decision to use the M1 test lay predominantly with Urologists. Though Urologists rarely administered the M1 test, their assumptions about M1 would affect the extent to which it was accepted into practice.

A possible reason for variation in acceptance may have been differences in the level of interest and knowledge of urodynamic testing held by Consultants. A commonly expressed view of both clinicians and Technologists who had used M1 was that awareness of M1 amongst Urologists generally was low. Not surprisingly, this lack of awareness was seen as an obstacle to convincing clinicians that it provides a useful diagnostic. For some Consultants the assessment of patients was based on a single urological measurement combined with an assessment of symptoms. This group of Consultants believed the provision of additional urodynamic information was unnecessary. In contrast, some Consultants had more interest in the urodynamic test methods and welcomed additional information. This group were more motivated to adopt non-invasive measurements in order to gain extra information to guide their clinical decisions. Finally, a remaining group of Consultants were much less concerned to engage with novel urodynamic test methods and or the details of testing. This group were content to devolve the decision relating to choice of test to technologists and their expectation was that the chosen test would provide an unequivocal and definitive test result that could be used to guide their subsequent clinical decision.

This suggests that that the adoption of M1 was affected by the levels of awareness of M1 amongst Urologists. As Urologists generally owned the decision to use M1 then poor understanding of M1 would lead to limited use of M1 in practice. Furthermore, technologists and nurse often had a significant technical understanding of M1, however, their ownership of the technology extend only to its use and had less influence on the decision to use M1 in routine practice.

7.3 M1a

M1a is a diagnostic technology used to inform the clinical decision-making of GPs. It combines imaging technology, which provides specific images of skin lesions that can show patterns indicative of melanoma, with a scoring algorithm developed specifically for primary care. As a consequence of this assessment a GP might provide reassurance that the lesion is benign, suggest a period of 'watchful waiting', or to refer the patient to a specialist Dermatologist. M1a does not automate clinical decision-making but does provide the GP with information on which to base his or her decision. Its use can complement and support the use of best practice guidelines and helps to ensure the most appropriate pathway is chosen for a patient. It has the potential to improve outcomes, reduce patient anxiety and reduce costs.

M1a addresses an area of dermatology that is challenging for GPs. Assessing skin lesions requires significant knowledge and experience and has traditionally been undertaken primarily by visual assessment with the naked eye or augmented with use of a checklist such as the seven-point checklist[200] as recommended in the NICE guidelines for referral for suspected cancer[201]. Magnification equipment or other imaging devices may also be used to help the GP's decision-making. Although there is a well-established set of guidelines on assessing melanoma, studies have suggested that even with additional training GPs can still be highly sensitive but less specific for the diagnosis of melanoma[202]. The consequences of missing a melanoma can be very serious for a patient but the effects of overly-cautious referrals to specialist Dermatologists are increased anxiety for patients and unnecessary referral costs to the NHS.

Development of M1a took place over several years. The core of the technology was invented by a post-graduate research student who subsequently gained funding and support to develop it further. A university spin-out company was then formed to commercialise the technology into a saleable product. Early prototypes were large and expensive, but by incorporating some emerging complementary technologies it was possible to develop versions of M1a that were less complex, more portable and less costly to manufacture. Although the spin-out company developed the technology as a skin cancer diagnostic it also produced variants for use in a number of non-medical markets so the core technologies used in M1a are also applied to a range of settings beyond the NHS including private clinics and the cosmetics industry.

The international academic literature contains a significant and growing body of knowledge on diagnosis and treatment of skin lesions, especially those that are forms of skin cancer. The development of the M1a is well documented in this academic literature. Over an extended period, studies have been done on various aspects of the technology underpinning M1a including: comparison of its underlying imaging technique to other existing

dermatological technologies and assessing the embedded algorithm's performance.

7.3.1 Experience of an early adopting GP practice

The adoption site where this research was conducted was a newly established GP Practice based on a new housing. The Practice GPs were keen to develop efficient and effective processes and, as one GP put it, "believed that the practice needed to be innovative and to …change what people knew as general practice". They aimed to develop an 'inverted pyramid structure' where the emphasis was on using nursing staff and healthcare assistants to provide routine services, thus freeing up time for GPs to focus on non-routine care. The practice was enthusiastic about the use of 'near-patient testing' and were actively searching for technologies that allowed checks to be carried out by nurse/healthcare assistants or even by patients themselves. They saw active involvement of the patient as an important factor in helping patients to self-manage their healthcare.

The decision to adopt M1a was championed in the Practice by a GP who had heard about it whilst working in a BUPA clinic. At that time there was very little published data that could support an evidence-based decision to adopt M1a. Consequently the decision to adopt M1a into the practice was made in a state of partial and equivocal knowledge about M1a's effectiveness in a GP setting. However, two triggers were important in the practice's adoption of M1a. The first was the case of a patient who presented very late with a malignant melanoma. None of the GPs had any specialist interest in dermatology and this case flagged up the need for the practice to review its diagnostic strategy in this area. A second trigger was that the newly-established practice had money available to spend on technology as part of its start-up funding. This made M1a affordable and so it was worthwhile for the Practice to seek advice from several sources, including the local hospital Consultant Dermatologist and a local GP with a specialist interest in dermatology, about its potential benefits. As a result, though aware that they would be a relatively early-adopter of M1a, a purchase decision was made.

For about six months M1a was used by the GP Practice in parallel with their standard approach to assessing patients concerned about skin lesions. During that time approximately fifty patients had been screened using the technology, five of which were referred to hospital. On the basis of their experiences it was decided to use the technology on a routine basis. In particular, they were pleased with M1a's ability to:

- provide improved imaging

- make objective comparisons between readings taken across several months

- the ease with which the results given could be communicated to patients, other GPs and specialists

When M1a was initially considered by the practice, three possible ways of implementing it into the practice were considered, based on whether it would be used:

- solely by the GPs

- by a nurse or healthcare assistant with referral to a GP when it was felt to be necessary

- by the patient who would then forward the results to the GP

The third option of allowing patients to use M1a was quickly discounted. However, the possibility that nursing staff would undertake the monitoring was taken more seriously in the practice. However, it became apparent that nursing staff were reticent to take on responsibility for referring patients. (This anxiety was heightened by the severe consequences of missing a diagnosis.) For this reason the practice decided that M1a would be used solely by GPs as an integral part of the consultation with their patients.

During a consultation the GP explains how M1a is used and discusses with the patient the interpretation of its results. The Practice finds patients react well to its use. Patients often seem to be relieved to see technology being used in the assessment. But more significant is that it forms a valuable focus of discussion during a consultation. Patients are able to understand what features of a skin lesion the GP is looking for and how the information from M1a informs a clinical decision. This has been found to be important in improving the level of patient participation in clinical decision-making– an important quality outcome.

The practice is active in adhering to the national care guidelines and M1a is regarded as a valuable tool to support diagnosis and guide the referral decision. They regard M1a as "adding science into a referral decision". The lead GP likened the technology to other diagnostic tests, such as the PSA test used for prostate cancer, highlighting that it does not provide definitive diagnosis on its own but adds objectivity to his decision, particularly when used over time.

There is, however, a medico-legal dimension to the use of M1a. Where it flags up a case for which the scoring criteria indicating the patient should be referred, a GP is in a position where he or she cannot legitimately override that information, whatever his or her own professional view based on observation. This may result in more false-positive cases being referred to the hospital.

As a result of implementation in the Practice believes M1a has contributed to the wider quality agenda of the practice in four ways:

- Increased patient involvement in clinical decision-making

- Supporting the implementation of best practice guidelines

- Providing increased objectivity and the ability to audit clinical decisions

- Increasing the number of clinicians whom patients can consult regarding skin lesion issues (not just the 'specialists'), thus increasing their access options

7.3.2 Consultant Dermatologist Perspective

The Consultant Dermatologist from the local hospital who had initially advised the early adopting Practice had a general interest in devices that could aid assessment and diagnosis of skin lesions. This interest included M1a, for which she had acted as an advisor during its earlier development. The Consultant had been positive about M1a and encouraged the Practice to adopt it.

In common with several other Dermatoloists she had used M1a in her own work. Despite the fact that it had been originally developed for use in General Practice, she had found it beneficial to use the images it produced to inform her own clinical decision-making. However, she did not use the output from the algorithm, believing that it was better to rely on her own judgement. She welcomed the use of additional technologies, but was cautious in relying on them in isolation, believing instead that inspection of lesions still required careful application of experience and judgement, a skill one of her colleagues likened to "…appreciating a good wine"; suggesting experience inspecting lesions gained over many years was still vital to a reliable diagnosis. She believed this to be why some Dermatologists had been slow or even reticent in adopting technologies such as M1a themselves.

Reflecting on the use of M1a the Consultant believed it provided valuable information in her own practice. However, based on her experience of the patients referred, she perceived the algorithm to be overly cautious and tended to over-refer patients. The Consultant observed that use of M1a, by GPs or herself, had not necessarily improved diagnostic certainty but could actual have reduced it because of the increased detail given. Images produced by M1a often showed more underlying detail than might be apparent using other imaging techniques. However, this extra information could be ambiguous, increasing uncertainty rather than narrowing the diagnosis. As a result, she believed use of M1a has tended to lead to more excisions.

It is apparent from this Dermatologists view of M1a that benefits from its adoption into General Practice was by no means clearly defined and it is likely that her view, if shared by other Dermatologists, would potentially impact on the wider adoption of M1a.

7.3.3 Clinical trial of M1a

Part of the M1a's development has involved a clinical trial to assess its use in GP practices. Funding for the trial was made available at a similar time to when M1a was being taken up by early adopting GP practices. However, several years passed between gaining funding and the trial getting under way. Unfortunately, at the time of writing the results of the trial were unpublished.

A dilemma for the team developing the clinical trial was in what sense the technology should be evaluated. One possibility was to compare use of the technology against common standards of practice in GP surgeries. However, it was understood that diagnostic practice was not consistent across all GP surgeries and that not all practices even applied best practice, as defined by national NICE guidelines. Instead, the clinical trial compared the use of the technology with best practice procedures against the use of best practice procedures alone. Hence, the trial was able to make conclusions about whether the technology improved on best practice alone.

During the clinical trial some interesting issues were raised that potentially provided insight into adoption behaviours. When setting up the trial surgeries were encouraged to include nursing staff as lead clinicians in the study. However, only two out of thirty surgeries included nurses as lead clinicians. GPs were generally very concerned about the reliability of their referrals due to the dangers of missing a positive case. For this reason they may have felt less inclined to include nursing staff in the diagnosis process. Overall, assessments of the participant's experiences of M1a during the clinical trial showed that it was regarded very well by both lead clinicians and patients. To a certain extent this may indicate that technology reassures both clinician and patient by respectively providing a framework for applying best practice and an impression that the examination given to the patient is rigorous and 'scientific'. It is important to note that it may not necessarily be more accurate than the clinician assessing the lesion without the use of technology.

7.3.4 Adoption issues

This case provides an example of M1a's implementation by an early-adopting group of clinicians. Though now fully embedded into their normal practice its ultimate use differs from that initially envisaged by the lead GP in the practice. Furthermore, the adoption benefits are very different from those anticipated. Anecdotally, M1a has not led to a reduction in NHS costs through a reduction in referrals. Indeed both the GP practice and the hospital Consultant believed that the use of M1a had actually increased referral rates and the number of excisions carried out on patients; suggesting that the practice may not have achieved an improvement in the sensitivity and specificity of GP referrals. However, other benefits were

unanticipated, especially the improvement in quality of service provided by the GP practice.

Adoption of a technology may, to a greater or lesser extent, support use of best practice. The GP Practice in the case adopted M1a as part of a wider concern to improve its ability to identify malignant lesions at an early stage. Central to this strategy was the consistent application of best practice guidelines. M1a has many key features of best practice embedded within it, both in terms of the software algorithm but also through the interface that it presents to users. The case highlights the difficulty of making an assessment of the wider benefits of implementing a technology, for example by facilitating better decision-making, an interest in a specialism, or consistent application of best practice. Conventional health technology assessment methodologies are not able to assess technologies in his respect, especially where there may be a synergy between adopting a technology and ensuring the application of best practice; This is particularly relevant in areas where there are concerns over variation in practice (for example see more general concerns in variability of cancer referrals in *The NHS Atlas of Variation in Healthcare*[203 p.70]).

The case of M1a highlights the extent to which adoption of innovative technologies changes practice. M1a has made an important change to the nature of the GP-patient consultation and improved patient participation in, and understanding of, clinical decisions. However, the impact of this is very difficult to assess so balancing them against the cost of the technology is difficult. Linked to this change in practice were the medico-legal implications discussed above. At the heart of the issue of increasing precautionary behaviour is the fact that use of M1a does not necessarily result in an increase in certainty around diagnosis. It is quite possible that the extra data provided by M1a results in increased uncertainty rather than increased confidence.

Finally, the case highlights the significant issue of how implementation of innovative technologies should and/or does change job roles and responsibilities. The extent to which nursing staff and healthcare assistants are comfortable with using technologies that shift responsibility for clinical decision-making towards them, even when done so with significant support from more senior clinicians, can be a significant block to implementation within novel service designs.

7.4 Discussion

Both cases in this pair are examples of diagnostic devices that inform, rather than automate, clinical decision-making. Though they are used in different clinical areas, several common themes emerge from the pair of cases. As such, for these technologies the extent to which NHS origin impacts on adoption seems very small. None the less there are several important themes that can be developed from the cases.

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7.4.1 Adoption decisions

Within the evidence-based paradigm, adoption decisions should be based on established evidence that a technology is clinically and economically effective. Neither of these two cases had uncontested evidence on which to base adoption decision-making. Adoption decisions were made without full knowledge of the technologies' actual performances. Therefore, both cases highlight the extent to which adoption decision-making only partially follows the rational evidence-based paradigm. The pair of cases also demonstrates that supporting evidence for adoption of diagnostics can sometimes be heavily contested. In both cases the completion of large multi-centre trials took several years so potential adopters had to either wait for the trials to be completed, or go ahead without trial evidence. Even on completion, it could be claimed that the trial results were equivocal and could be contested, thus leaving the way open for adopters to believe they have made the correct decision when relying on their professional experiences to make judgements about effectiveness and risk when adopting innovative technologies.

7.4.2 Implementation

A striking feature of both cases is the extent to which the purpose of adoption of a technology was flexible and subject to change. The nature of diagnostic devices, as compared to many other classes of medical device, is such that multiple-purposes can be served by a specific diagnostic technology. For M1a, purposes served included: cost reduction, self-administered screening, triage, diagnosis and supporting shared clinical decision-making between clinician and patient. Similarly, the role of M1 varied between it being understood to be to provide a more rapid test, an additional test, a replacement test or as a means of monitoring patient outcomes. The range of purpose illustrated the extent to which users of diagnostic devices will shift their understanding of a technology and its espoused purpose over time. This suggests that while initiatives to promote adoption of new technologies may assume the technology will serve a fixed purpose, there is significant interpretive flexibility in how technologies can be implemented and adoption initiatives need to recognise that the local implementation will be subject to negotiation and change.

The extent to which interpretive flexibility impacts on sustained adoption into practice depends upon three factors. First, the flexibility may be caused by users discovering new purposes for a technology. In this type of situation the basis for an adoption initiative may have been inappropriate, yet users have discovered how benefits can be gained through their use of the technology. Second, the flexibility is a consequence of the sustained ambiguity of the technology's purpose. The extent to which M1 was viewed as either a replacement or an adjunct created ambiguity. Finally, the technology's purpose may be affected by inter-professional disagreements on the technology.

8 M3: a technology for monitoring during surgery

This pair of cases looks at two minimally invasive monitoring technologies, M3 and M3a, that are used to assess the cardiac output and haemodynamic status of patients. M3 and M3a are two of a range of cardiac output monitors that are available. The traditional alternative to all of these monitors is a much more invasive technology, the pulmonary artery catheter, that carries a risk of significant complications. This case is looking specifically at the adoption of M3 and M3a by anaesthetists for use during surgery. Their purpose is to guide the appropriate administration of fluid and drugs in order to prevent on the one hand, a reduction in the circulating blood volume, and on the other, fluid overload. The prime target patient audiences for both technologies are those undergoing major or high-risk surgery (such as cancer, transplantation, orthopaedics, colorectal, gynaecology and urology) and high-risk patients undergoing any surgery. Therefore, the purposes of using M3 and M3a and the types of patients for whom their use is indicated are exactly the same. However, there are a number of differences between them:

1. Origin - perceived as NHS-developed versus not perceived as NHS-developed

2. They do not use the same underlying methods to fulfil their function

3. The way data is gathered from the patient is different. M3 is only used on anaesthetised patients because it requires a probe to be inserted in the patient's oesophagus and it cannot be used if the surgeon uses diathermy. M3a requires an arterial line to be in place and can be tolerated by awake patients so can be used in a range of acute care settings.

4. The level of activity and amount of decision-making required of the user is not the same

8.1 Data collection

Data for this pair of cases was collected from a variety of sources. Face to face interviews were conducted with anaesthetists in a number of trusts and a smaller number of interviews conducted by telephone with anaesthetists, other clinicians and the manufacturers of the technologies. Half of the anaesthetists interviewed only used M3 but the other half had switched, in part or almost entirely, to M3a and so were able to comment on the adoption of both technologies. Interviews were also conducted with those trying to increase the level of adoption of these technologies. Further information was gathered by personal email communications with key

stakeholders including the original developer of M3. A large number of published sources were also studied. These included refereed journal articles, government-backed reports and other items of grey literature such as newspaper and magazine articles and sales material.

8.2 The development of M3

The origins of M3 can be traced back more than 40 years to research funded by the Medical Research Council and the Wellcome Trust and conducted at a London Medical School. The findings of this early research were extended over the following decade or so by other groups of anaesthetists and medical physics experts working in a number of countries. Independently of them, a then Medical Registrar in an NHS hospital had the idea for the technology that has become M3. He approached a commercial firm with highly relevant expertise and they worked together to produce the probe that lies at the heart of M3. Rather than being based on any existing technologies, this development exercise started from first principles. Importantly where this current research into the origins of technology is concerned, the development of M3 was able to benefit from the hospital setting in which it was being carried out because the hospital possessed CT scanning equipment which was new at that time. This equipment allowed anatomical measurements of the thoracic region to be obtained and used to inform the design process.

By undertaking a clinical study the developer was able to show that the probe was capable of collecting the data needed for accurate noninvasive monitoring and he was able to establish relationships between important variables and build a nomograph that would allow the data collected to be interpreted.

The findings of a randomized trial, carried out in a London teaching hospital, to evaluate the technology were published in 1995. This study looked at 60 patients undergoing cardiac surgery. The patients in the protocol group were monitored using the technology and given fluid replacement based upon the results and those in the control group were treated according to 'standard practice'. The study found that use of the technology delivered a number of benefits including:

- Reduced incidence of gut mucosal hypoperfusion

- Fewer complications after surgery

- Reduction in mean number of days spent in hospital

- Reduction in the mean number of days spent in intensive care

Two years later a report of a similar study looking at use of the technology during operations to repair fractured hips found similar benefits. However, a short time later an editorial in the British Medical Journal called for more studies to be undertaken. In total, the results of seven high quality

randomised trials (596 patients in total) that compare use of the technology with standard care have now been published. There have also been two systematic reviews and a number of other studies that investigated use of the technology and compared it with options other than 'standard care'. A number of informal evaluations have also been conducted by anaesthetists in their own hospitals.

8.3 The adoption process

Adoption of this technology only requires purchase of the necessary equipment and training in its use. (The amount of training needed has been described elsewhere as "brief" and insertion and removal of the probe has been described as "straightforward".) Its use during surgery only alters the work of the anaesthetist. No other members of staff are affected directly. Essentially, the anaesthetist deploys the probe when he or she feels it is appropriate to do so, adjusts the position of the probe to get the best reading, observes the results on a separate set of monitoring equipment, and uses his or her judgement to decide whether fluid or drugs should be administered in order to try to optimise blood flow. This requirement for skill in focussing the probe and judgement, and hence a substantial degree of tacit knowledge, are important points to note. Some of the other monitoring equipment used by anaesthetists gathers data automatically and uses it to generate very clear signals that require little or no interpretation on the part of the anaesthetist. M3 is different. The anaesthetist has to: decide when to gather a reading; undertake the actions necessary to obtain it; and then interpret the result. In the words of one interviewee:

You need to use it sensibly and not just believe whatever it says and ignore other evidence. However, regular use does lead to greater faith that it is giving accurate results. It is occasional use that is problematic because it is user-dependent. There are also some patients, albeit a small minority where it is difficult to obtain and/or maintain a reliable trace.

Adoption can occur on an individual anaesthetist basis. For example, in one site where interviews were conducted members of a team of four anaesthetists each used the technology to different degrees that range across the whole spectrum from 'every occasion where its use is indicated' to 'not at all'. These different patterns of adoption are the result of personal preference on the part of the four clinicians themselves and reflect their individual views on the usefulness of the technology and the consequences it had for patients. It is worth noting, however, that at most of the other sites investigated all anaesthetists or no anaesthetists are using the technology and some of them spoke of the efforts they had made to extend use across colleagues after becoming personally convinced of the benefits of adoption.

At 2011 prices the initial cost of the monitoring equipment is £11000 per monitor and the disposable probe costs are approximately £85 per patient but there is good evidence that the cost savings are in the region of £1100 per patient.

8.4 Slow growth of adoption

The adopters interviewed fell into three camps as far as their own initial awareness of the technology was concerned. Some were introduced to it quite some years ago during their own training or when studying for advanced qualifications, usually through contact with the developer and/or his collaborators/colleagues. (Three of this group were studying overseas at the time they became aware of it.) Others have a very long standing interest in cardiac output monitoring and became aware of the technology from the developers' or first wave adopters' research. At the other extreme, two interviewees had only been introduced to the technology much more recently by colleagues in their current hospital.

It is clear from many of the interviews conducted with anaesthetists that this technology has some extremely strong supporters. Those spoken to who remain current adopters use it as part of their standard practice for all cases involving major or high-risk surgery and for high-risk patients. In some cases, having started to use the technology they had participated in clinical trials of it, and almost all of those who had not been involved in formal trials had carried out or taken part in some other form of evaluation of the technology. Some of the current adopters interviewed had authored scholarly papers about the technology and a slightly larger number of them had spoken at professional gatherings, conferences, training events and the like. They were all extremely convinced of the benefits delivered by the technology and were entirely happy with their experiences of using it. Most of them also expressed disappointment or even dismay that its use is not a lot more widespread. When asked to suggest reasons for non-adoption the suggestions they put forward included:

- It requires anaesthetists to perform more activities during surgery and they might be reluctant to undertake these or believe that they divert attention from other more important matters.

- Perceived lack of user-friendliness, 'especially where probe focus is concerned'.

- It is only suitable for sedated patients and some anaesthetists are working in surgical areas where a lot of regional anaesthesia is used.

- The main concern of some anaesthetists is what happens to patients up to the point they leave the Recovery Unit but the main benefits to patients from using this technology are only seen subsequent to that.

- Accounting processes mean that the cost of using the technology is incurred in a different cost centre from the one where cost savings are accrued.

- Historically, outcome data has not been collected and reported on a routine basis and even where it has, its accuracy has been questioned. A consequence of this is lack of appreciation of the size of the opportunity adoption offers.

- Reluctance to change on the part of some anaesthetists.

8.5 Efforts to increase level of adoption

Although the technology has been in use for two decades it is only recently that the level of adoption has started to become significant. This big increase is a largely a consequence of substantial efforts on the part of organisations linked to the NHS. These efforts began following a technology assessment with positive results published in the US in early 2007. In the UK, a report by the Improving Surgical Outcomes Group appeared a short time later. It looked at three key areas for improving surgical outcomes, one of which involved use of this technology. Very positive results from two hospitals were featured in the material used by the Department of Health to alert all NHS trusts and strategic health authority Chief Executives to the report's contents.

The US technology assessment also formed the main basis for an evidence review conducted by an executive agency of the Department of Health. This appeared in 2008. This review found that for patients undergoing high risk surgery use of the technology alongside conventional clinical assessment was likely to reduce the number of complications experienced after surgery, decrease the death rate and reduce the amount of time spent in hospital. It concluded that the technology had 'significant potential'. At around the same time as this evidence review's findings were published, a project supported by the NHS Technology Adoption Centre (NTAC) began at three sites. This project was designed to generate information on procurement and implementation of M3 that could be used to develop a guide for other adopters. It is interesting to note that the existing baseline usage in eligible patients across the three sites was only 12 per cent at the start of this project but it had had risen to 63 per cent by the end. The NTAC guidance is now available and covers topics such as: a summary of the clinical evidence for using the technology; advice on how to draw up an implementation project plan; a summary of the benefits of the technology and the barriers to implementation; and factors that are critical to successful implementation. It also incorporates a roadmap for implementation. There is considerable overlap between the barriers to implementation identified by NTAC and those suggested by interviews during this research. NTAC found that the clinical barriers were: resistance to changes in practice; need for training; technical difficulties of operation;

not suitable for all forms of major surgery; additional monitoring equipment could be distracting; need to develop a business case. The NTAC study also identified barriers from a service/trust manager's perspective, all of which centred on financial aspects.

The most recent boost to adoption has been provided by NICE guidance recommending this particular technology. This appeared in 2011 and stated that the case for adopting the technology for use by anaesthetists during major or high-risk surgery, or when high-risk patients are undergoing any surgery is supported by the evidence and that the technology should be 'considered for use' on this set of patients. It also accepted that the cost saving per patient is about £1100. The report was, however, also careful to say that this recommendation was not suggesting that M3 should be used in preference to other technologies that offered similar benefits.

Another major initiative that is encouraging adoption is the Innovative Technology Adoption Procurement Programme (iTAPP). This was commissioned by the Department of Health's National Director of Efficiency and Improvement as part of the QIPP (Quality, Innovation, Productivity and Prevention) agenda and is seeking to bring about the adoption of technology that will allow the NHS to improve the quality of care it provides whilst reducing costs. Under this initiative a prioritised list of technologies was developed and each of the ten Strategic Health Authorities (SHAs) were asked to select two or three technologies from the list and provided with support from NTAC to implement their choices. M3 lies at the top of the list in terms of the financial benefits it offers (it was estimated that if all 10 SHAs had selected it there would be a net saving of £807 million) though it is only half way down the list in terms of the number of patients who would benefit from its introduction. The consequence of iTAPP is that implementation of M3 is now being rolled out by a number of the SHAs into hospitals that were not using it before or were only using it to a limited extent.

The efforts described above are specific to M3 but there have also been initiatives that encourage use of cardiac output monitoring for fluid management during surgery more generally rather than emphasising the adoption of one particular technology for achieving this. Important amongst these broader initiatives are the Enhanced Recovery After Surgery (ERAS) Programme and the Department of Health's Enhanced Recovery Partnership Programme that grew out of it and which began in 2009. The requirement to provide 'individual fluid therapy during surgery' is one of the components of enhanced recovery against which the Enhanced Recovery Partnership Programme monitors compliance. A set of guidelines agreed jointly by a number of professional guidelines and published in 2009 (British Consensus Guidelines on Intravenous Fluid Therapy for Adult Surgical Patients (GIFTASUP) also supported fluid therapy guided by monitoring during surgery.

Suggestions for additional ways of increasing the level of adoption that were made by interviewees included better targeting of the Commissioning for Quality and Innovation (CQUIN) payment framework to encourage innovations of this type and making use of the technology part of the minimum monitoring guidelines set for anaesthetists by bodies such as the American Society of Anaesthesiologists (ASA) and the Association of Anaesthetists (AAGBI). It was also suggested that levels of adoption are likely to grow even without further measures as recent changes to the validation process for anaesthetists are rolled out and as greater and greater attention is paid to patient outcomes data. There are also a number of other clinical studies underway in the UK and around the world that may produce results that win over doubters and reluctant adopters.

Efforts such as these to increase the level of adoption of M3 are ongoing and there is evidence that they are having some success but there is still a long way to go to reach the levels of adoption many hope to achieve. One interviewee suggested in March 2011 that for every 30 patients who could benefit from the technology only one was actually doing so at that time. To put this in context, it is estimated ten per cent of all surgical procedures (801,000 in England) can be classed as major or high-risk or are carried out on high-risk patients.

M3's manufacturer revealed that the company sold its single use probes to approximately 200 NHS hospitals in 2010. They thus sold to about two-thirds of the NHS hospitals that regularly carry out moderate or major surgery. However, only a proportion of these will be intended for use during surgery (the same technology is also used on non-conscious patients in intensive care and perioperatively). Furthermore, the number of probes sold to individual hospitals varied from five (the minimum number possible because they are sold in boxes of five) to 1400, thus indicating an extremely wide variation in level of use even after allowing for differences between hospitals in the amount of activity.

8.6 Technology M3a

As was said at the start of this pair of cases, a range of minimally invasive monitoring technologies are available for assessing the cardiac output and haemodynamic status of patients. These technologies vary greatly in terms of the amount and quality of evidence to support their use. During the research into M3, participants were asked which of the alternatives available is the closest equivalent to M3. There was very widespread agreement that the nearest is the technology that will be referred to here as M3a, hence its inclusion in this research.

8.7 The development of M3a

M3a is a much more recent technology than M3. It is a version, specifically for use in the operating theatre, of a monitoring technology that was first

marketed in the UK in 2001. This monitoring technology has been the subject of a number studies but the first randomised controlled trial of M3a has not yet reported its findings. This trial is a single-centre study that is looking at patients over the age of 65 being treated for acute primary hip fracture. It is comparing fluid administration informed by use of M3a with fluid administration provided just at the anaesthetist's discretion.

The cost elements are broadly similar to those of M3 and are made up of the initial cost of the monitor plus a cost per patient for a sensor and associated disposables.

Although M3a has not been classed as NHS-developed it does have very early links to the NHS in that its underlying technological basis was invented by a Research Fellow at a London teaching hospital in the early 1990s. Therefore, like many other commercially-developed technologies it has benefitted from NHS involvement in its development.

8.8 The adoption process

Many of the adoption characteristics of M3a are just the same as those for M3. For example, M3a can be adopted on an individual anaesthetist basis. However, two major differences emerged during interviews with anaesthetists and some other stakeholders. These are 'ease of use' and the perceived differences in quality of the information provided by the technology. The manufacturer had made a very conscious decision to make the technology as easy to use and as adoptable as possible. Their aim was to design a technology that 'would fit seamlessly into the existing infrastructure' and get as close as possible to 'plug and play'. 'Ease of use' was definitely a major influence on M3a users' decisions to adopt and those who had switched from M3 to M3a said they had done so because colleagues who had resisted M3 had been willing to use M3a because it was so much easier to use. It is certainly the case that the manufacturers of M3a emphasise this point in their sales literature. They set out the instructions for using the technology in four simple steps that start with attaching a cable and finish with 'begin monitoring'. They also list 'quick and easy to set up' as the first of the technology's 11 features though it should be noted that the company does offer clinical training workshops in the use of its products. These are offered in conjunction with the London teaching hospital that hosted a major trial of its monitoring technology. Also, one of the anaesthetists interviewed for this research who had experience of M3 and M3a and of introducing more junior colleagues to the technologies suggested that although the training is different for each technology the total amount of training needed is roughly the same.

Perceived differences in the quality of the monitoring information provided by the technology operates in the opposite direction. M3 has a large body of evidence, built up over a number of years, demonstrating its effectiveness and the benefits it delivers. M3a as a much newer technology

does not have this at present. Attitudes to this discrepancy in the amount of evidence vary. One interviewee who was an early adopter of M3 and continues to be a major user has tried M3a. He described the latter as "easier to use" but also commented that for it "the evidence base is not there". However, another interviewee pointed out that although it is the case that alternatives to M3 may not have the same weight of evidence behind them this does not necessarily mean that they perform less well. It might just be that the evidence has not been gathered or made available yet.

8.9 Efforts to increase level of adoption

Some of the efforts to increase the level of adoption of M3 also encompass the alternatives to M3, especially M3a which is felt to be a closer equivalent to M3 than some of the other options. These efforts are those referred to earlier that encourage use of cardiac output monitoring for fluid management during surgery more generally. Regardless of which technology they had currently chosen to use, many of the anaesthetists interviewed stressed the value of monitoring and were critical, sometimes highly critical, of those anaesthetists who had not adopted any of the technologies that are available. One commented: "Any method is better than none – it is measuring versus guessing."

It is the case, however, that M3a has not been the subject of any specific initiatives other than those taken by its manufacturers to increase the level of adoption. Unlike M3, M3a is not the subject of NICE guidance and despite the best efforts of the manufacturer and other supporters, M3a was not included in the NTAC supported project.

Adoption of M3a was also increasing at the time this research was conducted and was expected to benefit substantially if positive results emerged from the study that had yet to report. It was estimated that overall, the monitors produced by M3a's manufacturer have about 7 per cent of the worldwide market for this type of technology. This is perhaps a greater share than M3 but the proportion of M3a's sales accounted for by the overseas market is greater than those for M3 where the UK market is more dominant at present.

8.10 Discussion

Across all of the interviews conducted for this pair of cases two things have stood out very prominently. The first is the high level of passionate support adopters of M3 expressed for the technology. Without exception, all adopters, even those who had transferred most of their usage to M3a, were extremely convinced of the benefits it delivered for patients and the overall costs savings it delivered for trusts. They were also all very critical of those anaesthetists who had not adopted any of the less-invasive technologies for assessing the cardiac output and haemodynamic status of patients. This

latter point links to the second thing that stood out very prominently. Most anaesthetists who had stayed with M3 felt everyone should use M3, whilst the remainder, mainly but not entirely those who had adopted M3a, believed it was the use of less invasive monitoring that was essential. They considered the specific technology used to carry out the monitoring was much less important providing the option chosen worked.

There is a sense that because a competing set of technologies have been evolving over a long time they have generated a complex set of evidence that allows those who are not keen to adopt to construct arguments against adoption. For example, the older studies of M3 were conducted more than a decade ago which leaves the way open to suggest that other changes that happened in the intervening years make the findings less valid today.

Another issue is the extent to which efforts to convince colleagues to adopt have been successful. Some adopters of M3 have been so convinced of its benefits that they have, persisting over a lengthy period of time, put considerable effort into persuading colleagues and have, in the end, been successful. Others have had less success. In other trusts, strong supporters of M3 have realised that reluctance to adopt M3 are too great to be overcome but have been able to achieve widespread use of M3a. But of course this peer pressure only works where there is already sustained, regular adoption of one or other of the technologies. What about situations where this is not the case?

There is wide agreement that the overlapping reasons of general reluctance to change, satisfaction with the status quo and unwillingness to take on new additional tasks combined with the existence of accounting processes mean that the cost of using the technology is incurred in a different cost centre from the one where cost savings are accrued are preventing adoption. It is perhaps time to look more closely at ways of motivating anaesthetists to adopt the technology. Expectancy theory might be useful here. This is concerned with the general processes that lead to choices between alternative courses of action, various degrees of effort expenditure and the persistence of this effort over time. It holds that an individual's decision to work hard on a particular task is a function of:

5. his or her estimate that expending effort to achieve a particular goal will be followed by certain outcomes, and

6. the desirability of those outcomes to the individual.

Thus people will expend effort if they think that something desirable will actually happen as a consequence of that effort. If an individual is indifferent towards a particular outcome or feels that nothing that can be done would allow a particular goal to be achieved, then the strength of motivation will be zero. In the language of expectancy theory the relationship between effort and outcome is called a *performance–reward contingency*. In the context of technology adoption it is important to note that even when this contingency exists (for example, when trials have

provided the clinical evidence that the technology works) it has little motivating potential in itself unless the individual concerned views the outcome as desirable enough to pursue it. If an anaesthetist were to experience greater 'felt responsibility' for patient outcomes in the days following surgery then it is very likely the outcomes achieved through use of the technology would be valued to a greater extent.

9 Q1: a clinical assurance technology

Q1 and Q1a are technologies designed to support quality assurance (QA) and hospital governance. These, and other technologies that are similar to them, comprise the delineation of standards, systematic protocols, audits, reporting arrangements and quality improvement methods. In this sense they are computerised management information systems. Unlike the other technologies in this study they are therefore concerned with the management and control of processes in healthcare rather than with the direct delivery of care.

Periodically, QA emerges as one of the top priorities in healthcare. Usually this follows the emergence of serious shortcomings in one or other part of the health service. These include serious outbreaks of hospital acquired infections such as *C Difficile* and MRSA, the administration of the wrong clinical procedures, and the substantial neglect of patients. QA of clinical care has been stipulated as a priority for board directors of hospital trusts on at least equal par with financial focus[204]. Technologies designed to help provide clinical assurance are therefore part of the core mission of healthcare organisations.

The main purposes of healthcare QA technologies are threefold. The first is to enable conformance with top-down imposed reporting requirements. The second is to provide nurses and other clinical practitioners with clear protocols and guidance which enable them to achieve consistency of practice and work to recognised and defined standards. The third is as a means of identifying opportunities for continuous improvement.

These technologies therefore have multiple objectives and are required to serve multiple stakeholder constituencies. They are designed to meet the needs of nurses and other clinicians by clarifying standards, measuring conformance with standards and providing feedback while also meeting managerial needs by providing the tools and the data which allow clinical governance to be exercised. They also aim to meet the needs of national policy level agents by responding to their demands for systems to be in place to demonstrate accountability. And they may also be required to meet the needs of patients by offering reassurance that systems are in place to ensure quality and safety of care.

No single technology designed to support QA and hospital governance dominates the market. Instead, a range of largely locally developed systems have emerged, often very similar to each other. Some of them have been adopted and adapted by trusts beyond the originating site but others have been more or less confined to the developer's organisation. The scopes of the technologies available vary. Some are narrowly focused on a specific aspect of clinical practice such as infection control while others seek

to cater for the quality reporting requirements of a whole NHS trust, including the various demands of a whole array of external audit and regulatory bodies, in one single package. There are thus significant choices to be made by potential adopters. In practice, the QA technologies available often combine a response to expectations placed on a trust by national policy with locally perceived requirements in order to underpin governance across all or part of a trust. The balance between these two drivers leads to significant variance between QA technologies based on a number of variables including:

- Local interpretation of national policy and initiatives

- Scope

- Balance of purpose between control, QA or improvement/development

- Range of data sources to call upon

- Frequency of audit

- Balance between complex, holism or simplicity of use

- Focus on nursing or wider

- Methods of audit

- Aspiration to make information transparent to staff, patients or external organisations

- Intent to create internal competition

- Challenging targets or minimum standard thresholds

- Scope of use: single department, division, hospital, trust or beyond

- Involvement with commercial partner

9.1 Choice of case technologies

Q1 exists in more than one form. It began as a wholly paper-based system but a more sophisticated version, provided as a spreadsheet program is now available. It has been adopted in one form or another by several trusts but individual adopting sites vary in the extent to which they have adopted it.

In identifying a technology to pair with Q1 it was seen as important to maintain a focus on QA rather than select another category of management information system. The specific characteristics of QA in the NHS mean that external policy pressures have a strong influence on the development and adoption of technologies to support such systems. Commercial involvement in the development of Q1 was minimal and was largely confined to marketing. It was therefore decided that the choice of the second technology for this pair of cases should be guided by the extent of commercial involvement in the development of the technology. Q1a was

chosen because a commercial organisation had played a very large part in its development. A commercial software company had started with some software originally written by staff from an NHS trust but the commercial company had reverse engineered it and then rewritten the software. As a consequence, in contrast to Q1, Q1a is a software package written to commercial standards and supported by a coherent service package.

A third case (Q1b) is also included because it reveals very different motivations and dynamics in both development and adoption.

9.2 Data Collection

Interviews to gather data for this pair of cases were conducted within five separate NHS hospital trusts, four of which were foundation trusts. Staff from two commercial companies which undertake technology development and technical support were also interviewed. Information was also gathered from senior NHS staff and from three independent experts/consultants with backgrounds in health service policy and administration. The interviews have been supplemented with information from documentary sources, including extracts from the technology packages and papers describing the technologies which had been prepared for clinical governance committees and boards.

9.3 Q1

Q1 lies at the broader end of the spectrum where scope is concerned. It was developed within a trust in response to a number of background factors and triggers. 'Standards for Better Health' had been issued by the Department of Health in 2004 become operational in April 2005 as the basis for the inspection and audit regime used by the then Healthcare Commission. The trust realised it needed some means of organising its response to these externally-led requirements. Around the same time the trust also experienced a higher than expected incidence of infections. A third prompt was the arrival of a new Head of Nursing who had been involved in a nation-wide project looking at clinical governance and nursing practice.

The early phases of development were driven by a small team of nurses and a member of the audit department. The team used 'Standards for Better Health' as a starting point to develop a paper-based version of Q1. Their aim was to translate the standards into a form which would allow nursing care to be assessed on a regular basis. An important priority was to decide what kinds of evidence could be used in order to show compliance with the standards. In the end, a number of measurement techniques were combined. These included: a matron's spot check of each ward or department; a checklist of questions for matrons to use in order to assess the awareness of different levels of staff about practical matters related to patient safety; a quarterly medicines management checklist; an audit of

paper records showing, for example, whether patient observation charts were up to date and up to standard; staff perception questionnaires; and patient questionnaires. Each group of standards is rated using a traffic light grading system:

- Red: need for urgent corrective action;

- Yellow: non-urgent further work needed;

- Green: the ward or unit is functioning to the standard;

- Blue: an area of excellence meriting wider sharing of good practice.

Q1 seeks to combine a holistic view of clinical assurance issues with data from multiple sources to assess performance against key measures. Q1 was refined over three years and then a computerised version was developed in collaboration with the IT department. After a further three years the computerised version was implemented across the whole trust. In addition, a number of specialised variants were developed for areas such as outpatients, maternity, day cases, operating theatres, critical care and the radiotherapy suite. Although Q1 is still mainly nursing focused its development has continued in order to adapt it to reflect priorities at both national level and local levels. Its champions regard it as an organic rather than a static application and so various adaptations continue to be made.

Q1 also allows quality monitoring and continuous improvement by drilling down into the detail beneath the overall results. This helps managers clarify the link between activity, performance, and the quality of outcomes and then use this knowledge to improve practice within the trust. It also feeds into clinical governance and reporting to external regulatory agencies.

The extensive adoption of Q1 within the developing trust can be explained by the support/ pressure from the higher levels of the trust's senior management. A Practice Development Unit within the trust also played a significant role in promoting and supporting the use of Q1.

The developing trust has been willing to share Q1 and its own experience of implementing it with other NHS trusts. It has done this by offering Q1 in both a paper-based and electronic version at nominal cost, using support from an NHS innovation hub. The trust has also provided additional support by hosting visitors from other trusts and running workshops. Q1 has now been adopted in a small number of trusts, though in each case far less fully than in the originating trust. The trust has shown little desire to market Q1 aggressively and has not attempted to gain significant income from sales to other trusts.

9.3.1 Adoption of Q1 by Trust A

This example of Q1's adoption approaches a wholesale adoption with very few attempts to alter the technology. Exactly the same set of standards was used along with the same methods of collecting performance data. A

key factor in the adoption decision by Trust A appears to have been the fact that Q1's main champion, a senior nurse, had previously gained direct experience of Q1 while working at the trust where it was developed. When asked by Trust A to develop a clinical assurance system he recommended Q1 be adopted instead of starting from scratch, arguing that Q1 offered simplicity and ability to integrate data and would enable the trust to conform to standards. A small team from Trust A visited the trust where Q1 had been developed and on the basis of that visit decided to adopt Q1.

However, there has only been partial adoption across Trust A. The division of the hospital where the champion had a direct responsibility and authority for clinical governance matters embraced Q1 thoroughly but other divisions were slow to adopt. In part, this was because legacy systems were in place which, in a more fragmented way, collected similar data. Staff, including senior staff in most divisions, were reluctant to abandon their existing systems and there was little sign of support/pressure for adoption from trust level senior managers and directors. Furthermore, there was no equivalent in Trust A to the Practice Development Unit that had played a part in diffusing Q1 throughout the developing site. To a large degree the champion in Trust A is a lone voice in advocating diffusion across the trust. Hence, although the technology is essentially the same in Trust A and the developing trust its utilisation is dramatically different in each. This reveals the importance of sponsorship for these kinds of technologies to be used in everyday practice.

9.3.2 Adoption of Q1 by Trust B

Trust B, a large teaching hospital, has also adopted Q1. In common with Trust A, the local champion for Q1 in the Trust B already had some direct personal involvement in the development and use of the technology and this played a key part in Trust B adopting it. The champion had an interest in and responsibility for nurse education and continuing professional development. She also had experience within the trust's organisational development (OD) unit. She arranged a visit by a small team to the developing trust to explore how they were using Q1 and this visit resulted in the team supporting its adoption. Trust B did not consider any commercially-develop alternatives to Q1, in part because an alternative would be likely to have required a business case to be made. Q1 was seen as a low cost and viable system that could be tailored by the hospital to meet its own needs. Subsequently, Q1 has been adopted across the whole of Trust B, albeit with some amendments. Work on these amendments was carried out over a period of 20 months by a small team comprising matron representatives and ward sisters from each division. Being able to make this input was seen as crucial in building a sense of ownership of the toolkit across the trust. For example, a three day event was organised involving matrons, infection control nurses, and other senior nurses where they reviewed a range of standards and other recommendations to help assess

the adequacy and suitability of the acquired toolkit. National standards were balanced alongside local needs. The exercise helped reduce the breadth of coverage to concentrate upon what were regarded as the 'critical standards'. As a result, the refined version of Q1 used in Trust B is shorter and simpler than the original and requires less data to be inputted. As in the trust which originated the technology, a practice development unit in Trust B helped to bring Q1 into routine use. As a consequence of the introduction of Q1, several groups of senior staff at Trust B are now involved in the quality assessment process, but the higher echelons of the trust's management, including the trust board, make little use of the information Q1 generates.

9.4 Q1a

Q1a has a narrower focus than Q1. It is specifically concerned with infection control. It is a web-based system marketed by a computer systems supplier as one of a portfolio of applications that support healthcare processes in primary and secondary care organisations. One of the company's other products has been very successfully taken up by a large number of NHS trusts but to date, Q1a has had less commercial success with only four NHS trusts adopting it.

As noted at the start of this section, development of Q1a was not carried out completely separately from the NHS. (Indeed, effective development of a QA system for use within the NHS would be very difficult without any NHS involvement.) Development of Q1a has therefore followed a process that can best be described as 'lead user innovation'. A commercial company has collaborated with expert users, based in an NHS trust to produce a commercial product. The nature of this development process has undoubtedly affected the design and functionality of Q1a in a positive manner and the close collaboration with an NHS organisation has given it a level of legitimacy it might not have otherwise had. It is worth noting that this mode of development had been used by this company before when developing other applications for use in the NHS. Their strategy was to identify promising new systems that were in an early stage of development and then re-develop them as commercially robust systems. This strategy was helped by the company's geographical co-location with a technology transfer organisation working with the NHS.

The commercial company after reverse-engineering the prototype and developing a new system, now markets Q1a to NHS trusts as a managed service and charges an annual license fee. Because Q1a is web-based integration with a trust's own IT systems is not required.

A full, formal, and quantitative evaluation of the Q1a has not been undertaken. Such an evaluation would be difficult because it would be hard to distinguish between the consequences of changes to national policies and other initiatives and those resulting from the adoption of Q1a. Some

evaluations of administrative savings, such as data input costs, and improvement in availability of information, have been made and there is anecdotal evidence it motivates ward staff to improve practice. No evidence has been gathered to show whether it improves outcomes.

One of the trusts comprises a number of hospitals that are geographically dispersed across a wide area. The largest hospital adopted Q1A first and is using it comprehensively but the other hospitals in the trust are not using it to anything like the same extent. Ensuring adoption across the whole trust has been challenging.

Despite the pressure at national level to improve infection control, the task of selling Q1a to potential adopters has been extremely difficult. Most hospital trusts already have existing internal systems and this presents a marketing challenge if Q1a is to displace these systems. Furthermore, it is common in the NHS for doctors to undertake audits and improvement projects as part of their training. At present these projects tend to run alongside but separate from the use of Q1a; again constituting a complicating factor to Q1a's potential use. Without unequivocal evidence to support the adoption of Q1a it is difficult to see how convincing arguments to adopt it over locally developed solutions can be prepared by the commercial company.

9.5 Q1b

As explained earlier, Q1b is being included here because it is an example of an NHS-developed technology that has a particularly interesting feature in the context of this research: its wider diffusion or commercialisation is being resisted by its developers. It was developed in a trust controlling a major teaching hospital, using the original paper-based version of Q1 as a starting point. This trust considers Q1b to be strategically important and central to the success of the trust as a whole and during the development of Q1b there was significant high-level, top-down championing of the project. However, far from wanting to see its wider adoption into other trusts across the NHS, the originating trust wants to keep its much enhanced version in-house as part of the organisation's core capability. The competitive advantage it is perceived to provide stems from the improved and assured high quality of care which results from Q1b's use in the trust's wider system of continuous improvement. The trust's focus is on earning a high reputation for good quality of care amongst GP commissioners and patients. This concern far outweighs any concerns about loss of revenue that might have been derived from licensing Q1b's associated IP.

Involvement of commercial developers in Q1b by has been very limited. A private sector developer has been used to provide system development and user support but they do not have ownership of Q1b or any licence to market the system to other trusts.

9.6 Findings and conclusions

NHS hospital trusts now require clinical QA tools and technologies to support them. This is stimulated by requirements at a number of levels: individual clinicians; internal performance management; and the external regulatory system. Overarching all of these is the national policy level which from time to time launches campaigns and initiatives and provides an overall climate that is highly receptive to the development or adoption of QA technologies. Yet, despite these 'readiness for change' signals, the adoption of QA technologies is limited.

Q1, Q1a and Q1b are all capable of having a political impact on adopting sites. The adoptions at all sites were politically charged processes with stakeholders using or resisting the technology in order to protect their own interests. The adoption of Q1 at Trust A also illustrated the competition between different innovations; adoption of Q1 was impeded by some staff believing it did not offer any more than their own existing systems. This provides a good example of where the adoption of information systems is unable to follow evidence-based principles, mainly because of the general lack of evaluation that would allow direct comparisons of effectiveness to be made.

These cases show the extent to which the adoption is undoubtedly driven by external factors, principally expectations set by national policy on clinical governance. It seems unlikely that without these external drivers adoption, or even the development by NHS-developers, would have occurred. This highlights the impact that policy initiatives can have on technology adoption behaviour by individual trusts. This is especially the case where adoption projects were triggered by (sometimes negative) external inspection reports. The generally low levels of adoption of Q1 and Q1a reflected the wider picture where even well-sponsored national initiatives have often not been fully adopted across the NHS. Technologies such as Q1, Q1a and Q1b, despite their limitations, could in general be considered as well ahead of the norm. According to several participants in this study, the utilisation of systematic QA packages even now remains very patchy across the wards and departments of NHS hospitals.

There was significant adaptation of the clinical governance technologies. In fact adoption sites clearly 'borrowed' features from the systems developed at other trusts to inform development of their own systems. This is perhaps a significant benefit of NHS-development of such technologies. The result of passing systems between trusts has been that the key features have been transferred between trusts and through adaptation tailored to the needs of adopting trusts. The transfer of the systems is therefore very beneficial for facilitating transfer of learning between trusts. The clinical governance systems are therefore important objects that facilitate organisational learning across the NHS. This also echoes themes in the NPfIT in which a major tension was between nationally standardised systems and the need for local contextualisation. Adoption was complicated by the need to

dovetail the new system with existing systems, especially in those areas of a trust outside the most immediate influence of the local champion. It is clear that existing systems would often stubbornly be retained, despite the introduction of the new system. The power to decommission a technology is as important as the power to decide to introduce a new one.

Probably the most striking feature of this class of technologies is the extent to which the NHS-developers were active, or not, in gaining wider adoption of the systems that they had developed. Developers of Q1 were keen to allow other trusts to adopt their system, to the point that they made it available for nominal sums. They used commercialisation processes to try to improve amount of adoption. In the case of Q1b the developing trust was resolute in not wanting to the drive diffusion to other competing trusts. Obviously, these different positions have implications for technology adoption. For the systems that were essentially, 'given away', the adopters often treated the systems as prototypes from which to develop their own systems. Furthermore, though the sharing of technologies between NHS trusts would appear laudable, the limited income gained from sharing means it is not possible to fund sustained development to improve the technology or support its wider use.

10 S3: an engineered component

In 1977 a Scottish orthodontist invented an appliance for the treatment of severe cases of overbite where the upper jaw and teeth overlap the bottom jaw and teeth by far more than the normal 2 - 4mm. Various clinicians experimented with the appliance and found that adjusting it during the course of treatment so that the relative position of the upper and lower jaw changed gradually gave better results and was much more comfortable for the patient and therefore less likely to be abandoned before treatment was complete. These gradual adjustments are referred to as 'advancing the appliance'. The standard method of advancing is to add further cold- or self- cure acrylic to the appliance. This is either done chair-side, i.e. in the clinic, or in the laboratory.

This pair of cases looks at two alternatives to this standard method. Although there are some differences between these two alternatives they share many similarities to the point where it is sensible to consider only some aspects of them separately. This sub-section will therefore set out information relating to each of the technologies separately before presenting a single analysis section. A single conclusion section will also be presented, highlighting any differences where appropriate.

10.1 Data collection

Data for this pair of cases was collected from two main categories of sources. The first is a series of interviews (face to face and telephone) with Consultant Orthodontists, hospital-based laboratory managers and technicians and non-hospital-based laboratory personnel. The second is published sources, including journal articles and on-line resource and personal electronic communication with NHS and commercial company staff.

10.2 The development of S3

S3 was developed by a Technician working in a major hospital that is at the heart of a foundation trust. The innovation process was initiated at the request of the Consultant for whom he worked. The Consultant was very aware of the drawbacks of the standard method of advancing the appliance and felt that a better alternative could be found. When advancement was conducted in the clinic using the standard method it exposed the clinician and the patient to the health hazards associated with mixing and using acrylic. It was also time consuming, lengthening the time needed for each appointment, and thus costly in terms of clinician time. When advancement was carried out in the laboratory instead of the clinic the risks to health were reduced but an additional appointment was necessary after each

advancement to re-fit the appliance. This was inconvenient for patients, and those who accompanied them to the appointments, and also took up clinician time.

The Technician's attempt to find a solution began in 1994. Relying entirely upon his own skill and expertise, the Technician made various prototypes. He undertook all of the activities involved with this and often worked in his own time and at home. These prototypes were tried out on patients and refinements added as a result of that. For example, one change was to replace the nylon screws in the advancement mechanism with metal screws and at a later point a screw housing was added. Eventually a version was arrived at that met the requirements and it started to be used on patients. The design of the product that is used today dates back to 1997.

The Consultant was keen to share the technology with colleagues from elsewhere so the need to protect the intellectual property arose. The Technician himself drew up and filed a UK patent application. The fees for this and the cost of some assistance from a Patent Agent were paid for by originating trust. The laboratory started making the advancement mechanism available to other trusts and embarked upon what was to become a long and difficult search for a commercial partner to manufacture and distribute the product. Finally, in 2001 the product was licensed to a UK company. The Technician believes that this result would not have been achieved without assistance from an intellectual property project that ran in his region from 1998 to 2002 and which covered three teaching hospitals and four universities.

This was the commercial partner's first experience of taking on an NHS-developed project and they found it more time consuming than expected. They spent some time considering 'design for manufacture' but the bigger task was securing regulatory approvals such as those required to obtain CE compliance. They contract out manufacture to a firm local to them that makes a lot of products supplied to the NHS.

10.3   Efforts to secure adoption of S3

The developer and the Consultant for whom he works have made significant efforts to draw the attention of their counterparts elsewhere to the advancement mechanism. They have written papers, spoken and presented posters at conferences and delivered lectures. Indeed, all but one of the adopters interviewed for this project had become aware of the product as a result of conference or meeting attendance; the remaining adopter heard about it through a conversation with a fellow Consultant. The mechanism is also promoted on its manufacturer's website. This provides illustrated instructions on how to use S3 and offers on-line ordering. It is also featured on the website of the NHS innovation hub that took over from the intellectual property project that had helped to find the commercial partner.

10.4 The development of S3a

In the very early days of the development of S3 the developer approached an orthodontic manufacturer that occupied, and continues to occupy, a leading position in the worldwide market for orthodontic products with a view to working with them on the project. This company, which is based in mainland Europe, turned the proposal down, but subsequently, in the mid 2000s, they worked with a leading orthodontist based in Germany and Switzerland to produce an alternative advancement mechanism. The products are similar in the way they work. The major difference between them is that S3a allows a total of 5mm of advancement whereas S3 is capable of up to 12mm.

10.5 Efforts to secure adoption of S3a

S3a's developer has also made significant efforts to draw colleagues' attention to the advancement mechanism with which he is associated. He has also written papers, spoken at conferences and delivered lectures. S3a is also promoted on its manufacturer's website which provides illustrated instructions on how to use it and in 2011 the manufacturer uploaded a video on YouTube to promote the product.

10.6 Findings

Both alternatives can be described as very self-contained. Adoption alters the work of the clinician and technician involved but it in any one adoption site it would be perfectly possible for one clinician to adopt and another working alongside him/her not to. Both alternatives are equally applicable in a setting that has on-site laboratory facilities and one that does not.

The NHS-developed alternative is only marketed in the UK whereas the non-NHS-developed alternative is marketed internationally. In the UK the NHS market is much larger than the private market because patients suffering from the condition to the extent that use of the technology is indicated are highly likely to be referred for NHS treatment. Obviously, the market for each of these alternatives is entirely confined to users but that is a much larger market that either, or indeed both taken together, are reaching. The standard method of advancement using acrylic remains the most widely-used option. Contact made with actual and potential adopters suggest that the NHS-developed alternative is used far more widely in the UK than S3a. Indeed, it was very difficult to find adopters of the non-NHS-developed alternative and those that were located were only using a very small number of items. It may, of course, be the case that adoption is great in other parts of the world where the NHS-developed version is not available.

For the NHS-developed version the rate adoption in increasing has slowed considerably over the decade since it became available via the commercial

partner. Early adopters remain very enthusiastic about S3 and continue to use it as their sole method of advancement (one said "If you have a system that works you tend to stick with it") but few new adopters are coming forward. An interviewee from a laboratory that supplies NHS and private clients said he has about 15 customers that use S3, half of which are NHS and half private. He reported, "Orthodontists who do use it are very pleased with it but the number using it is not growing. Those who start to use it continue to use it." One Consultant Orthodontist reported using 130 per year and another 100. There was just one exception to those reporting complete satisfaction with the product. One Consultant Orthodontist heard about it and thought it sounded useful, so he discussed it with his Technician and they decided to give it a try. It was used on two or three patients. In line with normal practice, very careful records were kept of those patients' progress and it was found that their progress was less good than that achieved using the conventional cold-curing acrylic reactivation method. One problem they experienced was the mechanism breaking in the appliance allowing the screw used to come out of half of the appliance. This failure had rarely, if ever, been seen with the conventional method so they decided to return to that.

The consequences of adoption of either option are fourfold:

1. At the start of treatment a technician prepares the appliance and fits the advancement mechanism. At this stage adoption means an increase in costs due to the purchase price of the technology and the approximately 30 minutes of additional technician time needed to fit the mechanism.

2. During treatment it takes the clinician about five minutes to complete each advancement. This represents a substantial saving compared with the standard method and allows more patients to be seen. There is no need for a second appointment to re-fit the appliance after each advancement.

3. The hazards associated with working with cold-cure acrylic outside of the laboratory are eliminated.

4. The mechanism provides greater accuracy of adjustment and reduced opportunity for error because the exact amount of adjustment is known.

The Department in which S3 was developed conducted a very detailed cost/benefit analysis to evaluate the consequences of using S3. This analysis found that use of the mechanism had "generated considerable financial savings for our hospital trust, by reducing clinical time at review stages, reducing laboratory workload, and avoiding the need for second appointments." An interviewee at an adopting site said: "Cost savings have not been calculated but the Department is certain they exist. The costs of using the system (initial purchase cost plus cost of additional technician time to fit at start) are less than the costs of adding acrylic at various stages during treatment, in part because a clinician's time costs a lot more than a technician's time." These savings apply to a slightly less extent for

S3a because its purchase price is higher. However, for either technology the cost savings are small in relation to the bigger picture, totalling in the region of perhaps a few thousand pounds per annum for a large trust.

Very interestingly, however, there is a perception elsewhere that the standard method is cheaper. An interviewee from a laboratory that supplies NHS and private clients (referred to above) said "Use of an advancement mechanism increases the cost of the appliance by £30 to £40. Though it reduces the 'chair side time' in the surgery the main alternative (adding acrylic) is cheaper." The Consultant Orthodontist who abandoned adoption after early failure said that although cost was not factor in his decision to discontinue, "it may mitigate against adoption elsewhere, particularly in the private sector, because it adds between £20 and £25 to the cost of treating each patient." Because the findings of the detailed cost/benefit analysis that was prepared have been classed as confidential there is no firm information available to dispel this misapprehension.

10.7   Conclusion

The development of S3 showed high levels of skill, expertise and commitment on the part of the developer. His efforts led to a product that was successful in meeting an identified need and which was capable of delivering benefits to adopters and their patients. Some potential adoption sites are using the technology and are very pleased with it but the overall level of adoption is disappointing. S3 and S3a have failed to displace the standard method despite the advantages they offer.

The biggest difficulty S3's developer experienced was in finding a commercial partner and he regrets that this was not done sooner. At the time he also felt he was out of his depth in terms of protecting the IP though the knowledge he gained in the process has had longer terms benefits because he has subsequently been able to use it to help others in similar situations.

S3a came to market substantially later than S3 and is a very small part of the large product range of a leading international manufacturer. Perhaps for this reason it has made little impact in the UK and neither it nor S3 has been able to dislodge the standard method of advancement despite offering advantages over it.

The differences in perception of the financial costs and benefits are very interesting. It is very likely the case that belief that the standard method is cheaper than using S3 or S3a is due to the fact that purchase costs of the technologies are more visible than savings in the Orthodontist's time per patient, especially since this reduction leads to more patients being treated.

11 Discussion

This chapter examines some of the wider themes that have emerged from the research. It is in the nature of empirical studies that a broad range of anticipated and unanticipated findings emerge as a result of the fieldwork. Some of the issues are specific to individual case studies and have already been discussed in previous chapters but others are common across several technologies and so it is worthwhile examining these in more detail here. The emergence of themes across cases not only suggests a level of triangulation that improves the external validity of the research, it also provides valuable additional perspectives that increase richness.

The development of themes in the chapter has been based on a clustering of findings across both stages of the research. Table 4 shows a summary of this analysis. Reading across the table each finding is listed along with exemplar technologies and mapped against one or more of the research questions and the relevant theme to which it contributes.

When interpreting the table a couple of points are worth noting. First, specific findings do not always relate to just a single research question and several of the themes identified are related to a number of research questions. Secondly, some of the findings have been further validated by data relating to technologies that were investigated at the start of Stage 1 but failed to meet some of the criteria for criteria in the study.

The remainder of this chapter is split into three sections. The first section outlines issues that arise from defining technology as either NHS-developed or commercially-developed. The second section considers the impact of a technology's origin on it subsequent adoption into the NHS. The final section looks at the wider health technology innovation system and the potential for applying an open innovation perspective.

Finding	Exemplar technology	Related Question				Theme
		1	2	3	4	
NHS Developers create overly narrow/niche technology	L1, L3	●	●			Role of NHS Developers in affecting trajectory of development and subsequent adoption
NHS Developers create technology 'ahead of the curve'	Q4	●				
NHS developers create incremental rather radical innovations	S5, I1	●				
Scope for adoption limited by need for significant investment or extensive service change	C3a, I4, Q1, Q2	●	●		●	
NHS development enabled direct user-input to design	I2, C5	●				
Motive of NHS-developers not always commercial ambition	C3	●		●		
NHS development linked to wider research projects	C3, M1, M3	●				
NHS developers members of extensive professional networks	C3, M1, M3	●		●	●	
Dual role as developers and NHS staff roles creates potential conflicts of interest	M1	●				
Difficulty in gaining ideal industrial partners	S3	●				Innovation partners
Partners lack necessary capabilities for effective development of the technology	S2	●				
Partners do not see NHS as a primary market for the technology	Several technologies excluded from study.	●				
National policy leads to driver/barrier to adoption	C2,C4, C6, Q1, Q2 and S2		●	●		External adoption drivers
Treatment tariffs acting against adoption of new technologies	M3a		●	●		
Absence of relevant evaluations	M1a, C3a	●			●	Evaluation and evidence
Adoption not dependent on rigorous evidence	C1, I5, Q3, Q4, S5				●	
Complexity of building evidence base	C3a, M1, M1a	●			●	
Existing evidence contested by different stakeholders	M1				●	
Time lag involved in building/publishing evidence	C3a, S2				●	
Ownership of technology/services	C3, C3a, M3		●		●	Professional and structural barriers
Professional/budgetary silos	C3, C3a, M1,M3		●		●	
Piecemeal adoption funding	C3, M1				●	Adoption decision-making
In-direct motives for adoption	C3a, M1				●	

Table 4. Development of themes from findings

11.1 NHS-developed versus commercially-developed innovations

This research set out to examine the extent to which the origin of a technology influences the level and success of its adoption into the NHS. Specifically, a comparison has been made between NHS-developed innovations and equivalent technologies that were commercially-developed.

Within this study, a range of technologies have been identified as 'NHS-developed'. This group is by no means homogenous in terms of the way in which innovation occurred. For some, the initial invention was devised by an NHS member of staff but quickly taken up by a commercial partner. For these innovations, the balance of control over how innovation was managed lay predominantly with an industrial partner. In contrast, other NHS-developed technologies remained under the control of the individual or group within the NHS who made the original invention. Overall, it is fair to say NHS-developed technologies have been found to have been developed using a range of innovation processes, controlled through a diverse range of structures, and with varying degrees of success where subsequent adoption is concerned.

Technologies that are classed as commercially-developed technologies may still have had NHS involvement in their development. For some, though they originated outside the NHS, involvement of NHS staff was still an integral part of the innovation process. For instance, NHS staff may have been involved as advisors or as 'lead users'. Other commercially-developed technologies have been developed within UK universities with involvement from staff within adjacent teaching hospitals. There are also examples where innovations have been created by NHS staff but the innovation process took place almost entirely outside the NHS. Therefore the distinction between NHS- and commercially-developed is not always clear; many commercially-developed technologies have benefitted from knowledge and skills possessed by NHS staff.

The extent to which a specific innovation is described as either NHS-developed or commercially developed is not always straightforward. It became evident during Stage 1 of this research that the original criteria for NHS-developed - that an NHS member of staff developed the technology or played a very large part in its development - needed refinement. The survey of technologies suggested that an important distinction was where the balance of influence/control between NHS and commercial stakeholders lay during and after the development process. Figure 19 illustrates how the extent to which innovations are either NHS or commercially-developed can vary depending upon a combination of the source of knowledge and this balance. The Stage 1 survey suggested that the NHS-origin become important where both the source of knowledge and influence/control over development lay with NHS staff though initiatives, such as lead user collaboration or technology spin-outs can have a mitigating effect.
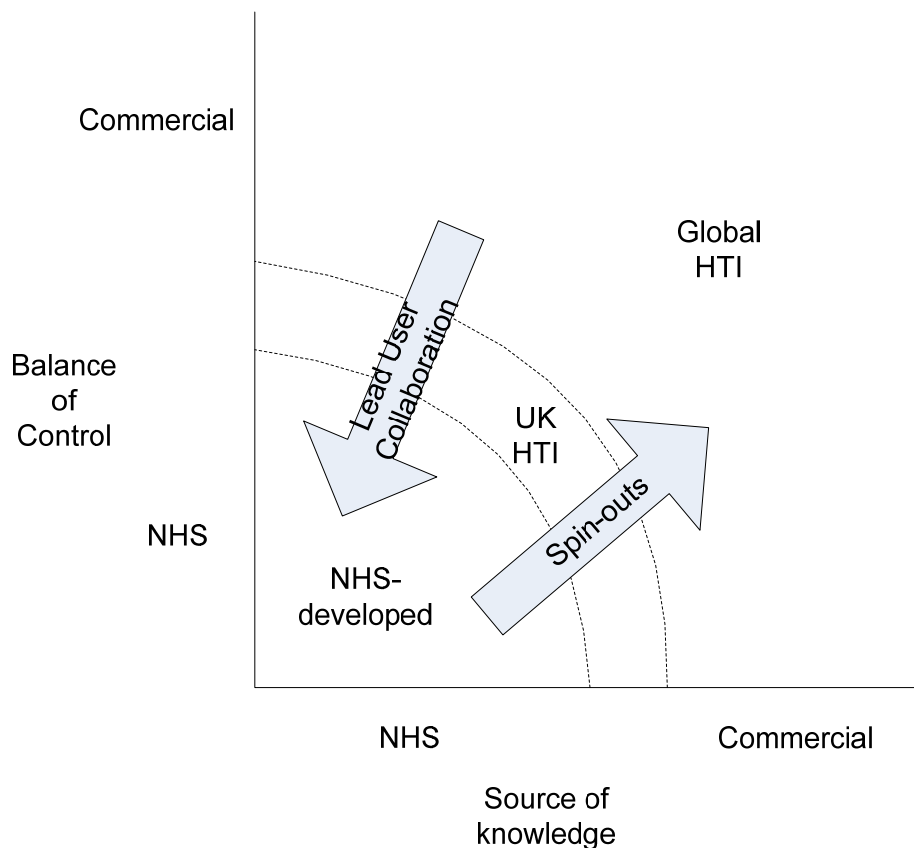
Figure 19.   Balance of control between NHS-developed and commercially-developed technologies

One factor affecting the innovation process followed by NHS-developed technologies is the level and type of management support provided to innovation projects within the NHS. Across the technologies examined, the quantity and quality of support was very variable. This was partly due to regional differences in the level of innovation management support available to NHS staff but it was also due to changes that have taken place over time. The invention and early development of some of the innovations included in this study occurred before 2002, when more formal arrangements were put in place for managing IP created by staff within the NHS. For these earlier innovations the role of the NHS was often passive, with NHS organisations playing no formal role in the development. The NHS context was still important though. The innovations drew on the training and experience of NHS employees and their employment by the NHS provided developers with access to tangible and intangible resources. More recently, NHS–developed innovations have usually been much more closely linked to the inventor's trust and support at local and regional level has been made available to exploit inventions commercially. For these innovations the NHS has therefore played a significant role in the innovation process. This role has included a more formal process for protecting and exploiting IP, with NHS trusts asserting their ownership of the IP. It is now common for NHS-developed innovations to be commercialised through licensing agreements with partners (two-thirds of

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the technologies surveyed in Stage 1 had been licensed in this way) or in some cases spin-out companies have been formed. Through these mechanisms, NHS-developers and the NHS trusts have been able to maintain a degree of control over innovation projects beyond the early stages of development.

11.2 Impact of origin on technology adoption into the NHS

This research has shown that the relationship between an innovation's NHS origin and its subsequent adoption by the wider NHS is not a simple one. The blurred boundary between NHS-developed and commercially-developed technologies makes it difficult to prove beyond doubt that one or other origin has a positive or negative impact on adoption. There is, however, strong evidence to suggest that the origin of an individual technology does give rise to certain characteristics that encourage or inhibit its adoption, but looking across a range of technologies there is not a consistent pattern of benefits or disbenefits. In short, being NHS-developed can, under certain circumstances, bring significant advantages in terms of securing adoption, but this is not the case for all technologies. There are circumstances where it does constrain adoption. For example, NHS origin can have a negative impact on potential adoption due to the technology produced having a rather narrow focus. Narrow applicability may be the result of a single inventor taking a somewhat blinkered view of the purpose of the technology being developed or the range of its possible uses. In the case of C3, the number of potential sites for the systems as originally developed was relatively small so it was only when the concept was applied across a number of specialist areas that a critical mass of potential adopters in the NHS emerged. Evidence that some NHS-developed technologies were too narrowly focused emerged during the early search phase of Stage 1 of this study. It was clear that some technologies developed within the NHS were failing to reach the market because their very restricted focus made them commercially unviable. In contrast, the more market-oriented approach taken by a commercial developer ensures that the scope of a technology is extended to attract as broad a market as possible.

It is also the case that the simpler the technology, the less marked the effect of origin. I2 was selected for inclusion in Stage 2 because it is a simple piece of equipment and its adoption is extremely straightforward. It is therefore representative of the eight technologies surveyed in Stage 1 that lie at the lower end of the complexity range. The I2 case study makes the point that a well-designed product emerged as a consequence of community nurses identifying a particular need and using their knowledge and expertise to engage in a collaborative design process. However, as the case goes on to say, this does not mean that the NHS necessarily needs to be involved beyond the identification of need and guidance on what properties an effective solution needs to possess. At that point development

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could be handed over to a commercial company. This would still lead to the product being available for NHS adoption but it would also mean that the NHS would have little or no financial reward for its input. If sales of the product were very high then income would be likely to outstrip the financial costs of supporting and produce a good return on investment. However, the Stage 1 survey suggests that sales of the technologies in the low complexity category are often disappointing in which case the return on investment could well be negative if all the costs are taken into account. There could still be other benefits such as increased staff morale but perhaps an evaluation exercise ought to be undertaken to assess the real costs and benefits of developing technologies such as I2.

Role of NHS developers

One of the reasons for studying the impact of NHS-development on subsequent adoption was the extent to which NHS developers have an opportunity to influence, not just the trajectory of technology's development, but also its subsequent adoption into the wider NHS. The six NHS-developed cases have illustrated a range of ways in which developers influence subsequent adoption, but they have also shown that the extent of this influence does vary considerably.

All the research showed that NHS-developers were well placed to recognise a specific need within their own practice and were able to develop solutions to the problems that they perceived. Sometimes these needs were too narrow to attract commercial organisations to invest in development effort. For example L1 and L3 all addressed very niche or emerging problems. The problems addressed were also sometimes ahead of the curve with respect to commercial development and concerns in the NHS. For example, Q4 addressed a problem that was yet to be seen as a widespread issue in the NHS though the developer believes it will only take one high-profile crisis to increase interest and potentially lead to widespread adoption of the technology.

The sophistication of solutions produced by NHS-developers was variable. Sometimes solutions were just incremental improvements on existing technologies. For example in the case of S5 and I1 the solutions were neither radical nor sophisticated. The extent to which these developers were driving a significantly new technological trajectory was limited, but the value of their work lay in succinctly identifying a clinical or operational problem and suggesting a viable solution. Other technologies were much more sophisticated technically and required very significant amounts of development effort but were very context specific. This meant that their scope for adoption was limited to a small number of specific organisations or processes. I4 is an example of this though it is a very high value technology for which there is a worldwide market. Other technologies, such as Q1 and Q2 address widespread needs but require tailoring for individual adoption sites. In one sense, the most successful group are those

technologies that were developed to solve the NHS-developers' immediate problems but are widely applicable and have ended up being highly adoptable.

The overriding property of the NHS-developed technologies in Stage 1 is that they represent innovations that were the product of direct user input into the design process. As noted in the I2 case study, the products of NHS-developed innovation can benefit from collaborative design processes, where the users can work with specialist designers. NHS-developers can also be important lead users for the healthcare technology industry as in the case of C5.

Each of the NHS developers of technologies in this research has his or her individual motives for embarking on the innovation process. It is striking that the vast majority of NHS developers are primarily concerned with improvement of patient care and/or bringing benefits to colleagues and they are seldom driven by commercial motives. Commercial success was a concern for many NHS developers only in as much as it represented the point where an innovation had become viable for use within the NHS and adoption elsewhere validated their work.

For NHS-developed technologies, the NHS developer would often become active in marketing of their technologies. In this role NHS staff can be valuable champions for a technology, especially in the case of senior clinicians. The impact of NHS staff promoting a technology can be to increase credibility and legitimacy. In particular they are in a position, often through membership of networks, to communicate benefits of a technology to their own peer group more effectively than sales representatives. For research-active clinicians, promoting the use of their technologies is closely coupled with their own research projects and development of new knowledge in their discipline. In these cases, adoption of a technology will often be just part of a broader initiative within a specialism. For example, M3 grew out of research and C3 and M1 were both technologies that supported wider research initiatives with M3 subsequently becoming an important component of a wider initiative on enhanced recovery. It is common for NHS-developers to be active in speaking at events and conferences and writing articles and journal papers. These are important in legitimising research underpinning the technologies, raising awareness amongst their professional peers, and actively marketing technologies. C1, for example, has gained many of its adopters from attendees at conferences where the developer has presented.

Technologies have been embraced by the inventors' peers working within the NHS, especially when the inventor was an active member of a professional group. For example, for C3, the network of clinicians that made up an emerging specialism was a very receptive group and the status of the inventor as part of the group clearly improved the acceptability of the technology. Even for technologies where the overall level of adoption has been recognised as problematic (e.g. M1 and M3), take-up has been

strong amongst a network of clinicians with common professional values, whose paths had crossed earlier in their careers or who had got to know each other through involvement in special interest groups. In contrast, commercially-developed technologies seemed less likely to attract this peer-group commitment.

There are however several potential risks of NHS-developers taking a role in promoting adoption. NHS staff may themselves feel, or be seen by others, to have a conflict of interest. This might lead to potential adopters believing the information provided by an NHS-developer to be biased or invalid in some way. Similarly, the politicised nature of some medical specialisms can mean that low adoption rates reflect competition between centres or other factors that have provoked a 'not-invented-here' response.

NHS-developers require significant commitment to become involved in the marketing of technologies. NHS staff with busy routine work commitments struggle to make time to promote technologies to others within the NHS or elsewhere. Though potentially very valuable as a way of facilitating adoption, the ability of staff to put in the required effort is easily lost, especially when new priorities emerge. It can even be the case that once the innovation is in place for their own use the developers regard the innovation project as finished. This appears to be the case for S5.

Innovation partners

NHS-developed technologies very rarely become viable products, marketed back into the NHS, without the collaboration of one or more commercial partners. These partners provide key capabilities that are unavailable within the NHS, including management support, product design, manufacturing, marketing capability, and make capital available for investment. Without this support it seems likely that most NHS-developed technologies would not get beyond prototype stages of development.

Within this research a recurring theme has been the role taken by the industrial partners. Despite the undoubted benefits of partnership, the ultimate success of gaining adoption of the technologies back into the NHS is inextricably linked to appropriate choice of partners. Developing partnerships was difficult for many of the technologies, as it was not always possible to develop an agreement with the ideal partner. For example, the ideal partner to progress S3 was a market leading supplier, but this supplier was not interested in the project and later brought out its own version of the technology. Generally for NHS-developed technologies, there is only a constrained choice of partners and so partnerships seem to be more often based on whether there is the opportunity to create a partnership, rather than whether it is the most appropriate partnership.

It was evident in this research that choice of industrial partner from those available was mediated by a number of factors. One was the perception of how easy the potential partner would be to work with. (Often a smaller

organisation was perceived as easier to deal with than a larger one.) It was also common for partners to be selected on the basis of existing relationships. This obviously increased levels of trust between developer and partner, but perhaps also introduced a tendency to limit the search for a partner to known organisations, rather than to look for and cultivate those organisations that might be most appropriate. During Stage 1 of this study, a number of NHS-developed innovations were excluded as they had not yet come to market, despite several years of development. It was apparent that one reason for stalling of innovation projects was poor choice of industrial partners.

In at least one example (S2), partnership with a small organisation resulted in the innovation project being impeded by a lack of technological capability and ability to attract financial investors. NHS organisations are poorly placed to make financial investment in product development so the role of partners in attracting funding to support development and marketing of technologies is critical. Unfortunately, the ability of small organisations to raise sufficient investment funding is also limited and so though a partnership may appear appropriate, subsequent failure of a partner to finance innovation, can limit both progress of development and marketing of technologies.

A final issue related to choice of industrial partner is the extent to which the partners have an interest in the UK NHS as a primary market, as opposed to wider global markets. For many NHS developed technologies the only way for technology suppliers to gain significant sales is to promote technologies to global markets. It was not uncommon within this study for technologies to be marketed outside the UK, with at least nine technologies in Stage 1 already being marketed abroad. For widespread adoption, global marketing is vital to ensure that specialist technologies, with only a limited market within the NHS, have a market large enough to make them viable commercial products. It is also the case that differences in regulation, funding and local professional practice can make markets abroad easier to access than those in the UK.

External adoption drivers

For many technologies included in the Stage 1 survey, external drivers, such as national policy, were reported to have had little significant influence on their adoption performance. This is particularly true for the less complex technologies. However, for some of the other technologies (for example C2, C4, C6, Q1, Q2 and S2), external drivers or lack of them, did affect adoption to a significant extent. Three of the stage 2 cases (C3, M1, and M3) were complex technologies for which external adoption drivers did impact on technology adoption. The cases suggest that in order to gain widespread adoption of a technology it is necessary to set the broad policy context for NHS organisations correctly. Bottom-up initiatives to generate widespread adoption were not sufficient. National policy clearly has a role in

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acting as a focus for adoption of new technologies, not least in relation to governance and patient safety issues as seen in C6, Q1 andQ2. Specific policies such as the inclusion or exclusion of a technology in a specific care guideline or policy can have a profound effect on adoption. For example, M3 is now directly cited in several NHS policies and this has led to a significant increase in adoption. In contrast, the lack of detail on non-invasive testing within care guidelines has reduced the visibility of technology M1 to adopters. Less prescriptive policy leaves more discretion at the local level about which technologies are adopted which may explain why technologies related to implementing protocols or governance issues, such as C6, Q1 and Q2, face a range of competing solutions, many of which have been developed at a very local level. Policy initiatives that identify key problem issues may result in local pressure to adopt technologies that address these issues. For example, publication of positive outcome data has undoubtedly increased pressure to adopt technologies such as C5 and M3. Whilst it is clearly the case that adoption of technologies does still occur in situations where there is a policy vacuum, it is also clear that adoption occurs more slowly and less extensively under those circumstances. However, it is equally true that even when initiatives are in place they do not guarantee success and there is often a lag between initiative and adoption.

A wider issue that is illustrated by this study is the tension between formal external drivers for adoption, such as clinical guidelines and payment tariffs, and reliance on competition in the health technology market to achieve adoption of new technologies. Development of compliance mechanisms to encourage the use of innovative technologies is one strategy that can be used to increase adoption rates, but the question is whether they should they refer to a specific product, a generic technology, or some other means of improving an outcome. Strong adoption compliance mechanisms would be at odds with the competitive nature of the health technology industry and it is the latter that is often a major driver of innovation. Inclusion of a specific product in a guideline or best-practice tariff would undoubtedly have a positive effect on take-up, but also needs to be seen as an active intervention into the technology market. This might suggest that where a number of different products can fulfil a similar purpose, then it may be more appropriate to provide a more general requirement, citing a generic type of technology rather than a specific product. In fact, being highly specific risks the blocking of wider innovation of technologies as prescribing specific product may reduce scope for competition. So though adoption of improved technology might be achieved in the short term, in the longer term newer technologies may be unable to displace older, less effective technologies due to their linkage with guidelines or tariffs. This issue has already arisen where M3 and the alternatives to it (including M3a) are concerned.

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Evaluation and evidence

One of the issues that appeared to affect both NHS-developed and commercially developed technologies is the extent to which evidence and the evaluation approach that produced the evidence impacts upon adoption. For five of the technologies in the Stage 1 survey (C1, I5, Q3, Q4 and S5), formal evaluation is not relevant but for others a significant body of evidence was required in order to justify use within the NHS. (M3 is a prime example.) However, adoption did not automatically follow strong evidence.

It is not always clear what constitutes sufficient relevant evidence. For example, M1 and M1a are measuring/monitoring technologies and as such the form their evaluation should take is not as clearly prescribed as for other technologies such as pharmaceuticals or certain classes of medical device. These two cases both illustrate the potential blockages to adoption caused by the absence, ambiguity, fragmentation or lack of legitimacy of evaluation information. The M1a case showed adoption decisions being made when only equivocal evidence was available, either due to the length of time needed to complete evaluation studies, or because evaluations provided only partial insight into how the technologies perform within a service. In contrast, M1 showed that it is possible for relevant clinicians and health professionals at potential adoption sites to be unaware of evidence that is available. This suggests that though technological developments are often reported in professional and academic journals, backed up with presentations at conferences and workshops, there is an inconsistent approach within the NHS for systematically reviewing new technological developments at a local level and absorbing it into practice. The extent to which this is due to the oversight of potential adopters, as opposed to complacency towards new technologies, procedures or service-designs is difficult to ascertain. A final relevant lesson from this pair of cases is that the evidence underpinning technologies, including peer-reviewed evidence, can be subject to negotiation and can be strongly contested. For both M1 and M3 there was some evidence of clinicians' professional judgement and assumptions over-riding evidence-based arguments for adoption.

The consequences of selective use of evidence are complicated further by adoption decisions also relying on judgements about whose evidence counts for most. This study suggest that that a personal recommendation of a technology, such as C3, can have greater influence on adoption than published papers. While it may be that a published body of evidence can be vital in 'qualifying' a technology for consideration, the impact of the personal experience of a clinician perceived as a peer of a potential adopter may have greater power to 'win' the adoption decision.

The M1a case identifies another potentially important aspect of technology evaluation. The case shows that the implementation of a technology can in turn play a role in supporting the implementation of a best practice but the evaluation carried out on M1a was unable to assess the technology's impact

in this regard. It is almost always easier to assess the benefit of a technology in isolation than it is to undertake a full system-wide evaluation and yet it is essential to strive for optimisation across the whole. This is a crucial issue, especially in areas where variation in practice is very large. In this situation adoption of a technology that encourages implementation of best practice may be a substantial and important benefit in its own right and worth achieving even if the technology of itself provides little extra benefit.

A further issue with making evidence available is the relative clock-speed of the technology development lifecycle compared to the technology evaluation lifecycle. For example the adoption of S2 was held back by the significant lag between coming to market and publication of trial results. This was partly due to the length of time required to carry out trials, but it was also exacerbated by the delays in the academic peer-reviewed publishing cycle. For other technologies such as Q2 and C6 there was a lack of evaluation data as developers did not have the time and resources to carry out detailed evaluations.

The results of the study therefore suggest that to aid rapid adoption and implementation of healthcare technologies new approaches to evaluation are required. These may require a broader perspective than that given by a traditional clinical trial, using an extended epistemology. Furthermore, the range of approaches may need to be extended. The RCT model, adapted from pharmaceutical trials, may not be ideal for other classes of healthcare technology. Hence, the evaluation of measurement devices, diagnostics, assistive, clinical information systems and other technologies may require specific evaluation methods that can provide faster assessments that provide a more balanced view of a technology's performance in context.

Professional and structural barriers to adoption

The extent to which financial and knowledge silos created by professional groups within the NHS form barriers to innovation is already well documented. Typically this relates to issues associated with the costs of investment falling on one area, while the benefits are gained elsewhere in the system. For example the capital cost and increased effort of using M3 rested with anaesthetists, while the financial benefits gained from the enhanced recovery of patients were accrued in other cost centres. Related to this is another complicating factor in that it is the anaesthetist who makes the adoption decision but the surgeon is the 'owner' of the operation in which the technology is used. This was a factor that was also evident in the C3 case.

Professional silos can also create some other less obvious barriers to adoption. For professional groups that believe existing practice is already sufficiently effective, challenging their beliefs that adoption of a technology is unnecessary is very difficult. For M1 and M3 the extent to which the new

technologies were recognised by clinicians as relevant (in the case of M1) or worthwhile (in the case of M3) to their practice was not always consistent. This suggests that the non-adoption of technologies may often be due to professional groups simply not recognising their need for a technology or its relevance to an individual's practice, despite evidence to the contrary. A further factor that can cause professionals to ignore technologies is the perceived ownership of technologies. For M1 the ownership of technology was ambiguous between clinicians and technologists leading to lack of co-ordination between how diagnostic technology could be used within a pathway.

Adoption decision-making

If technology adoption was to follow a purely evidence-based approach, adoption decision-making would be an entirely rational process. A carefully constructed case would be produced and then objectively reviewed and, if accepted, a coherent plan for implementation would be developed and enacted. Unfortunately, the processes of adoption observed in this study rarely followed this process. First of all adoption processes were often not simple, deliberate linear processes in which the decision-making flowed naturally from stage to stage. Instead, they were often made in an incremental manner, gradually developing over time as various stakeholders built their understanding of a technology and 'bought in' to the decision. Decisions were also often triggered by significant events that prompted stakeholders to either take action to move adoption forwards or to stall progress. As such, though individuals were often taking decisions 'rationally', based on their own perspective and situation, when the decisions taken by a range of stakeholders were reviewed over time and across the whole, the overall logic of the processes was not clear.

It was evident that the adoption of technologies in the study were sometimes funded in an *ad hoc* fashion. For example, some of the adoption sites for M1 and C3 used research funds to purchase the technologies because there was no other budget available. Even where there is an economic argument in favour of adoption it is sometimes difficult to 'spend money in order to save money'.

Adoption decisions do not always just focus on the immediate, direct benefits of adopting a technology into a service. Cases such as C3a and M1, illustrate how part of the adoption rationale related to achieving wider objectives, such as shifting staff roles or building capacity in a new area. This might be by enabling staff to use a novel technology in preparation for future more extensive changes. Adoption can be part of an organisation's aspiration to build technological capability by piloting new technologies. Under these circumstances, developing a cost-benefit analysis of the adoption is very difficult because short-term operational benefits are important but not substantial and longer-term improvements in organisational capacity are very difficult to quantify.

11.3 Open innovation and the wider healthcare innovation system

At the highest level, this study highlights that technology adoption has to be seen as part of the wider healthcare technology innovation system. It has also shown that adoption is not a process that takes place in isolation of other activities in the innovation system but is part of a complex innovation pathway. Several interrelated factors affect adoption, many related to earlier phases in the innovation pathway. In developing an effective strategy to facilitate rapid adoption of innovative healthcare technologies these linkages need to be taken into account, not least the complex linkage between clinical need, research findings, complementary technologies and capabilities. A key challenge is ensuring the effective knowledge transfer between organisations, potentially in a diverse range of sectors. This suggests that it is valuable to adopt an open innovation perspective on healthcare technology innovation and adoption. Not all innovation will be based in the R&D departments of commercial organisations and it is necessary to recognise the role of technology users in the innovation process. Thus clinicians, technologists, managers and patients can potentially engage in user-led innovation activities. Finally, for both the NHS and commercially-developed technologies in this study there is a clear sense that the involvement of NHS staff as lead users in innovation projects was of great value.

The relevance of open and user-led innovation suggests that to improve technology adoption a better model is needed of the wider innovation system. The following section proposes an extension to the triple-helix model technology transfer proposed by Etzkowitz and Leydesdorff[205]. Etzkowitz and Leydesdorff's work on technology transfer emphasised the iterative relationship between universities, government and industry as representative of how technology transfer operates within the innovation process, most notably the triple-helix model of technology transfer. They suggest that the relationships between the three strands in the helix are dynamic and continue to be re-defined over time. This model represents a potentially useful basis for understanding the various transfers of knowledge that ultimately result in technology adoption in the NHS.

The triple helix model's main limitation is that it is not focused on a specific sector, nor does it explicitly address industries where user-led innovation processes take place. However, several other researchers have proposed candidates for a fourth strand to the helix model. Most notably, these include: intermediate organisations that support or enable innovator organisations[206 p.20]; Public/civic society[207]; users[16 98 208-212]; media-based and culture-based public[213]; and within the UK, the need for involvement of patients and the public in development has also been identified as important to healthcare innovation[214-216].

Arnkil *et al.*[217] reviewed many of the debates considering what might constitute a fourth strand in the helix and concluded that a prime candidate would be the users of a technology, as the quadruple helix would then take account of user-centred innovation more effectively. As a consequence, they suggested four variants of the quadruple helix that emphasised a continuum of user involvement. Their analysis was non-sector specific but has potential relevance to the healthcare sector this study might inform the refinement of the quadruple helix concept for healthcare technology innovation.

The triple helix model applied Mode 2 knowledge production and the extent to which knowledge is often created within operationally-focused, rather than just research-focused settings[218 219]. The cases in this study illustrate this with innovation occurring on the periphery of formal research organisations and across boundaries. However, in most published examples of open innovation commercial technology manufacturers maintain a significant level of power over the trajectory and focus of the innovation. (See, for example, Huston[220] and Lüthje[209].) In contrast, several cases in this study exhibited a different power balance with NHS staff able to maintain significant influence on the process and trajectory of the innovations; acting also as clinical champions and opinion leaders.

The study highlights that the process of technology transfer of NHS-developed technologies does not match the triple-helix model. The triple-helix model emphasises the interactions between industry, universities and government, while users development roles are subsumed to the "...emerging overlay of communications, networks, and organisations among the helices"[205 p.112]. This study illustrates that health professionals can control development and marketing; a function assumed associated with industry within the triple-helix. The role of the healthcare system in technology innovation is underplayed by the separation of just three distinct institutional categories: government, universities and industry.

This study suggests the potential for extending the triple helix model by defining a fourth strand: the healthcare system itself. This addition allows the specific role of health professionals, as technology users and developers, to be reflected in the overall innovation process.

The NHS is a significant source of knowledge and as a major strand in the helix has opportunity to assert its position as a source of knowledge in the healthcare technology industry. This suggests that the NHS would benefit from strategies that position it as the lead user of choice for universities and healthcare technology suppliers as part of a broadly based open innovation system. This would be advantageous as it would mean that the situated knowledge from the NHS would potentially be more effectively embedded within new technologies. This could result in development of technologies that have a fit with the NHS in general. In addition, the involvement of NHS staff in development of technologies would build the absorptive capacity of the NHS and support subsequent widespread

adoption. In addition to NHS staff, patients, their carers, and the wider public may also have a role to play as lead users, for further detail see Savory's framework[214] for integrating patient and public involvement in translational research.

11.4 Limitations of the research

Every research method has strengths and weaknesses so it should come as no surprise that the methods used here have given rise to some general limitations. For example, although some quantitative data has been collected there has been an emphasis on qualitative data and where quantitative data is provided it often lacks precision simply because more precise data would be very difficult to access. Another example results from using the case study method to undertake stage 2. Although a multiple case approach was used it remains the case that case study findings are not generalizable in the conventional sense.

This section will look at limitations that are specific to this study rather than rehearse the limitations it shares with all work of this type.

Lack of patient perspective and the 'voice of the patient'

This research has gathered data that looks at the development and adoption of technologies from the perspectives of NHS staff and commercial partners. The views of patients have not been sought directly and the 'voice of the patient' with respect to technology adoption has only been included where recounted by NHS staff. The rationale for not including patients in the research was primarily because the research was concerned with the decision-making and processes of adoption by care providers. The extent to which patients are party to adoption decisions concerning the types of technologies considered was expected to be and was found to be very small. That is not to say, however, that for many of the technologies studies the extent to which a technology is acceptable to patients is not important. The acceptability of a technology to patients is a concern for many developers and adopters and so for several technologies (for example M1 and C3) trials were developed that specifically measured acceptability to patients. These studies have been available to the research as secondary data. As such, the authors are confident that where necessary the 'voice of the patient' has been included within the accounts of technology adoption to an acceptable extent.

Hidden innovations

Identifying innovations developed within the NHS is not always straightforward. It is bound to be the case that the NHS has produced a range of intellectual property that has led to innovations that have not been considered for inclusion in this study. That is because it is not always possible to identify where and when innovations are developed. More often

than not, the innovations included within this study have followed formal development routes using the support of trusts or technology transfer organisations. Very often development teams, trusts or technology transfer organisations have promoted their projects and so they are relatively 'visible'. Other innovations that have not followed formal development pathways (for example, those such as T5 where individual members of staff have organised the innovation process without formal support) are much more difficult to identify and it is therefore very likely that a number of examples of 'hidden' NHS-developed innovations have not been included in the study. It is not possible to say whether these 'hidden' innovations represent a significant proportion of NHS-led innovations or whether they differ in their characteristics,.

Access to busy staff

Researching the adoption NHS-developed technologies requires the good will of staff to participate in the research. For several of the technologies identified as NHS-developed, NHS staff were approached and asked to participate. Unfortunately, lack of available time meant that some staff declined to participate in the study, leading to the exclusion of a technology from the study. This has affected the inclusion of technologies in both Stage 1 and Stage 2 of the study. It is worth noting that, for the majority of technologies, staff were keen to discuss their projects. The motives for participating are important to the validity of the research. For the majority of participants the researchers believe that the motivation was based on wanting to be able to tell their story and highlight issues that they believed to be important to improving the effectiveness of technology development and adoption in the NHS.

Positive spin given by staff to project success

Many of the participants recruited were generally very positive about the technologies of which they had experience. This may have led to some providing a potentially overly positive view of a technology in terms of its benefits and the success in its adoption. It is also likely that for commercial reasons there was pressure to provide a positive view of a technology. The researchers on the study have been aware of this and have where ever possible removed data that they believed was designed to over-emphasise the success of an innovation project.

Focus on technologies rather than institutions and taking a snapshot view

The unit of analysis in this study has been the individual technology. While this has allowed a broad view of how adoption takes place, it has meant that the specific features of organisations with regard to innovation and adoption have not been studied closely. Although this study has looked at

key events that have lead up to adoption where adoption is concerned it has tended to provide a snapshot view of a single occurrence within an organisation. To understand the attitudes, behaviours, processes and structures that an individual organisation exhibits and the way they change over time it would be necessary to follow a number of adoption projects. A longitudinal study might have provided a richer view of the organisational capabilities required of an NHS organisation to facilitate effective technology. A more detailed longitudinal approach also makes it possible to follow the dynamics of technology adoption and to include fully events such as discontinuation of use, decommissioning of redundant technologies and ultimately the results of service configuration. Taking a snapshot of an adoption situation cannot show how the dynamics of adoption change over time.

Limited consideration of where adoption occurs outside NHS e.g. private, abroad or local authorities.

For a number of NHS-developed technologies in the study it was clear that though the NHS was a potential adopter, other categories of organisation such as healthcare organisations in the private sector or outside the UK or other public organisations such as local authorities were sometimes seen as the prime market for the innovation. In such cases the study's focus on adoption into the NHS has prevented a full understanding of how NHS-developed technologies undergo adoption. This is particularly important for technologies that straddle the domains of health care and social care. Further research could take this broader view and would be valuable, especially with respect to technologies for which the NHS is generally a follower rather than leader in adoption. Hence the extent to which a technology is adopted into a healthcare service outside the UK may in turn improve its attractiveness for adoption by the NHS.

12 Recommendations and conclusion

12.1 Recommendations

The survey of technologies conducted during Stage 1 and the more detailed cases investigated for Stage 2 of this research do raise many issues concerning the adoption by the NHS of technologies that were developed within the NHS. These have been set out within this report. In this section ways of addressing these issues will be considered.

Creating systems for innovation

The findings of this research suggest that consideration should be given to creating systems for technological innovation in healthcare that have structures and processes to support adoption at their heart. These systems would need to operate at different levels. At one extreme there is likely to be a need to look across the NHS and at the other a system would need to operate at the level of the individual technology and treat each innovation as an individual project, or part of a portfolio of projects, depending upon the nature of the technology. One approach would be to examine how an improved innovation system might draw on open innovation strategies developed in other sectors. Adopting an open innovation approach would potentially enable optimal management of both NHS-developed and commercially-developed technologies whilst still allowing recognition of the extent to which the NHS is able to contribute to the healthcare technology innovation.

This research has shown several specific areas of the current innovation system that could be used to inform development of these new systems.

1. There is a need for a project/portfolio level system to include mechanisms for reviewing the market implications of NHS-developed technologies at an early stage and take these into account when deciding the form, scope and wider design features of the innovation. This will need to take on board the question whether to involve potential partners at a very early stage and may even mean that the idea is not taken forward within the NHS, or even at all. Where projects do go ahead it is necessary to support NHS-staff in managing their involvement in those projects. One extremely important aspect of this is the provision of support to NHS developers in identifying an appropriate partnership strategy that is likely to result in widespread, successful adoption. Strategies should reflect the need for appropriate matching of capabilities but also branding of subsequent technologies. Adoption issues also need to be are addressed early in the innovation process. As part of this it is necessary to build processes that will improve the visibility of new technological developments to professionals, especially in relation to how new technologies enable improvements to services.

2. Several examples in this study suggest that there is still scope for improving the existing mechanisms for building relationships between NHS innovation teams and potential industrial partners. This includes identification of the most appropriate partners and the provision of incentives for those partners to collaborate with NHS teams.

3. Evidence suggests that there is not always an effective champion for innovation projects, especially during the adoption phase. For effective adoption it is critical to have senior members of a professional group who can take this role but these champions need to be seen as independent of any commercial interest in a technology. The study has shown that professional groups can have a significant role to play in supporting the take-up of new technologies. Further work could examine how best to encourage professional groups to build points of contact between developers and professional bodies in order to improve awareness of the opportunities offered by the technologies.

4. A recurring theme within this research has been problems associated with the speed and scope of HTA processes. This suggests that there is scope for extending HTA processes to include a whole system view that looks at the technology and at the services within which it is embedded. The development process has to be followed with further work to provide evidence of the efficacy of the technology and the benefits it brings. One aspect of this is to consider extending the HTA process to allow a more pluralistic view of acceptable forms of evidence and/or making greater use of alternative approaches to evaluation, such as realistic evaluation. An important dimension to this increased plurality would be the development of a range of HTA processes that were specific to different classes of technology. Choice of process could also take into account the type and magnitude of risk associated with a particular technology. The aim would be faster assessment, and hence sooner deployment, of low risk technologies. Where necessary, subsequent monitoring could be undertaken to gather evidence of longer term benefits and reveal any emerging problems. HTA would also be enhanced if the insights from early adopters were included in assessments. This would allow the challenges in implementation to be assessed as part of an HTA process and provide for a more ongoing review process. HTA processes should also be extended to evaluate the extent to which adoption of a technology might contribute to an organisation's capacity building or 'future readiness'.

5. At present support is sometimes available for early adopters but for the next and subsequent waves of adoption there is often a shortage of project management skills. This means that even where adoption guidance is provided implementation problems still arise. The provision of more support in this area at project/portfolio level therefore needs to be considered

6. Another suggestion based on this research is that NHS organisations consider how to approach 'softer' issues such as culture and commitment during adoption. Individuals and professional groups can be reluctant to adopt a technology despite the availability of high quality evidence to support its use. Adoption processes need to be able to address this. One option might be to introduce external measures to accelerate adoption rates but this would raise the very difficult question of how best to balance autonomy and control within the culture of the NHS. It is already accepted that clinical guidelines, professional standards, patient expectation and funding/tariff systems have significant parts to play but even taken together they are not always sufficient to deliver the desired change. Strengthening coordination between agencies to ensure that efforts to increase adoption of innovative technologies are more closely coupled could be considered.

7. The research has highlighted the potential delays in adoption caused by mismatches between ownerships of technologies and adoption decisions. Within a specific pathway the ownership of a technology and the process within which it is used can be complex. New approaches could be developed to ensure that when preparing for re-design of services, techniques such as process mapping are augmented with an analysis of the ownership of technologies and sub-processes.

8. The study has shown that use of compliance mechanisms may be appropriate in some cases where adoption is slow. However, the root cause of many adoption failures may lie not in a failure of willingness to adopt but the very real difficulty in organising and coordinating service change. This would suggest that in addition to compliance measures, better mechanisms to address the challenges of service change are required. At a basic level this might constitute provision of project management expertise that can supplement the efforts of health professionals. Within this study there was a common problem that adoption was slow due to the lack of project management expertise available. Further support is needed in facilitating the negotiation, design and implementation of redesigned, technology-enabled services.

Figure 20 shows a model on which the design of such systems could be based. The aim of using the model would be to ensure that each resulting system was robust and capable of purposeful action without failure. The model incorporates: a decision-making subsystem; a performance-monitoring subsystem; and a subsystem to carry out the tasks of the system and thus effect its transformations by converting inputs into outputs. It also indicates the connectivity between components that is needed and the forces that will try to disturb it. It thus shows the structures and processes that are likely to be needed and the relationships

that would have to be in place in order to manage innovation projects successfully.
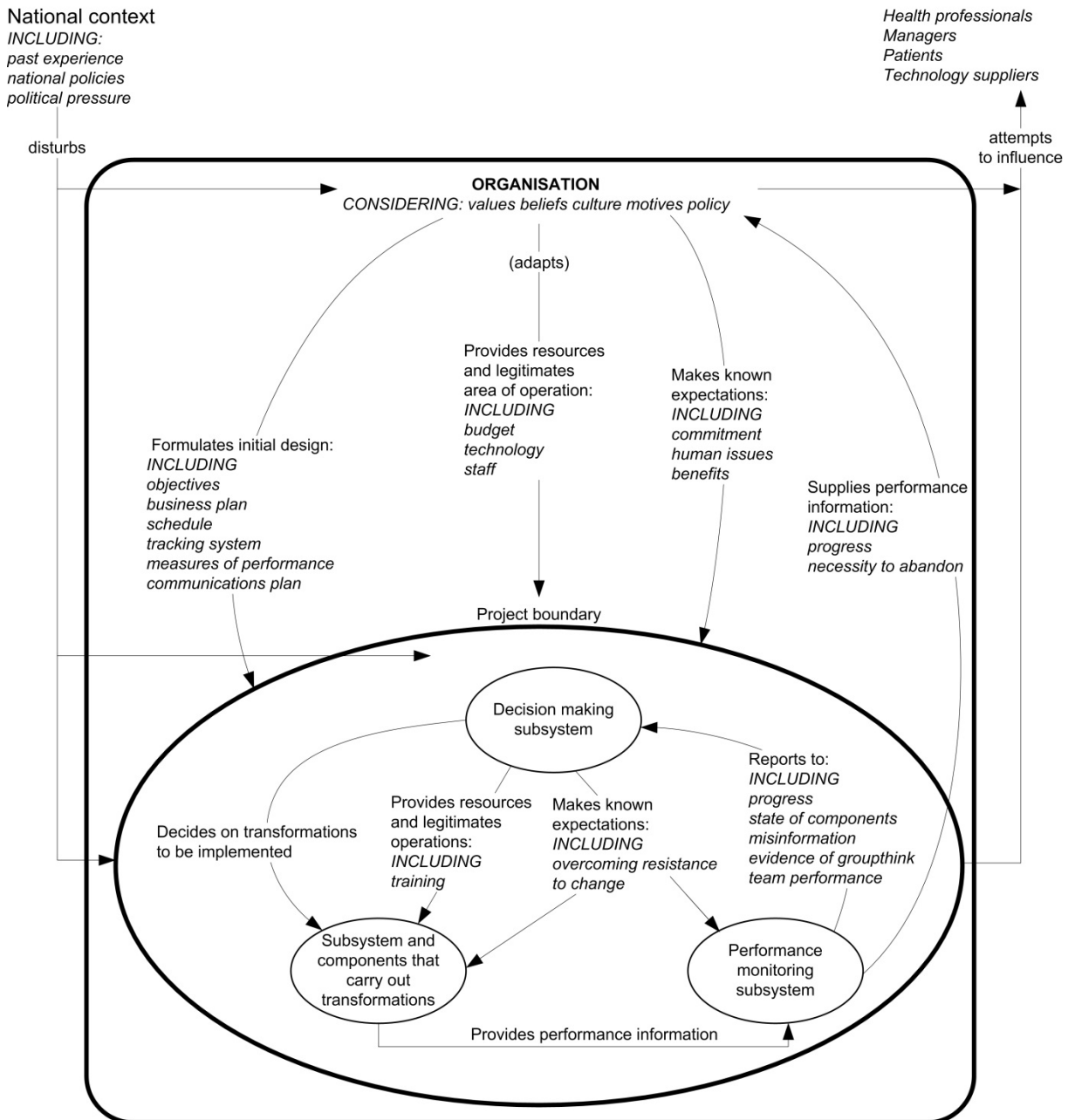
National context
INCLUDING:
past experience
national policies
political pressure

Health professionals
Managers
Patients
Technology suppliers

disturbs

attempts
to influence

ORGANISATION
CONSIDERING: values beliefs culture motives policy

(adapts)

Provides resources
and legitimates
area of operation:
INCLUDING
budget
technology
staff

Makes known
expectations:
INCLUDING
commitment
human issues
benefits

Formulates initial design:
INCLUDING
objectives
business plan
schedule
tracking system
measures of performance
communications plan

Supplies performance
information:
INCLUDING
progress
necessity to abandon

Project boundary

Decision making
subsystem

Reports to:
INCLUDING
progress
state of components
misinformation
evidence of groupthink
team performance

Decides on transformations
to be implemented

Provides resources
and legitimates
operations:
INCLUDING
training

Makes known
expectations:
INCLUDING
overcoming resistance
to change

Subsystem and
components that
carry out
transformations

Performance
monitoring
subsystem

Provides performance information

Figure 20.   Project-specific version of the Formal System Model (Adapted from White and Fortune[221])

12.2   Conclusion

It is clear from this research that the origin of the technology does affect adoptability in terms of both the extent of adoption (within a site and across sites) and the level of success achieved in an individual adopting site. It is also clear that being NHS-developed sometimes has a positive effect and sometimes a negative. Paying attention to the issues identified

by this research could increase the proportion of NHS-developed technologies that gain a positive advantage from their NHS origin. However, it is fair to say that this research has shown that many of the adoption problems encountered by NHS-developed technologies are shared by those developed independently of the NHS so many of the recommendations that will be set out here apply to technology adoption by the NHS generally.

The findings of this research support other studies examined in the literature review that have shown that the ultimate levels of adoption gained are mediated by a number of factors. Awareness of these factors is vital to attempts to deliver successful adoption of appropriate technologies. It is therefore essential to recognise the extent to which technology adoption is a 'wicked problem', especially as it is not possible to identify a single, comprehensive set of measures that will guarantee widespread adoption of a technology in as varied and complex an organisation as the NHS. There is no silver bullet to solve the problems of technology adoption. Having said that, this research does suggest a number of interventions have the potential to bring about improvements and these have been posited above. Interestingly, although the *Innovation Health and Wealth* report[10] had not been produced until this research was almost completed, the suggestions made here do chime with some of the specific adoption issues that are relevant to actions proposed in that report.

12.3 Further research

This research needs to be seen as part of an ongoing search for ways in which the NHS can make greater and better use of technological innovations in order to help it fulfil its mission in difficult times. This piece of work has focussed on adoption of NHS-developed technologies but this is only part of the wider innovation system. Further work to look at creating a system for technological innovation in healthcare has been suggested here. In addition to that, the findings of this study suggest several potential areas for future research. These include

- Exploration of the ways that broad open innovation principles can be applied to the NHS to support a more systematic development of technological solutions in response to clinical and operational problems.

- Evaluation of the success to which NHS-developed technologies are successfully commercialised as part of a wider service package. For example as a social enterprise or some other organisational form.

- Evaluation of the impact of initiatives that seek to promote a more interactive approach to technological innovation in respect of healthcare.

- Evaluation of how the revised NHS structures, in particular Care Commissioning Groups, support inward and outward technology transfer.

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Appendix 1: Protocol and participant information sheets

NHS adoption of NHS developed technologies - telephone survey
REC REFERENCE NUMBER: 09/H0305/56

This protocol relates to Stage 1 and Stage 2 of the study.

Protocol Stage 1

The data collection and analysis for Stage 1 of the study will involve the following stages.

1. Identification of a number of NHS-developed technologies and their respective development. This identification will rely on the co-operation of NHS innovation hubs and other technology transfer organisations that are responsible for facilitating the commercialisation of NHS-developed technologies.

2. Recruitment of participants. A member(s) of each development team will be approached, provided with information about the research project (PIS/CF) by email or hard copy, and requested to participate in the project. Hard copies of the consent form will be used for recording formal consent to participate in the study by members of development teams.

3. Interview development team member(s). Representatives from the development teams will be asked if they are willing to be interviewed and an indication of the content of the interview will be provided in advance of the interview. The interview schedule "NHS-based technology developers" will be used to conduct the interviews. Each interview is expected to last approximately 45 minutes and will be conducted by telephone. Each interview will be recorded providing the participant agrees to this at the start of the interview. If permission to record is not granted notes of the interview will be made.

4. Identification and contact with adopters. The interview data will be used to draw up a list of adopters. A sample of adopters on the list will be approached and provided with information about the research project. Adoption team members will be approached, provided with information about the research project (PIS/CF) by email or hard copy, and requested to participate in the project. Hard copies of the consent form will be used for recording formal consent to participate in the study by members of adopter teams.

5. Interview innovation adopters. A second round of interviews using the schedule for "NHS-developed technology adopters" will be conducted. (See step 3 above.)

6. Coding of interview data. Interview audio recordings/notes will be coded using conventional qualitative data coding techniques (Miles and Huberman 1994; Strauss and Corbin 1998).

Protocol Stage 2

The purpose of Stage 2 of the project is to develop twelve case studies of technologies that are currently being adopted into the NHS. Stage 2 builds on the previous stage by carrying out a deeper and more extensive inquiry into the technology and how it is

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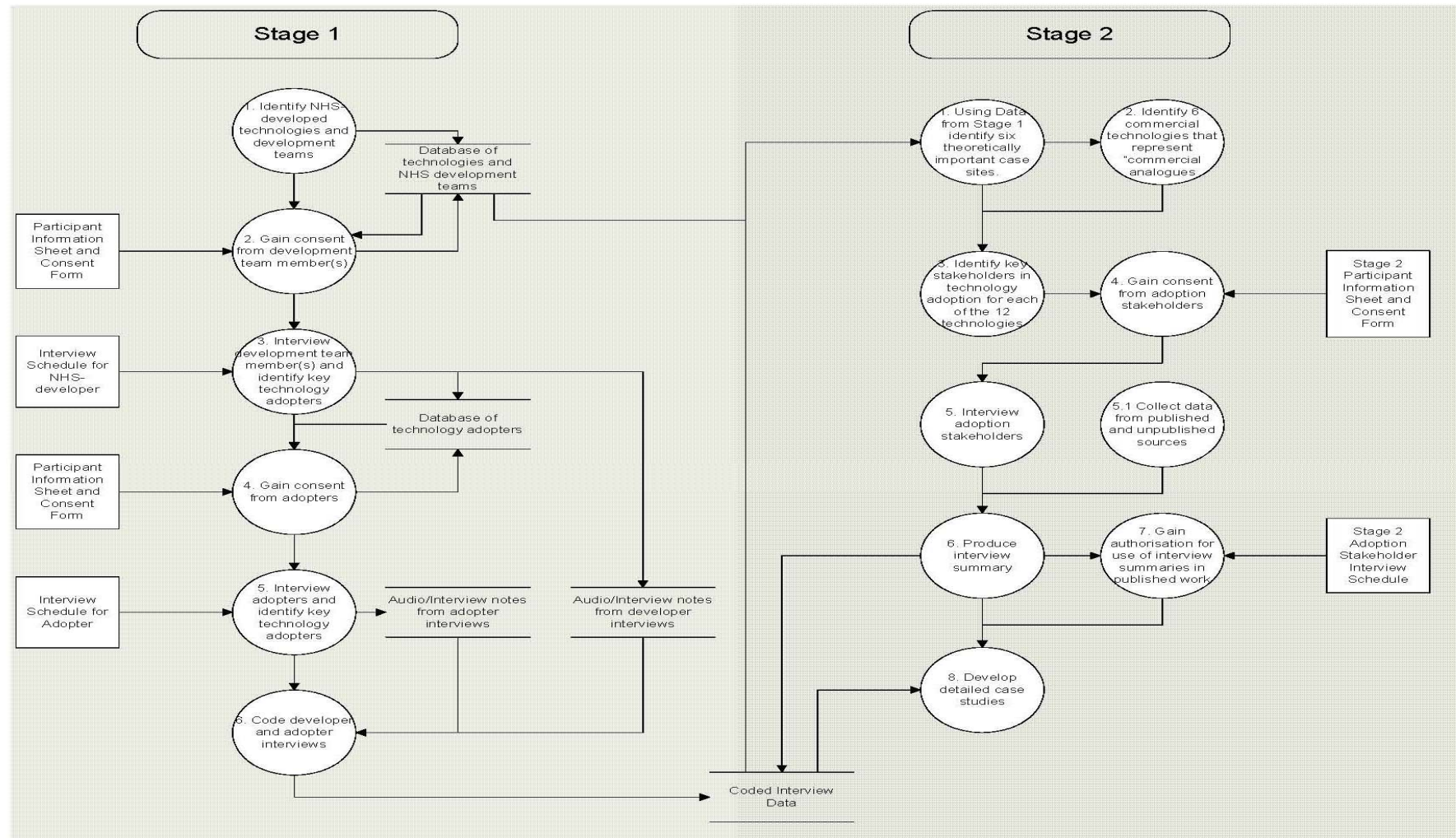6/04/10
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being or has been adopted into the NHS from the perspectives of a range of adoption stakeholders.

1. Using data from Stage 1 identify six theoretically important case sites. Based on the survey in Stage 1 six NHS-developed technologies will be selected on the basis of theoretical sampling strategy (Eisenhardt 1989) in which distinctive examples of technology adoption are identified. The cases will be selected on the basis that they incorporate a significant element of exploitable intellectual property. Other characteristics will also be taken into account including: nature of the product, e.g., herapeutic/diagnostic medical devices, service improvement; extent to which adoption impacts on service design; extent of adoption; and level of success.

2. Identify six commercial technologies that represent "commercial analogues". For each of the six selected cases, a commercial analogue of each technology will be selected. This will be a technology that serves a similar purpose or solves the same or very similar clinical problem to the NHS-developed technology. Thus the technologies researched in Stage 2 will be made up of six pairs of technology, with each pair comprising an NHS-developed and a commercially developed technology.

3. Identify key stakeholders in technology adoption for each of the twelve technologies. Once the twelve technologies have been identified, key stakeholders in the adoption process will be identified. These are likely to include: NHS staff involved in with the development or adoption of the technology; staff in non-NHS organisations involved in development, marketing or other innovation related activities; and staff who provided support during the adoption process.

4. Gain consent from adoption stakeholders. Using the Stage 2 Participant Information Sheet and Consent form, informed consent will be gained from all NHS staff who will participate in Stage 2.

5. Interview adoption stakeholders. Interviews with participants will be held either face-to-face or by telephone. With the agreement of the participant the interview may be recorded using a digital recorder.
    5.1   Collect data from published and unpublished sources relating to the technology and its adoption.

6. Produce interview summary. After each participant interview with the participant a summary will be produced of the key content of the interview. This will be based upon contemporaneous notes taken by the researcher and /or audio recording of the interview. The summary will represent the data that the researcher would wish to use in any published work and will be a themed summary of key points using *verbatim* quotations where necessary.

7. Gain authorisation for use of interview summaries in published work. Participants will be given the opportunity to review the summary of their interview and to add, amend or remove details. Once they are satisfied that the

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Participant Information Sheet and Consent Form:

Technology Developers

Adoption of NHS-developed Technologies Stage 1

The National Institute for Health Research Service Delivery and Organisation Programme (NIHR SDO) has commissioned a number of studies into technology adoption in the NHS. One of these is looking at the adoption by the NHS of technologies that are developed within the NHS. It will be comparing these with commercially-developed technologies.

The chief investigator for the research is Clive Savory, Senior Lecturer in Technology Management at the Open University, based in Milton Keynes. You are invited to participate in this research project. Insights from this research may also inform course development in the area of technology management at the Open University.

Project Aims

The NHS is experiencing a massive amount of technological change. In all areas of healthcare, pharmaceutical, diagnostic, therapeutic and informatics technologies are being developed that have potential to improve the efficiency and the effectiveness of the NHS. Indeed, actual improvement of NHS services is dependent on the extent to which new technologies can be adopted successfully. It is the case, however, that adoption of this new technology will inevitably lead to the need for organisational change, re-design of NHS processes and the re-definition of staff roles.

This research is concerned with whether technologies developed within the NHS have inherently different adoption characteristics compared with technologies developed outside the NHS. It is asking whether the fact a technology was developed by NHS staff, in an NHS context, makes it more or less likely to be adopted successfully in other parts of the NHS.

This research will investigate whether the adoptability of NHS-developed technologies differs from equivalent commercially-developed technologies. The study will therefore assess how the balance of influence on technology development between technology users and technology suppliers influences the adoption process.

The research will seek to investigate:
- Does the origin of an innovation, either from within or outside the NHS, impact on the technology assessment process that underpins adoption decisions?
- Are adoption decisions of NHS-developed innovations affected by associated informal professional networks?
- Does the origin of an innovation in the NHS make it more compatible for adoption in the NHS compared to equivalent commercially-developed technologies?
- Do the evidence-bases and implementation guidelines developed by NHS-developers reduce the perceived complexity, relative advantage and trialability of NHS-developed innovations?

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The research will take place in two stages. The first stage involves telephone surveys that will investigate the experience of adopters of NHS developed technologies. The second stage will select a small number of examples of technology adoption for more detailed investigation. This information sheet is just related to Stage 1 of the study.

Why have you been asked to take part in this research study?

You have been approached to be involved in this research study because you are involved in the development of an NHS-developed innovation. You have been identified as a potential research participant by staff at an NHS innovation hub or other technology transfer organisations with whom you have been in contact.

Potential Benefits and Risks of Participation

The main benefit of taking part in the study is that you will have an opportunity to contribute your views on the benefits and problems that you perceive in the adoption of NHS-developed technologies. The perspective you contribute to the research on adoption of NHS-developed technologies will be represented in published findings and will be used to inform NHS policy and practise. This study has been funded by the Service Delivery Organisation of the National Institute for Health Research. An integral part of the funding application process was an expert review of the study to ensure that it was relevant and worthwhile for the NHS. The study has also been reviewed by the Cambridgeshire 4 Research Ethics Committee. You can therefore be confident that any time you allocate to participating in this study will be worthwhile and contribute to the improvement of NHS procedures.

There are no significant risks associated with taking part in this study. Individual participants, their organisations and the technology products discussed will be anonymised in any published data. It is however important to note that where an innovation is distinctive there are limits to the extent to which anonymity can be maintained. For example, some technologies are only produced and used by a relative narrow range of organisations.

The technical detail of specific innovations is not the principal concern of this research. This means there is little risk of commercially sensitive information relating to intellectual property inadvertently being released. However, it is important that participants know that any intellectual property associated with the innovation have been properly protected commercially and its details are free to be placed into the public domain before they take part in the study. Should you be in any doubt about the extent to which details can be made public, you should consult with staff in the R&D department of the NHS trust in which you work or other individuals or organisations with an interest in the intellectual property.

Research Procedures

Once all your questions have been answered to your satisfaction and you decide to participate in this research study, you will be asked to sign the consent form attached.

As a participant, you will be take part in a semi-structured telephone interview lasting approximately 45 minutes. The main purpose of the interview will be to allow you recall your experience of either the development or adoption of NHS-developed technologies. It is intended that the interviews will be recorded but if you object to this please make this clear at the start of the interview and do not tick the box on the consent form giving permission for the recording of the interview.

Your responses in the interview will be anonymised prior to any publications of the data you provide. The data will be used to develop an understanding of the issues that affect successful implementation of NHS-

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developed technologies. If you agree on the consent form, we may also use *verbatim* quotations from your interview, however, if you would prefer us not use direct quotations then please indicate this on the consent form. In all cases, any references to people, institutions and specific technologies will be removed from the quotations prior to publication. A working paper that summarises the results of this telephone survey will be produced in late 2010. As a participant in this survey you will receive a copy of this paper. Data collected in the survey may also be published in other reports and articles produced by the project team.

During stage 2 of this research a small number of cases of technology adoption will be selected from those involved in Stage 1 and subjected to more detailed case study research. If you are invited to participate in stage 2 you will be provided with a participant information sheet and consent form specifically for stage 2. You will not be automatically enrolled into Stage 2 without your consent.

Confidentiality

All reasonable means will be used to ensure the anonymity of research participants. Data collected during this research will be treated as confidential and all personal data will only be available to the project team. All data collected from participants will be anonymised in any published work; the names of individuals and institutions will be removed.

It is the nature of technological innovations that they are distinctive. This implies that it may be possible for other specialists working in the field to identify individuals and institutions discussed in the research. In order to provide anonymity of participants, any technologies discussed in interviews will be identified in only general terms. They will be referred to using only a general description of the technology and its context of use, for example, an x-ray based diagnostic imaging technology used in the treatment of bowel cancer.

Data collected in the interviews will be handled in compliance with the Data Protection Act (1998). Access to the raw data will be limited to the chief investigator and other members of the project team at the Open University. Audio recordings of the interviews will be retained by the research team for twelve months after the study is complete, at which point the recordings will be erased. As members of staff at the Open University the project team are covered by the university's professional indemnity insurance whilst carrying out this research.

Participation

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time prior to the publication of the research findings.

Complaints

If you should have cause to complain about any aspects of the research, you should contact:

Glyn Martin

Head of Department of Communication and Systems

Faculty of Mathematic, Computing and Technology

The Open University

Walton Hall

Milton Keynes

MK7 6AA

Participant Consent Form

Research Project: Adoption of NHS-developed technologies

Please print two hard copies of this form and then after completion, sign both copies of the form. Then send both hard copies to the Chief Investigator at the address given below. You will then receive back one countersigned copy of the form.

I have had an opportunity to ask questions about my participation _____   ☐ *(please tick if agree)*

I understand that I can withdraw at any time without prejudice prior to the research findings being published

_____ _____   ☐ *(please tick if agree)*

I am happy for any interview I give to be recorded _____   ☐ *(please tick if agree)*

I am happy for verbatim quotations to be used in published work_____   ☐ *(please tick if agree)*

I understand that the chief investigator cannot guarantee that participants in the research will remain anonymous

_____   ☐ *(please tick if agree)*

I understand that insights and examples gathered during the research may be used in teaching and training events by the Chief Investigator and other members of the research team _____   ☐ *(please tick if agree)*

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form.

_____
Name of Participant (Printed)

_____
Name of Participant (Signed)

_____
Date

Should you have questions or concerns before, during or after your participation in this study please contact the chief investigator using the contact details below.

Clive Savory	Phone: 01908 653435
Chief Investigator	Mobile: 07855 553310
Technology Management Research Group	Email: c.savory@open.ac.uk
Department of Communication and Systems	
Faculty of Mathematic, Computing and Technology	
The Open University	
Walton Hall	
Milton Keynes	
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Participant Information Sheet and Consent Form

Technology Adopters

Adoption of NHS-developed Technologies Stage 1

The National Institute for Health Research Service Delivery and Organisation Programme (NIHR SDO) has commissioned a number of studies into technology adoption in the NHS. One of these is looking at the adoption by the NHS of technologies that are developed within the NHS. It will be comparing these with commercially-developed technologies.

The chief investigator for the research is Clive Savory, Senior Lecturer in Technology Management at the Open University, based in Milton Keynes. You are invited to participate in this research project. Insights from this research may also inform course development in the area of technology management at the Open University.

Project Aims

The NHS is experiencing a massive amount of technological change. In all areas of healthcare, pharmaceutical, diagnostic, therapeutic and informatics technologies are being developed that have potential to improve the efficiency and the effectiveness of the NHS. Indeed, actual improvement of NHS services is dependent on the extent to which new technologies can be adopted successfully. It is the case, however, that adoption of this new technology will inevitably lead to the need for organisational change, re-design of NHS processes and the re-definition of staff roles.

This research is concerned with whether technologies developed within the NHS have inherently different adoption characteristics compared with technologies developed outside the NHS. It is asking whether the fact a technology was developed by NHS staff, in an NHS context, makes it more or less likely to be adopted successfully in other parts of the NHS.

This research will investigate whether the adoptability of NHS-developed technologies differs from equivalent commercially-developed technologies. The study will therefore assess how the balance of influence on technology development between technology users and technology suppliers influences the adoption process.

The research will seek to investigate:
- Does the origin of an innovation, either from within or outside the NHS, impact on the technology assessment process that underpins adoption decisions?
- Are adoption decisions of NHS-developed innovations affected by associated informal professional networks?
- Does the origin of an innovation in the NHS make it more compatible for adoption in the NHS compared to equivalent commercially-developed technologies?
- Do the evidence-bases and implementation guidelines developed by NHS-developers reduce the perceived complexity, relative advantage and trialability of NHS-developed innovations?

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The research will take place in two stages. The first stage involves telephone surveys that will investigate the experience of adopters of NHS developed technologies. The second stage will select a small number of examples of technology adoption for more detailed investigation. This information sheet is just related to Stage 1 of the study.

Why have you been asked to take part in this research study?

You have been approached to be involved in this research study because you are involved in the adoption of an NHS-developed innovation. You will have been identified as a potential research participant by the innovation's developer, commercial organisation or technology transfer organisation.

Potential Benefits and Risks of Participation

The main benefit of taking part in the study is that you will have an opportunity to contribute your views on the benefits and problems that you perceive in the adoption of NHS-developed technologies. The perspective you contribute to the research on adoption of NHS-developed technologies will be represented in published findings and will be used to inform NHS policy and practise. This study has been funded by the Service Delivery Organisation of the National Institute for Health Research. An integral part of the funding application process was an expert review of the study to ensure that it was relevant and worthwhile for the NHS. The study has also been reviewed by the Cambridgeshire 4 Research Ethics Committee. You can therefore be confident that any time you allocate to participating in this study will be worthwhile and contribute to the improvement of NHS procedures.

There are no significant risks associated with taking part in this study. Individual participants, their organisations and the technology products discussed will be anonymised in any published data. It is however important to note that where an innovation is distinctive there are limits to the extent to which anonymity can be maintained. For example, some technologies are only produced and used by a relative narrow range of organisations.

The technical detail of specific innovations is not the principal concern of this research. This means there is little risk of commercially sensitive information relating to intellectual property inadvertently being released. However, it is important that participants know that any intellectual property associated with the innovation have been properly protected commercially and its details are free to be placed into the public domain before they take part in the study. Should you be in any doubt about the extent to which details can be made public, you should consult with staff in the R&D department of the NHS trust in which you work or other individuals or organisations with an interest in the intellectual property.

Research Procedures

Once all your questions have been answered to your satisfaction and you decide to participate in this research study, you will be asked to sign the consent form attached.

As a participant, you will be take part in a semi-structured telephone interview lasting approximately 45 minutes. The main purpose of the interview will be to allow you recall your experience of either the development or adoption of NHS-developed technologies. It is intended that the interviews will be recorded but if you object to this please make this clear at the start of the interview and do not tick the box on the consent form giving permission for the recording of the interview.

Your responses in the interview will be anonymised prior to any publications of the data you provide. The data will be used to develop an understanding of the issues that affect successful implementation of NHS-developed technologies. If you agree on the consent form, we may also use *verbatim* quotations from

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your interview, however, if you would prefer us not use direct quotations then please indicate this on the consent form. In all cases, any references to people, institutions and specific technologies will be removed from the quotations prior to publication. A working paper that summarises the results of this telephone survey will be produced in late 2010. As a participant in this survey you will receive a copy of this paper. Data collected in the survey may also be published in other reports and articles produced by the project team.

During stage 2 of this research a small number of cases of technology adoption will be selected from those involved in Stage 1 and subjected to more detailed case study research. If you are invited to participate in stage 2 you will be provided with a participant information sheet and consent form specifically for stage 2. You will not be automatically enrolled into Stage 2 without your consent.

Confidentiality

All reasonable means will be used to ensure the anonymity of research participants. Data collected during this research will be treated as confidential and all personal data will only be available to the project team. All data collected from participants will be anonymised in any published work; the names of individuals and institutions will be removed.

It is the nature of technological innovations that they are distinctive. This implies that it may be possible for other specialists working in the field to identify individuals and institutions discussed in the research. In order to provide anonymity of participants, any technologies discussed in interviews will be identified in only general terms. They will be referred to using only a general description of the technology and its context of use, for example, an x-ray based diagnostic imaging technology used in the treatment of bowel cancer.

Data collected in the interviews will be handled in compliance with the Data Protection Act (1998). Access to the raw data will be limited to the chief investigator and other members of the project team at the Open University. Audio recordings of the interviews will be retained by the research team for twelve months after the study is complete, at which point the recordings will be erased. As members of staff at the Open University the project team are covered by the university's professional indemnity insurance whilst carrying out this research.

Participation

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time prior to the publication of the research findings.

Complaints

If you should have cause to complain about any aspects of the research, you should contact:

Glyn Martin

Head of Department of Communication and Systems

Faculty of Mathematic, Computing and Technology

The Open University

Walton Hall

Milton Keynes

MK7 6AA

Participant Consent Form

Research Project: Adoption of NHS-developed technologies

Please print two hard copies of this form and then after completion, sign both copies of the form. Then send both hard copies to the Chief Investigator at the address given below. You will then receive back one countersigned copy of the form.

I have had an opportunity to ask questions about my participation _____   ☐ *(please tick if agree)*

I understand that I can withdraw at any time without prejudice prior to the research findings being published
_____   _____   ☐ *(please tick if agree)*

I am happy for any interview I give to be recorded _____   ☐ *(please tick if agree)*

I am happy for verbatim quotations to be used in published work_____   ☐ *(please tick if agree)*

I understand that the chief investigator cannot guarantee that participants in the research will remain anonymous
_____   ☐ *(please tick if agree)*

I understand that insights and examples gathered during the research may be used in teaching and training events by the Chief Investigator and other members of the research team _____   ☐ *(please tick if agree)*

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form.

_____
Name of Participant (Printed)

_____
Name of Participant (Signed)

_____
Date

Should you have questions or concerns before, during or after your participation in this study please contact the chief investigator using the contact details below.

Clive Savory	Phone:	01908 653435
Chief Investigator	Mobile:	07855 553310
Technology Management Research Group	Email:	c.savory@open.ac.uk
Department of Communication and Systems		
Faculty of Mathematic, Computing and Technology		
The Open University		
Walton Hall		
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Participant Information Sheet and Consent Form:

Adoption of NHS-developed Technologies Stage 2

This project is one of a number of studies that has been commissioned by the National Institute for Health Research Service Delivery and Organisation Programme (NIHR SDO) into technology adoption in the NHS. It is looking at the adoption by the NHS of technologies that are developed within the NHS and comparing them with equivalent commercially-developed technologies.

The chief investigator for the research is Clive Savory, Senior Lecturer in Technology Management at the Open University. You are invited to participate in this research project. Insights from this research may also inform course development in the area of technology management at the Open University.

Project Aims

This research is concerned with whether technologies developed within the NHS have inherently different adoption characteristics compared with technologies developed outside the NHS. It is asking whether the fact a technology was developed by NHS staff, in an NHS context, makes it more or less likely to be adopted successfully in other parts of the NHS. The study will therefore assess how the balance of influence on technology development between technology users and technology suppliers influences the adoption process.

The research will seek to answer the following questions:
- Does the origin of an innovation, either from within or outside the NHS, impact on the technology assessment process that underpins adoption decisions?
- Are adoption decisions of NHS-developed innovations affected by associated informal professional networks?
- Does the origin of an innovation in the NHS make it more or less compatible for adoption in the NHS compared to equivalent commercially-developed technologies?
- Do the evidence-bases and implementation guidelines developed by NHS-developers reduce the perceived complexity, relative advantage and trialability of NHS-developed innovations?

The research is taking place in two stages. The first stage involved telephone surveys that investigated the experience of adopters of NHS developed technologies. The second stage will select a small number of examples of these technologies for more detailed investigation and pair each of them with a similar or equivalent externally-developed technology. Semi-structured interviews will be carried out with adopters of these technologies and with those who played a part in the adoption decisions. This information sheet just relates to Stage 2 of the study.

Why have you been asked to take part in this research study?

You have been approached to participate in this research study because you are involved in the adoption of an NHS-developed innovation or an innovation that is similar or equivalent to one that is NHS-

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developed. You have been identified as a potential research participant by staff at an NHS innovation hub or other technology transfer organisations with whom you have been in contact.

Potential Benefits and Risks of Participation

The main benefit of taking part in the study is that you will have an opportunity to contribute your views on the benefits and problems that you perceive in the adoption of technologies by the NHS. The perspective you contribute to will be represented in published findings and will be used to inform NHS policy and practise. This study has been funded by the Service Delivery Organisation of the National Institute for Health Research. An integral part of the funding application process was an expert review of the study to ensure that it was relevant and worthwhile for the NHS. The study has also been reviewed by reviewed by the Cambridgeshire 4 Research Ethics Committee. You can therefore be confident that any time you allocate to participating in this study will be worthwhile and contribute to the improvement of NHS procedures.

The nature of this research project is such that there are inherent limits to the level of confidentiality that can be maintained for research participants. The case studies will be based on specific innovations that are by definition distinctive and some of them may only be used by a relatively narrow range of hospitals and Trusts. It is therefore possible that other members of the NHS and wider healthcare sector might be able to identify the innovation and some likelihood that they may associate it with your place of work. It is therefore not possible for the researcher to guarantee anonymity for any participants in this research. Further information on confidentiality is provided later in this document.

The technical detail of specific innovations is not the principal concern of this research. This means there is little risk of commercially sensitive information relating to intellectual property inadvertently being released. However, it is important that participants know that any intellectual property associated with the innovation have been properly protected commercially and its details are free to be placed into the public domain before they take part in the study. Should you be in any doubt about the extent to which details can be made public, you should consult with staff in the R&D department of the NHS trust in which you work or other individuals or organisations with an interest in the intellectual; property.

Research Procedures

Once all your questions have been answered to your satisfaction and you decide to participate in this research study, you will be asked to sign the consent form attached.

As a participant, you will be take part in a semi-structured interview lasting approximately 45 minutes. The main purpose of the interview will be to allow you recall your experience of the adoption of an NHS-developed technology or a similar or equivalent innovation. It is intended that the interviews will be recorded but if you object to this please make this clear at the start of the interview and do not tick the box on the consent form giving permission for the recording of the interview.

Your responses in the interview will be anonymised prior to any publications of the data you provide. The data will be used to develop an understanding of the issues that affect successful implementation of NHS-developed technologies and allow their adoption to be compared with technologies develop independently of the NHS. If you agree on the consent form, we may also use *verbatim* quotations from your interview, however, if you would prefer us not use direct quotations then please indicate this on the consent form. In all cases, any references to people, institutions and specific technologies will be removed from the quotations prior to publication. Information collected during interviews will be included in a report to the funder and may be included in other reports and publications produced by the project team.

Confidentiality

All reasonable means will be used to ensure the anonymity of research participants. Data collected during this research will be treated as confidential and all personal data will only be available to the project team. All data collected from participants will be anonymised in any published work; the names of individuals and institutions will be removed. In order to maximise the anonymity of participants, any technologies discussed in interviews will be only be referred to reports and publications by reference to a general description of the technology and its context of use (for example, an x-ray based diagnostic imaging technology used in the treatment of bowel cancer).

After the interview has been conducted you will be given opportunity to see a summary of the key points of the interview and any statements you have made that might subsequently be used in reports and/or publications. You will have the opportunity to clarify, amend or withdraw any statements that you have made and to indicate any statements that you would not wish to be made public. Any statements that are used in publications will not identify you by name. After reviewing the interview summary you will be asked to sign it to confirm that data in the summary can be placed into the public domain.

Data collected in the interviews will be handled in compliance with the Data Protection Act (1998). Access to the raw data will be limited to the chief investigator and other members of the project team at the Open University. Audio recordings of the interviews will be retained by the research team for twelve months after the study is complete, at which point the recordings will be erased. As members of staff at the Open University the project team are covered by the university's professional indemnity insurance whilst carrying out this research.

Participation

Your participation is entirely voluntary. You are free to choose not to participate. Should you choose to participate, you can withdraw at any time prior to the publication of the research findings.

Complaints

If you should have cause to complain about any aspects of the research, you should contact:

Glyn Martin
Head of Department of Communication and Systems
Faculty of Mathematics, Computing and Technology
The Open University
Walton Hall
Milton Keynes
MK7 6AA

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Participant Consent Form

Research Project: Adoption of NHS-developed technologies

Please print two hard copies of this form and then after completion, sign both copies of the form and send them to the Chief Investigator at the address given below. One countersigned copy of the form will be returned to you.

	Please tick if agree
I have had an opportunity to ask questions about my participation	☐
I understand that I can withdraw at any time without prejudice prior to the research findings being published	☐
I am happy for any interview I give to be recorded	☐
I am happy for verbatim quotations to be used in published work subject to my agreement after approving a summary of my interview	☐
I understand that the chief investigator cannot guarantee that participants in the research will remain anonymous	☐
I understand that insights and examples gathered during the research may be used in teaching and training events by the Chief Investigator and other members of the research team	☐

I have read this consent form and I understand what is being requested of me as a participant in this study. I freely consent to participate. I have been given satisfactory answers to my questions. The investigator provided me with a copy of this form.

_____
Name of Participant (Printed)

_____
Name of Participant (Signed)

_____
Date

Should you have questions or concerns before, during or after your participation in this study please contact the chief investigator using the contact details below.

Dr Clive Savory	Phone:	01908 653435
Chief Investigator	Mobile:	07855 553310
Technology Management Research Group	Email:	c.savory@open.ac.uk

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Appendix 2: Stage 1 Analysis

Assistive technologies

Technology Category	Assistive
Code	A1
Originator organisation/approximate year of development if known	NHS Trust / 1996
Developed by	Clinician
Partners involved	Service provider
Technology Triggered by (/potential)	Drawing on long term experience / Discussion with colleagues
Need technology fulfils	Existing operational need
Novelty	First in sector / 'Me too'
Evaluation process	Pilot study only
Benefits (/features)	Improved patient outcomes / Cheaper
Adoption/purchase triggers	Patient need
Cost of technology	£101-£1000
Implementation costs	None
Infrastructure requirements	Innovation self contained
Changes to WHO carries out procedures	No
Changes to WHERE procedures are carried out	No
Potential sites NHS	Adopted mainly in local authorities
Potential sites abroad	Only marketed in UK
NHS sites adopted (/length of time in use)	Abandoned
Non NHS sites adopted	Used in community
Sites abroad adopted	0
NHS sites abandoned	Discontinued/abandoned
Non NHS sites abandoned	
Ease of implementation	Easy
IP protected by	Not protectable
IP owned by	Not protectable
Different approach/ comments	Yes / Use a Hub next time
NHS financial investment	No direct finance BUT other support
Implementation guidelines or support	Written guidelines / Informal advice

Clinical IS technologies

Technology Category	Clinical IS	Clinical IS	Clinical IS	Clinical IS	Clinical IS	Clinical IS
Code	C1	C2	C3	C4	C5	C6
Originator organisation/approximate year of development if known	NHS Trust with University collaboration	NHS Trust	NHS Trust	NHS Trust with industrial partnership	Developed outside NHS (abroad) / 2003 then re-developed with NHS co-operation	NHS Trust
Developed by	Clinician	Clinician	Clinician	Clinician	Clinician	Technologist R&D Fellow within Trust
Partners involved	Other	Social enterprise			Marketing / Technologist / Service provider	Management support
Part played by a University	They helped on the project	Allowed clinician time/secondment		No	No	No
Technology Triggered by (/potential)	Perception of growing need	Shift care to community	Other		Discussion with colleagues	Incremental improvement to a clinical problem
Need technology fulfils	Existing clinical need	Improving care fro long term, conditions			Structure clinical decision making / Existing clinical need	Existing clinical need
Novelty	First in sector	First in sector	Not very but better than what we had before		Trailblazing / First in sector	First in sector / First in organisation / 'Me too'
Evaluation process	N/A	Clinical trial	Other	Inventor driven	Clinical trial	PDSA cycle
Benefits (/features)	Improved patient experience	Cheaper / Improved patient outcomes	Cheaper / Improved patient outcomes	Improved patient experience	Cheaper / Quicker / Improved patient outcomes / Process acceleration	Improved patient outcomes
Adoption/purchase triggers	Patient need	Shift care to community		Other	Patient safety agenda	Formal care guideline
Cost of innovation	£0-£100				£5000+	None to NHS £101-1000 non NHS
Implementation costs	None		£1001-£5000 / £5000+	N/A		£101-£1000
Infrastructure requirements	Standard infrastructure	Self-contained service package	Minor alterations / Standard infrastructure	Innovation self contained	Innovation self contained	Standard Infrastructure

Technology Category	Clinical IS	Clinical IS	Clinical IS	Clinical IS	Clinical IS	Clinical IS
Code	C1	C2	C3	C4	C5	C6
Cost savings to NHS (Direct/Indirect)	Yes/No	Yes			Yes	No/Yes
Changes to WHO carries out procedures	No	Consultant replaced by trained nurse	No	N/A	No	No
Changes to WHERE procedures are carried out	No	Outpatients to community clinic	No	N/A	No	No
NHS sites abandoned	0		One		0	0
Ease of implementation	Easy	Minor changes	Other	Easy	Minor changes	Other
IP protected by	Copyright	Copyright			Patent Trademark Copyright	Patent Trademark Copyright
IP owned by	Developer	Developer			Developer	NHS Trust
Different approach/ comments	Yes / Might have sought sponsorship or help from NHS earlier but did not want to lose control		No / Need the right technology to do the right job rather than its background		Yes / Management should be engaged earlier	Yes /Would have concentrated more on the disseminating process
NHS financial investment	No direct finance from trust	No direct finance from Trust		No direct finance from BUT other support	Trust bought system at reduced rate	No direct finance from Trust
Implementation guidelines or support	Written guidelines	Support from NHS-developer	Informal advice		Written guidelines / Formal training	Not necessary

Infrastructure technologies

Technology Category	Infrastructure	Infrastructure	Infrastructure	Infrastructure	Infrastructure
Code	I1	I2	I3	I4	I5
Originator organisation/approximate year of development if known	NHS Trust / 2000	NHS Trust with University collaboration	NHS Trust	NHS Trust with University collaboration	NHS Trust
Developed by	Senior Theatre Nurse	Nurse	Nurse	Manager	Clinician
Partners involved	Marketing / Manufacturing via partner	Manufacturer / Marketing	NHS Innovations North and DLAP	Manufacturer / Marketing	NHS Innovation Hub / Marketing
Part played by a University	They helped on the project	They helped on the project	They helped on the project		
Technology Triggered by (/potential)	Flash of inspiration or Eureka moment	Incremental improvement to a clinical problem	Incremental improvement to a clinical problem		
Need technology fulfils	Existing clinical need	Me too' product / Existing clinical need	Existing clinical need	Existing clinical need / Latent clinical need	Me too' product / Existing clinical need / Existing operational need
Novelty	Not very but better than we had before	Trailblazing / Just different	Trailblazing / First in sector	Trailblazing	'Me too'
Evaluation process	Clinical trial	PDSA cycle	No evaluation done		
Benefits (/features)	Cheaper / Improved patient experience	Improved patient outcomes	Improved patient outcomes	Improved patient outcomes	Health and Safety benefits for users
Adoption/purchase triggers	Financial benefits	Financial benefits	Safer	Safer	Financial benefits
Cost of innovation	£0-£100	£101-£1000	£101-£1000	£5000+	£1001-£5000
Adopter aware of NHS origins / origin affect decision to adopt		No / No	Yes / No		
Implementation costs	£0-£100	None	N/A	£5000+	None
Infrastructure requirements	Innovation self contained	Innovation self contained	Standard infrastructure	Major alterations	Innovation self contained
Changes to WHO carries out procedures	No	Yes	No	No	No
Changes to WHERE procedures are carried out	No	No	No	No	No

Technology Category	Infrastructure	Infrastructure	Infrastructure	Infrastructure	Infrastructure
Code	I1	I2	I3	I4	I5
Potential sites NHS	500 to 999	Most PCTs		25 to 49	1000+
NHS sites adopted (/length of time in use)	Some adoption	In routine use	Not in routine use	1 to 24	1 to 24
NHS sites abandoned	0	0	N/A		
Ease of implementation	Easy	Easy	Easy	Easy	Easy
IP protected by	Patent	Licensing	Patent	Patent	Not protectable
IP owned by	Inventor / NHS Trust		Innovations North	NHS Trust / University	NHS Trust / NHS Innovation NHS Innovation Hub
Different approach/ comments	No / But would try and do it quicker	No / Would adopt NHS technologies in the future because someone in NHS would potentially have better understanding of needs within NHS	No / Would have been useful to have a project manager	Yes / By limiting number of people/parties involved in the innovation	Yes / Many bogus ideas floating around needs balancing out a bit
NHS financial investment	Trust invested in development	Trust invested in development	Requested information on this		
Implementation guidelines or support	Not necessary	Written guidelines / Handbook/written guide	Not necessary	Formal training	Formal training

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Learning/training/teaching technologies

Technology Category	Learning/training/teaching	Learning/training/teaching	Learning/training/teaching
Code	L1	L2	L3
Originator organisation/approximate year of development if known	NHS Trust / 1984	NHS Trust	NHS Trust / 2003
Developed by	Medical Physicists	Clinician	Clinician
Partners involved	Software house and NHS Innovation Hub	Design	Manufacturer / NHS Innovation Hub
Part played by a University	They helped on the project	No	No
Technology Triggered by (/potential)	Incremental improvement to a clinical problem	Other	Flash of inspiration or Eureka moment
Need technology fulfils	Other	Other	Existing operational need
Novelty	First in sector	Trailblazing	Trailblazing
Evaluation process	No significant evaluation has been carried out	None	Pilot on site
Benefits (/features)		Other	Improved patient outcomes
Adoption/purchase triggers		N/A	Safer
Cost of innovation	£500 per licence	£0-£100	£1001-£5000
Implementation costs	N/A	N/A	£5000+
Cost savings to NHS (Direct/Indirect)	N/A	No/No	No/Yes
Difficulty showing savings	N/A	No quantitative evaluation carried out	No quantitative evaluation carried out
Changes to WHO carries out procedures	N/A	No	No
Changes to WHERE procedures are carried out	N/A	No	No
Influence of networks Informal/Formal			No/No

Technology Category	Learning/training/teaching	Learning/training/teaching	Learning/training/teaching
Code	L1	L2	L3
Potential sites NHS	Where radiologists are trained in UK and abroad	N/A	500 to 999
NHS sites adopted (/length of time in use)	25 to 49	N/A	1 to 24
Non NHS sites adopted	N/A	N/A	0
Sites abroad adopted	Many	N/A	1 to 24
NHS sites abandoned	0	N/A	0
Ease of implementation	Easy	Easy	
IP protected by	Copyright	Copyright	Licensing
IP owned by	NHS Trust	Developer	NHS Trust
Different approach/ comments		No / Approach with contingent to main working lives	Yes / Would use various funds that can be accessed for funding development work
NHS financial investment	No direct finance BUT other support	No direct finance from Trust	No direct finance from Trust
Implementation guidelines or support		N/A	Written guidelines

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Measuring/monitoring technologies

Technology Category	Measuring/monitoring	Measuring/monitoring	Measuring/monitoring
Code	M1	M2	M3
Originator organisation/approximate year of development if known	NHS Trust	NHS Trust	NHS Trust
Developed by	Clinician	Technologist	Clinician
Partners involved	NHS Innovation Hub / Manufacturer / Marketing	Manufacturer / Marketing	
Part played by a University	They helped on the project	Other	
Technology Triggered by (/potential)	Other	Other	Incremental improvement to a clinical problem
Need technology fulfils	Existing clinical need	Other	
Novelty	Trailblazing / Not very but better than we had before	Just different	Trailblazing
Evaluation process	Significant amount of evaluation done inc clinical trial of technology	Clinical trial	Clinical trial
Benefits (/features)	Cheaper / Quicker / Improved patient outcomes / Process acceleration	Cheaper / Quicker / Improved patient outcomes / Process acceleration	Improved patient outcomes / Process acceleration
Adoption/purchase triggers	Financial benefits	Other	
Cost of innovation	£5000+	£101-£1000	
Implementation costs	£101-£1000	None	£5000+
Infrastructure requirements	Minor alterations	Innovation self-contained	Between minor and major alterations
Cost savings to NHS (Direct/Indirect)	Yes	No/Yes	
Difficulty showing savings	Yes	N/A	
Changes to WHO carries out procedures	Yes	No	No
Changes to WHERE procedures are carried out	Yes	No	No
Potential sites NHS	200 to 499	1000+	
Potential sites UK non NHS	200 to 499	1000+	

Technology Category	Measuring/monitoring	Measuring/monitoring	Measuring/monitoring
Code	M1	M2	M3
Potential sites abroad	1000+	1000+	
NHS sites adopted (/length of time in use)	1 to 24	Many	In routine use
NHS sites abandoned	0	Other	0
Ease of implementation	Easy		Moderate change
IP protected by	Patent	Patent	
IP owned by	Partner Company / NHS Trust	Other	
Different approach/ comments	Yes / Dilemmas at start need a small partner willing to take risk, but later in lifecycle probably need a large partner with marketing clout	Yes / Do it faster have better marketing	
Implementation guidelines or support	Formal training		Formal training

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Security/Quality assurance technologies

Technology Category	Security/Quality Assurance	Security/Quality Assurance	Security/Quality Assurance	Security/Quality Assurance
Code	Q1	Q2	Q3	Q4
Originator organisation/approximate year of development if known	NHS Trust / 2005	NHS Trust / 2006	NHS Trust	NHS Trust / 2003
Developed by	Manager	Manager	Clinician	Technologist
Partners involved	NHS Innovation Hub	Marketing	Manufacturer / Marketing / NHS Innovation Hub	Marketing
Part played by a University	No	No		No
Technology Triggered by (/potential)	Discussion with colleagues	Crisis in clinical performance		Incremental improvement to a Organisational problem
Need technology fulfils	Existing operational need	Existing operational need	Me too' product	Other
Novelty		First in sector	Trailblazing	Trailblazing
Evaluation process	Impact study carried out by University	Very little		N/A
Benefits (/features)	Allows better use of resources	Cheaper / Improved patient outcomes	Improved patient outcomes	Improved patient outcomes
Adoption/purchase triggers	Formal care guideline	Financial benefits	Patient need	Change to care guidelines
Cost of innovation	£0-£100	£5000+	£1001-£5000	500 beds cost £2000 a year
Adopter aware of NHS origins / origin affect decision to adopt				
Implementation costs	None	£0-£100	£0-£100	Installation costs
Infrastructure requirements	Standard Infrastructure	Standard Infrastructure	Innovation self contained	Standard infrastructure
Cost savings to NHS (Direct/Indirect)		Yes		Yes/Yes
Difficulty showing savings		No quantitative evaluation carried out		Yes
Changes to WHO carries out procedures	N/A	No	No	N/A

Technology Category	Security/Quality Assurance	Security/Quality Assurance	Security/Quality Assurance	Security/Quality Assurance
Code	Q1	Q2	Q3	Q4
Changes to WHERE procedures are carried out	N/A	No	No	N/A
Potential sites NHS	All NHS institutions providing nursing care to patients	100 to 199	100 to 199	1000+
Potential sites UK non NHS	All non-NHS institutions providing nursing care to patients	0		Every site that views images
Potential sites abroad	1000+	0	1000+	1000+
NHS sites adopted (/length of time in use)	25 to 49	1 to 24	1 to 24	1 to 24
Non NHS sites adopted		0		0
Sites abroad adopted		0	1 to 24	
NHS sites abandoned	0	0		0
Ease of implementation	Easy	Easy	Easy	Easy
IP protected by	Copyright	Copyright	Not protectable	Patent
IP owned by	NHS Trust	NHS Trust / Developer	Not protectable	NHS Trust
Different approach/ comments	Yes / With hindsight would have made focus wider	No / Role of Hub very valuable but Trust very naive about how to commercialise	No / Products that come out of NHS a mild success rather than a roaring success	Yes / Getting use of technology incorporated in guidelines
NHS financial investment	Trust invested in development	No direct finance from Trust		Trust invested in development
Implementation guidelines or support	Demonstration by developers	Formal training	Written guidelines / Handbook/written guide	Handbook/written guide

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Medical/Surgical instrument technologies

Technology Category	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument
Code	S1	S2	S3	S4	S5	S6
Originator organisation/approximate year of development if known	NHS Trust / 2007	NHS Trust	NHS Trust but builds on technology developed much earlier / 1993	NHS Trust	NHS Trust	NHS Trust
Developed by	Clinician	Clinician	Technologist	Clinician	Clinician	
Partners involved	Manufacturer / NHS Innovation Hub	Manufacturer	Manufacturer / Marketing	NHS Innovation Hub / Manufacturer / Design	Healthcare firm	
Technology Triggered by (/potential)			Flash of inspiration or Eureka moment		Incremental improvement to a clinical problem	Incremental improvement to a clinical problem
Need technology fulfils	Existing clinical need	Existing clinical need	Existing clinical need	Existing clinical need / Latent clinical need	Me too' product	
Novelty	Me too'	Trailblazing	Trailblazing	Trailblazing / First in sector	Me too'	Trailblazing
Evaluation process	CE Marked	Clinical trial	Clinical trail		Significant evaluation	Pilot on site
Benefits (/features)	Cheaper / Quicker/ Process acceleration / Improved patient experience	Cheaper / Improved patient outcome	Improved patient outcomes	Improved patient outcomes	Improved patient experience	Cheaper / Process acceleration /Improved patient outcomes
Adoption/purchase triggers	Makes the process more efficient	Financial benefits	Professional support	Financial benefits	Other	
Cost of innovation	£0-£100	£0-£100	£0-£100	£0-£100	£0-£100	
Implementation costs	£0-£100	£0-£100	£1001-£5000	N/A	None	None
Infrastructure requirements	Innovation self contained	Standard Infrastructure	Innovation self-contained	Innovation self-contained	Standard infrastructure	Standard infrastructure
Changes to WHO carries out procedures	No	No	No	No	No	No
Changes to WHERE procedures are carried out	No	No	No	No	No	No

Technology Category	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument	Medical/Surgical Instrument
Code	S1	S2	S3	S4	S5	S6
Potential sites NHS	200 to 499	200 to 499	100 to 199	1000+	50 to 99	
Potential sites UK non NHS	200 to 499	0	25 to 49	1000+		
Potential sites abroad	1000+	1000+	0	1000+		
NHS sites adopted (/length of time in use)	1 to 24	0	100 to 199	Not yet on market	0	Occasional (as required)
Non NHS sites adopted	1 to 24	0	25 to 49	Not yet on market		
Sites abroad adopted		1 to 24	0	Not yet on market		
NHS sites abandoned			0	Not yet on market	N/A	0
Ease of implementation	Easy	Easy	Easy	Easy		Other
IP protected by	Patent	Patent	Patent	Patent	Not protectable	
IP owned by	NHS Trust	NHS Innovation Hub	NHS Trust			
Different approach/ comments	Yes / Possible flaws in innovators design but no action taken	No / Need to get clearest possible brief	Yes / Finding right company is really important Nothing happens quickly	Yes	No	No / Open to new ideas especially if they involve someone working for NHS because innovators would have same issues and problems as they have and understand issues
Implementation guidelines or support	Not necessary	Written guidelines / Handbook/written guide	Written guidelines	Written guidelines / Handbook/written guide	Not necessary	Formal training

Therapeutic technologies

Technology Category	Therapeutic	Therapeutic	Therapeutic	Therapeutic	Therapeutic
Code	T1	T2	T3	T4	T5
Originator organisation/approximate year of development if known	Teaching hospital	NHS Trust	NHS Trust / 2001		In clinician's own time
Developed by	Clinical researcher	Nurse	Other PAM	NHS Specialist Podiatrist	Clinician
Partners involved	Manufacturer / Marketing		Manufacturer / Marketing	Technologist	Manufacturer / Technologist
Part played by a University			No		
Technology Triggered by (/potential)	Scope for improved outcomes	Incremental improvement to a clinical problem	Other		
Need technology fulfils	Existing clinical need		Existing clinical need	Existing clinical need	Existing clinical need / Latent clinical need
Novelty	Not very but better than what we had before	Not very but better than what we had before	Trailblazing	Trailblazing	Trailblazing / First in sector
Evaluation process	Clinical trial	Pilot on site and clinical trial	Proof of concept	Clinical trial	Clinical trial
Benefits (/features)	Improved patient outcomes	Cheaper / Improved patient outcomes / Improved patient experience	Cheaper / Improved patient outcomes	Improved patient outcomes	Cheaper / Quicker / Improved patient outcomes
Adoption/purchase triggers	Evidence of its efficacy		Patient need	Evidence of its efficacy	Patient need
Adopter aware of NHS origins / origin affect decision to adopt		Yes / No			
Implementation costs	Minimal	£0-£100	Purchase price	None	None
Infrastructure requirements	Innovation self-contained	Innovation self-contained	Innovation self-contained	Innovation self-contained	Innovation self-contained
Cost savings to NHS (Direct/Indirect)					
Changes to WHO carries out procedures	No	No	No	No	No

Technology Category	Therapeutic	Therapeutic	Therapeutic	Therapeutic	Therapeutic
Code	T1	T2	T3	T4	T5
Changes to WHERE procedures are carried out	No	No	No	No	No
Potential sites NHS	1000+		1000+	200 to 499	1000+
Potential sites UK non NHS	1000+		1000+	1000+	1000+
Potential sites abroad	1000+		1000+	1000+	1000+
NHS sites adopted (/length of time in use)	Widespread	Very successful - in routine use	Total number sold to date between 550 and 560 some have been sold to private individuals So they do not know	Only just launched on market	
Non NHS sites adopted				Only just launched on market	N/A
Sites abroad adopted				Only just launched on market	N/A
NHS sites abandoned		0	0		
Ease of implementation	Easy	Easy		Easy	Easy
IP protected by	Patent		Patent		Patent
IP owned by	NHS Trust		NHS Trust	NHS Trust / Industrial partner	Company owns patent and IP
Different approach/ comments	In future projects would try and have a better understanding of the innovation process from the start	No / Would not give preferential treatment to other products value of product in terms of benefits and costs more important regardless by who it was made	No / Value of product in terms of benefits and costs more important than were it was made	No	Yes / Lessons learnt - need to change and adapt so that mistakes are not made
NHS financial investment	Mainly provision of time and resources		Trust invested in development		
Implementation guidelines or support	NHS developer produced handbooks and provides training and support to adopters	Formal training	Handbook/written guide	N/A	Not necessary

Appendix 3: Technology summaries

A1

A1 is an assistive technology that supports older people with a specific long-term condition in order to allow them to remain in their own homes. Essentially, it is a telehealth system, underpinned by mobile technology, developed by a consultant within the NHS but now operated by an organisation external to the NHS. It is being commissioned by the NHS, local authorities, and by individual patients/carers but has struggled to achieve widespread adoption. The industrial partner chosen for the project, though technically competent, has turned out to have insufficient resource to compete effectively.

The developer had seen similar systems in North America and recognised the opportunity to put a similar service in place in the UK. He experimented with a number of configurations before settling on existing mobile technologies configured to support the new service. An innovation hub then became involved in providing support to the project and helped the developer to negotiate £15000 of funding to development the service further. Unfortunately this funding was insufficient to employ someone to provide a dedicated support function for the service and this, together with several teething problems, hampered adoption. The low levels of start-up funding also made it difficult to market the service effectively. A national charity that supports people with the specific long-term condition was enthusiastic about the service but felt unable to endorse it because of threats this may bring to its perceived impartiality.

The business model used for the technology is a pay-as-you-go (PAYG) approach. This makes A1 relatively easy to adopt but has also made it easy for competitors to set up rival services. Alternative suppliers include large well established companies with significantly more resources available for development and marketing. As a consequence, while A1 is still marketed to the NHS and some local authorities, it has been overtaken in the market place by competing services offered by larger, established providers.

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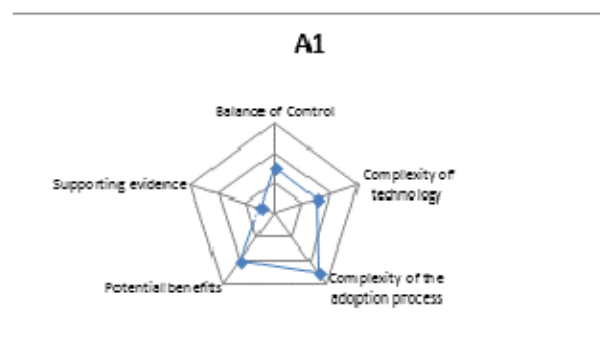
C1

Technology C1 is a database and associated software that allows dentists to conduct a structured search for a particular type of information. It was developed by a small team comprising a Consultant, a research student and a programmer employed by a local University. It was launched at a professional conference and the Consultant member of the development team has also attracted adopters when he has spoken about it at subsequent conferences. It is accessed via a website and some adopters have found out about it through the use of their internet search engines.

Dentists wishing to use the service pay a subscription of £30 which gives unlimited access for one year, though the likelihood of an individual user needing frequent access is very small. Worldwide, there are currently approximately 100 users. This is not a settled population of adopters. Individuals tend to register when they have a particular need for the information available but allow registration to lapse when the year is up and then re-register if their need for the information re-arises. In part, the cost of providing the service and keeping the information up to date is met by sponsors who have a commercial interest in the information being supplied.

The main beneficiaries of this technology are the particular patients who caused the dentists to use it. If the information the system provides were not available those patients would need more extensive (and more costly) treatment.
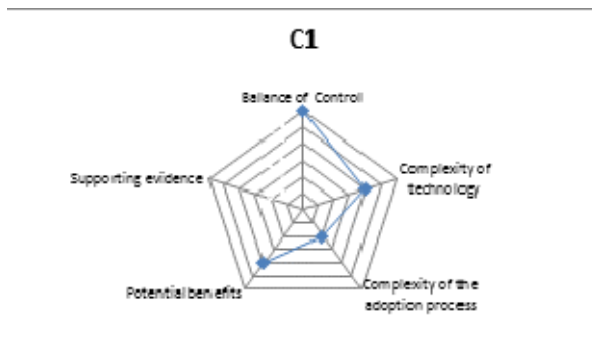
C2

C2 is a clinical decision support system (CDSS) that supports a service managing patients with specific long term conditions. The service is run as a clinic within GP surgeries by a trained nurse. The nurse carries out a periodic check-up for each patient, administering a number of physiological tests and then entering the data gathered onto the CDSS. The CDSS then produces a summary of the check-up findings for the GP and makes recommendations for the future management and treatment of the patient. These recommendations are based on the relevant clinical care guidelines produced by NICE and other agencies, thus ensuring that patients are

managed to the same standards as would be available in a consultant run, hospital-based clinic. C2 is available within a complete service package that can be commissioned by GPs. This package includes the technology and provision of the trained nurse.

C2 was devised by a hospital consultant. He originally conceived of it whilst working as a registrar but he only had opportunity to develop it when he progressed to consultant and was able to negotiate with his trust that he would develop the idea further but in his own time so that he could retain ownership of any IP. After a year he had developed a series of prototype systems. In co-operation with the trust he then carried out a number of tests of the CDSS. He began with 'synthetic patient data' and then moved on to retrospective historical patient data before starting to use the technology in parallel with normal decision-making. After a successful trial using 50 patients a combined study of several hundred patients was carried out. Results from these studies were presented as posters at conferences. The service aspect was then built around the CDSS and piloted successfully in a number of GP practices.

Following the success of these trials an NHS innovation hub became involved in the development of the service. Some funding from the local development agency was negotiated and a spin-out company was then created as a social enterprise in collaboration with the NHS trust. Agreement was reached with the trust that the consultant would be seconded for a third of his time to the company.

C2 has been adopted by three clusters of GP surgeries. Process targets such as the 18 week waiting target and the 2 week cancer target made use of the service attractive to adopters. The total cost of the service to the NHS (taken across primary and secondary care organisations) is lower than similar service models where consultants visit clinics in primary care. However, the emphasis of the service is the management of the large majority of patients who can be managed in a routine fashion. It does not allow for management of more complex patients which leaves it open to the accusation of of 'cherry picking'. Failure to offer a comprehensive service may make it difficult for C2 to fulfil the requirements of procurement and commissioning policies that are becoming increasingly common, such as the 'any willing provider' model of procurement. Ability to increase the number of adopters also depends on the willingness of GPs to commission a service that places the management of patients in the control of nursing staff using CDSS and there are some indications that there may be resistance to this on professional grounds. At present the critical mass of GPs needed to reach the roll-out across many locations.
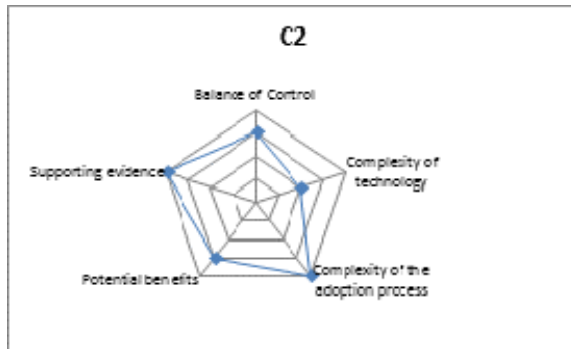
C3

C3 is an electronic questionnaire system to collect data on symptoms and quality of life from patients. The collected data can be used either as part of an initial assessment or for on-going monitoring of treatment outcomes. C3 comprises two components: a questionnaire builder and a system for administering the questionnaires to patients. The questionnaire builder enables development of clinical questionnaires and includes a facility to define complex routing rules. Use of complex routing rules allows patients to complete, even detailed questions faster and more easily.

C3 was the idea of a hospital consultant who subsequently assembled a team to develop a prototype system. The team comprised a range of clinical staff, technical staff from the hospital's medical physics department and academic staff. Over several years the team iteratively improved a working prototype, implementing it into clinical use in the hospital and local community. Part of this implementation involved modification to existing service designs. In collaboration with the local NHS innovation hub, the IP associated with C3 was protected and a spin-out company was formed to commercialise the technology. The spin-out company was a partnership with a small, local software house with previous experience of developing healthcare information systems. The formation of the spin-out company was important for two reasons. First, it completely reverse-engineered the system and rewrote the software to a commercial standard. Second, the company developed the system into a web-based service.

The company now licenses the system as a hosted service that includes user support. C3 has been adopted by a number of NHS trusts, mainly due to the marketing efforts of the inventor. Adopters have generally been active members of a professional network that includes him or have been influenced by direct contact with him at workshops and demonstrations of C3. Adopters are interested in the clinical evidence for C3 but it is not the main driver of their decisions.
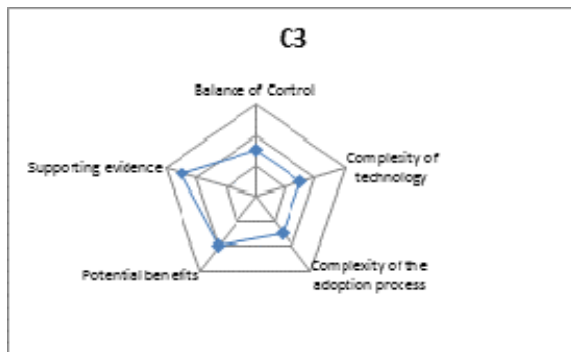
C4

This technology was developed by an NHS clinician though it took place separately from any formal NHS initiatives and was undertaken in his own time. Its purpose is to make up-to-date care guidelines for resuscitation, presented in diagrammatic form, available to health professionals as an iPhone app. The guidelines are developed by a third-sector organisation that funded the development of the technology and now shares ownership of the IP with the developer. (A senior clinician working in the same hospital as the developer is also an active member of this third-sector organisation.)

The developer had already written another healthcare-related app when he conceived the idea for C4. Importantly Development was rapid. Within three months of the start of the project the then current guidelines were made available to a small group of users via the technology. The appearance of a new set of guidelines (the guidelines are usually revised every five years) meant major revisions had to be made in the months following the initial release but even so, a fully functioning version was launched within about nine months.

Because the app is available for download free of charge, marketing in the conventional sense is not relevant. However, various steps have been taken to spread use of C4. These have included 'word of mouth' and generation of media interest. This has been successful - the number of downloads in the first year has exceeded 50,000.

In order to test the effectiveness of the technology it was made available to 40 junior doctors and, after they had been given time to become familiar with it, they were given a standard medical scenario simulating a situation where the guidelines should be used. They were then randomised into two groups: one working through the scenario using the C4; and the other relying just on their training. It was found that those using the technology adhered more closely to the guidelines.

From the perspective of the third-sector organisation that generates the guidelines, C4 is an inexpensive form of distribution because it only costs them about £1 per download. However, there is one major drawback: the information can be accessed very easily by iPhone users but to clinicians

without an iPhone it is simply not available. Although iPhones are popular amongst clinicians and other health professionals (approximately 50 per cent of the relevant staff in the hospital where the technology was developed have them) they are by no means ubiquitous. Adoption of C4 is therefore dependent on factors that are outside the control of an NHS trust unless they provide the phones and many trusts might regard this as a step too far.
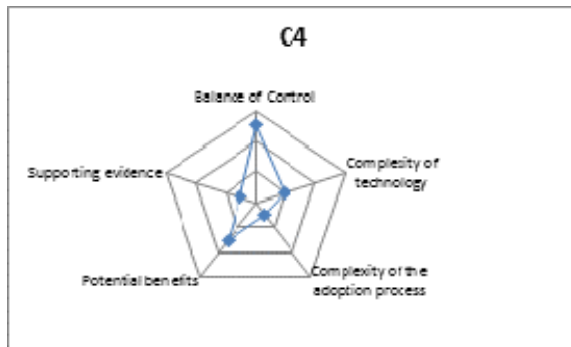

C5

C5 is protocol-driven, real-time clinical information system that is designed to improve patient safety and reduce length of hospital stay. Via a personal digital assistant (PDA), it takes data from routine bedside observations of a patient and uses the data to generate graded alerts if the condition of the patient has deteriorated.

The original idea for C5 came from an intensive care specialist practising in Australia. The technology was brought to the UK by his commercial partners and re-developed in conjunction with an NHS trust. Although the core principle of the original version has remained the same, C5 is very different in a number of important ways. For example, the original system was designed to respond to subjective judgements that a patient was deteriorating but C5 uses objective measures of a patient's condition and uses a scoring algorithm to convert these into a single numerical value. This value is then used to determine the severity of any alert that is required. The system then manages each alert to ensure that appropriate responses are made by medical staff within the timeframe allowed for the particular level of alert. If a doctor does not attend a patient within the time allowed the alert is escalated upwards to the next grade of doctor.

C5 has been the subject of a full clinical trial. This was able to measure a number of benefits of adoption including a threefold increase in clinical responses made within the appropriate target time, hospital length of stay reduced by a third on average, and substantial reductions in the number of patients going into critical care and the number of critical care bed days. Overall, the trial found there was a strong financial business case for adoption. C5 is sold as a software product with a license to use it and on-call support available. At the time the supplier was interviewed the cost of

this was in the region of £1 per bed per day. The infrastructure requirements are server space, wireless capability and PDAs to capture the data though these do not need to be dedicated to C5.

A clinician at an adopting site reported that, although the system was welcomed enthusiastically by nursing staff, there was resistance to adoption from some junior doctors and Consultants who felt the system reduced their autonomy.
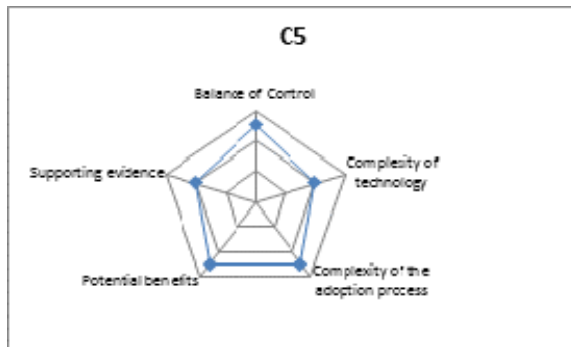

C6

C6 is a paper-based technology used in hospital wards to organize the recording of observation data such as temperature, pulse rate, blood pressure *etc.* and for using the data to ensure that early warning signs (EWS) are not missed. Several variations have been developed to cater for different groups of patients, such as adults, children, pregnant women. C6 also includes instructions for use and a series of protocols. Though it was developed prior to the publication of NICE Guidance 50, *Acutely ill patients in hospital: recognition of and response to acute illness in adults in hospital* (www.nice.org.uk/CG050), it supports conformance to this guidance.

C6 was developed by an R&D Fellow with support from a number of clinicians and senior nurses. The original trigger was a request by the Department of Health that the hospital should review its responses to a serious outbreak of an infectious disease in a local town that had occurred during 2002. This in turn led to a committee being formed to consider how EWS could be better managed. This committee, made up of senior/specialist consultants, anaesthetists and senior nurses, asked the R&D Fellow to examine current practice. He found that current practice was not always consistent and reliable, particularly where the calculation of EWS scores from observation data was concerned. He also found that appropriate actions were not always taken when the scores indicated cause for concern. These findings led to the development of C6. It was trialled it in a general medical ward and then a general surgical ward before being rolled out to other wards in the hospital and then across the trust.

With some support from an NHS innovation hub, C6 has been made available to NHS and non-NHS organisations. It is provided free of charge to the former and the latter each pay a one-off fee of £500. 22 NHS trusts

have requested it, some with the intention of using it in its existing form, and others who thought it could inform their own alternative technologies.

At the developing trust some attempts have been made to convert C6 into a PDA-based technology but lack of resources (there is, of course, almost no revenue stream from C6) meant that this development did not progress beyond implementation as an Excel spreadsheet instead of a paper-based version.
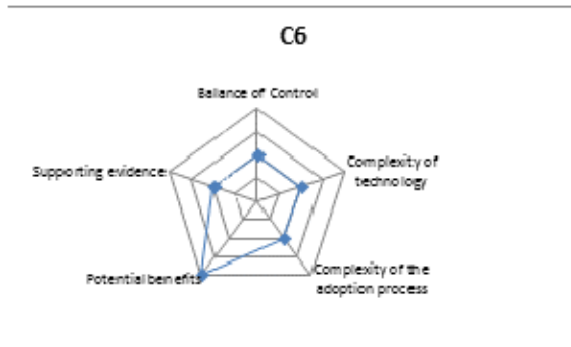
I1

I1 is a drip hook that was invented by a nurse working in intensive care. He had had his original idea some years ago whilst working at a different hospital and he then resurrected it and a colleague produced a metal prototype for him. His current trust's R&D Department then became involved and arranged for further development activities to be undertaken by a local university's design group in order to turn it into a commercial product. With support from the local NHS innovation hub, the trust protected the IP associated and entered into a formal agreement with a local company to supply I1. This company specialises in the marketing of innovations developed within the NHS and stresses the NHS origins of I1, including, for example, a photograph of the 'senior staff nurse inventor', in marketing materials. It also emphasises other features that are extremely important in the NHS context such as ability to withstand multiple sterilisation cycles.

I1 has been adopted by a number of NHS trusts and sold successfully in a number of other markets outside the NHS but I1 is essentially a commodity item for which there are many competing, commercially-developed alternatives so it faces strong competition, especially on price which is an important factor in adoption decisions for this type of product.
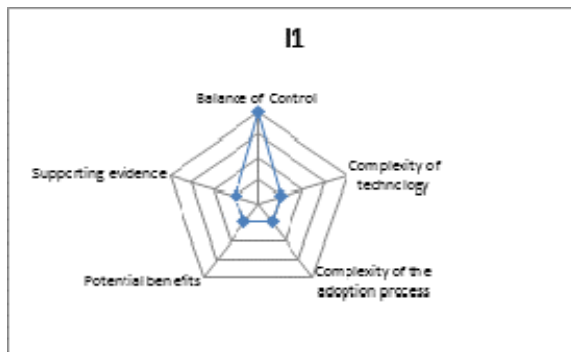
I2

Technology I2 is a portable drip stand designed for use during treatment in patients' own homes and in the provision of emergency care. It originates from a care team working within a primary care trust who recognised the need for a stand that was lighter, and hence more transportable, than the stands used in hospitals. It also needed to be sufficiently robust to withstand everyday use and transportation. They also realised the selling price would need to be relatively low to avoid the temptation to continue using improvised domestic equipment rather than adopting a technology specifically designed for this purpose.

Having developed the concept the team approached the innovation unit that had recently been set up in their trust. The unit brokered a partnership with a local SME and the care team, the innovation unit and the SME all worked together to enhance product design, establish intellectual property rights, gain regulatory approvals and make sure appropriate arrangements were in place for manufacturing and marketing. These processes took approximately two years to complete and resulted in a commercial product that could be marketed to the NHS and elsewhere. About six months after the original launch some improvements were made which lowered the weight of I2 still further and decreased production costs.

Adoption is extremely straightforward. I2 has been purchased by a number of hospitals, PCTs, clinics and health centres. Adopters of I2 report satisfaction with the product and praise its detailed design, especially those that make it easy to clean. However, the SME partner who is now marketing I2 is experiencing some difficulty in NHS adoption due to it being a relatively ordinary product for which most trusts have established suppliers who they tend to favour.
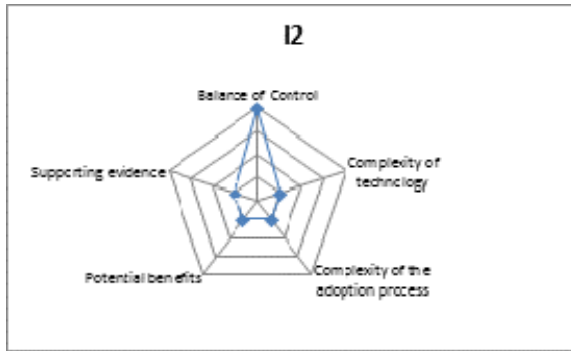
I3

I3 is a novel redesign of a piece of domestic equipment used by community nurses to provide a version that is designed specifically for the purpose to which they put it. Its advantages are: more portable; more comfortable for the patient; simple to use; and requires minimal training in its use. It is also thought that it might reduce the risk of infections.

The idea for I3 came from a community nurse. She had been made aware that her local NHS innovation hub was able to provide support to develop innovative ideas so she contacted the hub directly to discuss her idea. The hub arranged for a design group from a local university to work with her and after several meetings a final design was agreed. The hub also gave support in protecting the IP. I3 was then entered into an innovation competition in which it won an award and subsequently the hub negotiated with a company to market I3. Under the agreement reached the nurse's NHS trust receives royalties on sales.

Adoption of I3 into the NHS has been slow. The main reason for this is probably that I3 replaces domestic equipment which is already available and therefore has no cost implications. Although I3 has advantages these are only available by buying an extra piece of equipment and therefore all of its purchase price is additional expenditure. No significant evaluation of the effectiveness of I3 has been carried out and it is perhaps the case that this lack of evidence contributes to the difficulty of justifying the purchase of I3.
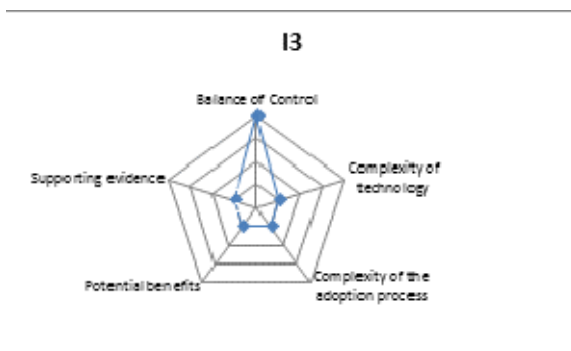
I4

I4 is a substantial and sophisticated piece of laboratory apparatus that is used during the provision of in vitro fertilisation (IVF) treatment. It increases the success rate of the treatment and thus brings benefits to patients and increases cost effectiveness for the NHS. The idea for this technology was developed by embryologists working in a specialist NHS facility within an NHS foundation trust. It incorporates a substantial amount of advanced scientific knowledge and also relies heavily on the considerable expertise of those involved in its development. A start-up company was set up to undertake product development and commercialise it. It was patented for the trust by the local NHS innovation hub. After a total development period of around four years it was launched at a European conference in 2008 and is now manufactured by a partner of the start-up company.

I4 is in use in a number of countries as well as in private and NHS clinics. Each I4 is customised to meet the buyer's particular needs. These needs vary across a number of dimensions including the number treatments provided per year, the size and shape of the space available to house it, the technological features required and whether it needs to incorporate existing equipment. The manufacturer project manages each installation, trains staff in its use and provide ongoing servicing and support.
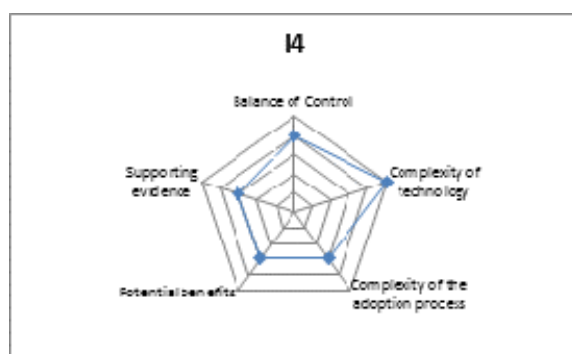

I5

Technology I5 was developed by staff within the Medical Engineering section of a teaching hospital's NHS foundation trust. It has no direct consequences for patient care but prevents theatre staff and nurses in ICU wards from sustaining lifting injuries. It thus has health and safety benefits for staff and cost benefits for the NHS.

The commercialisation process of this technology is particularly interesting. By 2005 prototypes were being used successfully in the originating trust. Interest in the technology from one or two hospitals in the locality led to contact between the developers, their trust and an NHS innovation hub. As a consequence an agreement was reached with a subsidiary of an

engineering company to manufacture the technology under license. In 2007 the assets of this subsidiary, including these licensing rights, were sold to a newly-formed company. They relaunched the technology onto the market in 2009.

Each of the commercial partners did further development work on the product that affected its actual design and its manufacture. Some of these changes represented substantial improvements. For example, one amendment addressed infection control issues. These issues were overcome by encasing the technology's working components in stainless steel so that they can easily be steam- or chemically-cleaned.

Adoption is very straightforward. The biggest barrier to adoption is cost. The product is substantially more expensive than the low-technology version it would replace and the savings generated by preventing staff from sustaining lifting injuries are not immediately visible even though they can be substantial. Targeted mail shots have not been effective in generating sales but allowing hospitals to trial the technology for a few weeks has led to some adoption. Despite this, however, actual sales are only a small proportion of potential sales and competing products are now available.
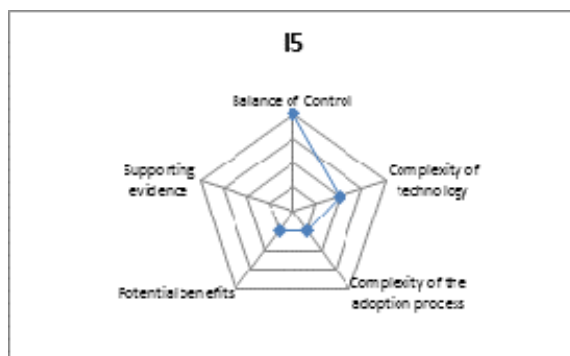
L1

L1 is a computer assisted learning (CAL) system for training staff to plan the technical details of a specialist medical procedure. This planning relies on a combination of detailed calculations and professional judgement and the training used to be provided using pencils and tracing paper. Development of L1 occurred in a hospital's Medical Physics Department. It was a natural progression from the development of some modelling software that lies at its heart. An interface was added that allows it to be used for in-house training.

Students on placement from the local university undertook the training, reported back to their university which then asked if it could use it too. The university then suggested that it should be marketed to other universities. The university's transfer office became involved in managing the exploitation of the associated IP. After several years an NHS innovation hub became involved and provided seed-funding for development of a new version of the software for a large university that wished to use the CAL

system within its distance-learning courses. The university indicated it would be willing to order a large number of licences but wanted the software's interface to be made easier to use and more robust. In addition it wanted L1 to be capable of being used via the web rather than just being available on stand-alone computers. These requirements had a significant impact on L1's development trajectory and led to very substantial improvements. Indeed, it can be said that the large university acted in many ways as a lead-user for the CAL system.

L1's popularity (it has been adopted into over 40 sites around the world with many adopters taking out multiple licences) and the continued renewal of licences suggest that it is very effective but, although some evaluation of the CAL system was carried out with the originating hospital's own students, no substantial evaluation of L1's effectiveness has been carried out. However, a decade has now elapsed since its development and the landscape is starting to change; it is likely that without significant investment L1 is reaching a point where sales will decline as better substitutes become available. Nevertheless, L1 has, for several years, been one of the most successful pieces of IP exploited by the NHS trust.

L2

L2 is an educational resource based on podcasts that supports medical students' exam revision. It was originally developed for delivery via the web but has subsequently been modified to become an app for the Apple iphone. The developers' intention was to provide high quality revision materials in a form suitable for use anywhere, and at anytime. Commercially-developed revision resources were already available on the market but these were very expensive so the aim was to provide a much more affordable option.

The technology was the brainchild of three medical students and used content provided by senior clinicians. The web site that was at the heart of the first version of L2 was developed by one of the team using a freeware web-site content management system. The subsequent iPhone app was developed in partnership with a small software developer. Development of the app was very rapid, taking only about six months. Funding for the

project was small and came from the developers themselves, a small donation from a pharmaceutical company and revenue from Google ads.

In its web-site form L2 had over 5000 registrations. No specific evaluation has been done beyond gaining feedback on user satisfaction. The level of satisfaction was found to be high but it has not been established whether L2 prepares students better for their examinations than other types of revision materials. Because adoption of L2 is dependent primarily on the personal decisions of medical students its adoption in an NHS context is therefore independent of formal NHS organisations. As time goes on, L2 is becoming part of quite a large market where several major publishers have invested in the development of similar resources and are making them available on a variety of portable devices.

Because the original project to develop L2 took place over a period of four years the developers became junior doctors during it and started to move between trusts. This meant that the development effort continued to be independent of their employing trust. Support for innovations developed by junior medical staff may have been more naturally provided at the level of a regional deanery, rather than an individual NHS trust. The status of this technology as an NHS-developed is therefore not entirely clear. In a strict sense, it is difficult to define the technology as one that is the result of a specific NHS organisation's efforts to innovate technology but as an outlier on the spectrum of NHS versus commercially developed it has significant NHS-developed characteristics. It depends upon NHS knowledge, essentially donated by senior NHS clinicians, and then structured by medical students/junior NHS medical staff into a coherent resource. Though not an explicit intention, the main benefit for all of the developers has been that their professional profiles have been enhanced by involvement in the project.

L3

Technology L3 is a device used to simulate a patient in order to train anaesthetists in a particular aspect of their work. It was developed by a Consultant Anaesthetist in a Teaching Hospital who had observed at first hand the problems associated with trainees' lack of opportunity to practise procedures and the consequent effects on the patients they treated whilst

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still developing their skills. The length of time between the original idea and a prototype that could be used successfully was two years and much of the development was undertaken 'out of hours'. After that, and with support from an NHS innovation hub, a partnership was formed with a manufacturer who developed the product further.

Within the NHS the potential size of the market is 20 to 30 hospitals who between them are training around 100 doctors at any one time. The device could also be used overseas and a small number of units have been sold into other countries since the product came onto the market in 2004. The IP associated with the product is not protected but is not felt to be under threat due to the unlikelihood of a competitor making a similar product now that this one is on the market.

The challenges faced by a potential adopter are trivial. A brief user's guide, written by the developer, is available and essentially the technology can be purchased (for approximately £5000) and put straight into use. However, it does require effort to be made to accommodate its use because it has to be used in theatre and requires x-ray and other equipment to be available. Securing this access and timetabling it in is essential.

The technology is not typical of many others developed within the NHS because it is a training device rather than something that is used to treat patients directly or to manage their care. It does, however, have a direct impact on patient care because it means doctors are much more skilled when treating patients and are able to avoid inflicting pain and discomfort, or even harm. However, no formal evaluation of the technology's effectiveness as a training device or the consequences of its use has been undertaken. The developer does regret that such an evaluation has not been carried out but he himself has not been in a position to do it.

This is very much a 'stand alone' product. It is probable that if the developer had not initiated the project, and seen it through from within his own role as a Consultant Anaesthetist and training provider, it would not exist. Although its benefits are very real they are limited in absolute terms where the NHS is concerned because the total size of the market is small.
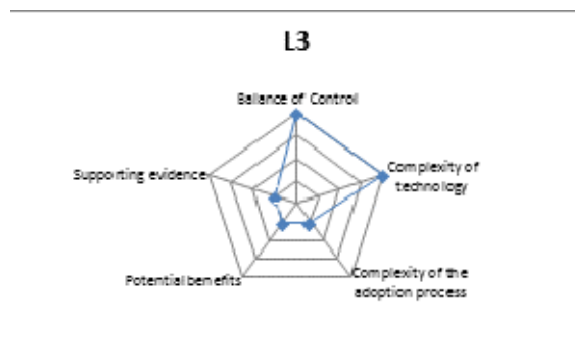
M1

M1 is a non-invasive diagnostic device that combines hardware with a software algorithm to generate information that can guide clinical decisions. M1 can be operated by a single member of staff, usually a nurse or medical Technologist and in principle can be used in clinics remote from a main hospital. The equipment capital cost is several thousand pounds but consumable costs are a few pounds per patient.

M1 is an alternative to an invasive test. It has been shown to be to be a reliable predictor of whether a specific surgical intervention will be effective in alleviating symptoms but it does provide less comprehensive information for making a diagnosis. On the other hand, it has advantages for the patient because it involves much less discomfort and carries fewer risks than the invasive test procedure and advantages for the NHS because it requires fewer staff and potentially less clinic time.

The development of M1 was based on the work of Technologists working in the medical physics department of a large teaching hospital. The hospital is a leading centre of urology research and was involved in development of treatments and new diagnostic technologies. The development project became a collaboration between clinical and technical staff in the hospital and local university. The medical physics staff had significant experience in designing clinical measurement devices and M1 was one instance of a range of innovations that the team had produced. An industrial partner was also involved from early on in the project.

Evaluation of M1 has been rigorous. Trials of the technology started on volunteers and then on patients. Using funding from charities a clinical trial was carried out that assessed the reliability, acceptability and validity of the technology during clinical use over a five year period. A final study based in the hospital was a blind clinical trial and showed that M1 was reliable in predicting the outcome of a surgical intervention within certain groups of patients. The clinical lead on the project believed that the assessments carried out in the hospital were probably much more rigorous than those carried out on many other diagnostic devices. Prompted by feedback from a national agency, a further multi-centre trial based at six UK hospitals was carried to ensure that the technology's benefits could be generalised to other sites.

Development of the technology has extended over several years and the technology's patent is nearing expiry. This means the technology supplier risks being unable to make substantial profits from the technology. Adoption of M1 has been in limited in the UK NHS, with just a small number of trusts adopting it into routine practice. Adoption in the US where several hundred devices are in use, and in other countries, has been more successful.
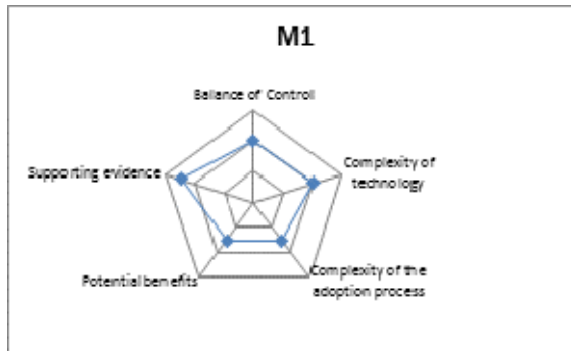
M2

M2 is an electro-mechanical monitoring device designed for use in clinics and GP surgeries by a skilled healthcare worker. The device was developed by medical physicists in a major teaching hospital. The developers had close links with an international standards committee for the class of device and with a major manufacturer of existing devices. Development of M2 was triggered by a concern that use of the mechanical devices that were currently in place might have to be discontinued because they used a chemical that might be banned. It was also decided to seek other improvements over the existing devices such as less frequent re-calibration, a better display and incorporation of indicators that would minimise errors during use.

The medical physicists worked closely with the device manufacturer during the development. This manufacturer was a long-standing, family-run business with a lot of expertise in mechanical devices but no history of developing electro-mechanical devices. The majority of the technological capability therefore rested with the Medical Physics Department. Development took approximately three years and M2 was launched in 2001. No extensive trials of were done within the teaching hospital where the development took place but the manufacturer funded a clinical trial at a major healthcare organisation ion the US. The results of this trial have unequivocally validated the device for clinical use and it was found to be more accurate than the traditional mechanical devices when diagnosing certain conditions.

The device is now marketed by the manufacturer, mainly by inclusion in its catalogue, web-site and at exhibitions. Take-up of the device has been modest and despite several hospitals buying some devices, only three hospitals use the device exclusively. The device has been included in the data collection protocol for some drug studies commissioned by pharmaceutical companies and this has created some demand from hospitals and clinics. However, although take-up is widespread it has been slower than expected, possibly because the anticipated ban of the chemical has not yet materialised. M2 is therefore only purchased to replace the mechanical devices when they wear out and now that market is at risk

because automated alternatives from other suppliers have become readily available.

M2 was developed during the 1990s when there was no comprehensive support for technology transfer from the NHS. It was developed by NHS staff with very little clinician involvement. The development was possible because the staff in the medical physics department were allowed the time and freedom to pursue promising ideas. It is unlikely in the current climate that the project would have been pursued as there is now much closer scrutiny of how staff time is spent. The bottom-up development of the project allowed the interests and creativity of the medical physicists to produce a novel technology. The strong links to the manufacturing company provided a default industrial partner though the extent to which the partner had the optimum mix of capabilities is perhaps questionable. The partner was well established and had a wide product range but its devices were all mechanical. M2's market is now dominated by automatic devices so perhaps a partner with different skills would have resulted in an innovation that was more disruptive.
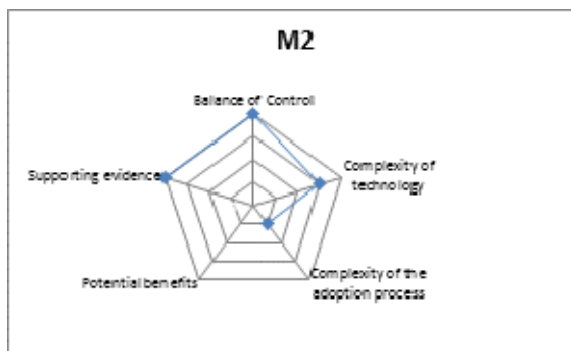

M3

M3 is a minimally invasive monitoring technology that is used by anaesthetists to assess the cardiac output and haemodynamic status of patients during surgery. The accepted target patient audiences are those undergoing major or high-risk surgery (such as cancer, transplantation, orthopaedics, colorectal, gynaecology and urology) and high-risk patients undergoing any surgery.

The technology has been developed, perfected and tested over a very long period of time. The findings of the first randomized trial to evaluate it were published in 1995 and there has been six more high quality randomised trials since then. Two systematic reviews have also been undertaken. Despite this quantity of evidence, adoption is still patchy. M3 has some very passionate supporters, many of whom adopted it some time ago, but other clinicians are reluctant to adopt it.

M3 is very self contained technology in the sense that if an anaesthetist decides to adopt it he or she can do so with no consequences for the work of colleagues. During surgery the anaesthetist deploys the technology when

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he or she feels it is appropriate to do so, observes the results on a separate set of monitoring equipment, and uses his or her judgement to decide whether fluid or drugs should be administered in order to try to optimise blood flow. M3 does, however, impose an additional cost per operation, but this cost is more than compensated for in terms of reductions in costs that occur further down the line. This is because adoption of the technology leads to a reduction in the mean number of days spent in intensive care and the mean total number of days patients spend in hospital after surgery.
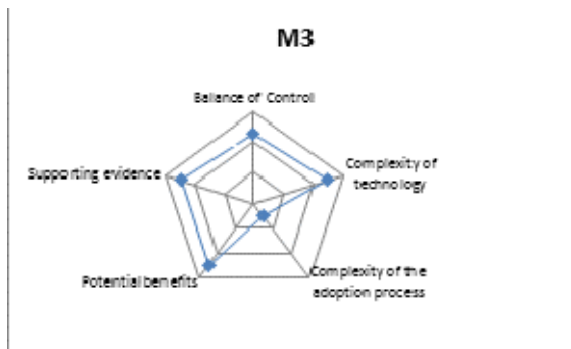
Q1

This technology is an computer-based tool used to assess the performance of individual wards and departments in a trust against a wide range of up to date standards that relate to various (mainly nursing) aspects of patient care provision. It generates information that can be used to guide improvement. Q1 can be used in a wide range of institutions from major teaching hospitals to small units. It was developed in a paper-based form by a small team in a teaching hospital and subsequently adapted into its current electronic form by informatics experts within the hospital. It is intended that further enhancements will be made to the tool, with particular emphasis on making it more multi-disciplinary and team-focused.

The tool, and training seminars in its use, are now available via the hospital's regional NHS innovation hub. It is recommended that a group of team leaders from a trust attend an initial training session before rolling Q1 out across the trust and that this be followed by a second session six months later.

A twelve-month impact study to evaluate the benefits of adoption was underway at the time this research was conducted. The belief was that it would show benefits from improved management such as better use of resources and more effective training provision. Although the trust owns the IP associated with the tool, the developers have not sought to make a profit from supplying it to other adopters. Indeed, it is likely that on balance there is a cost to the trust of supplying it because members of the development team host visits by potential adopters and sometimes pay visits to potential and new adopters' sites.
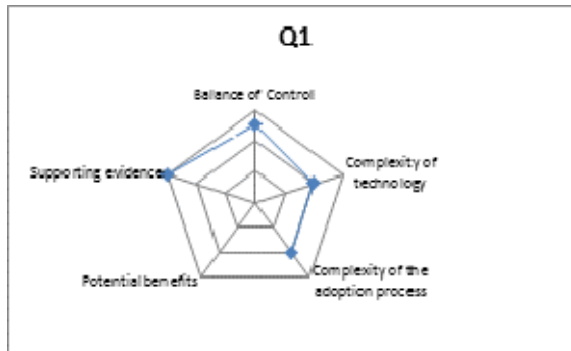
Q2

Technology Q2 is a web-based information system for managing the audit of infection control procedures within acute hospitals. The system has benefits at a high-level, such as enabling production of high level reporting data, and at the operational/ward level where staff on wards are able to see the performance of their own ward and other wards over time and thus see where opportunities for improvement exist.

Development of Q2 began in 2006. The team working on it comprised a senior Clinical Improvement Manager, the Head of Nursing, an infection control specialist and a member of the trust's IT department. The trigger for the innovation was a Department of Health report that criticised infection control practices in the trust and highlighted the poor level of staff awareness of good practice. As a result of this report the development of a suitable audit tool became central to the trust's initiative to improve standards of infection control.

An initial prototype was produced by the trust's IT department within 3 months and then an iterative improvement process began to develop this prototype further. Unfortunately this process was delayed because the IT department came under pressure to prioritise work related to the National Programme for IT. This delay continued until the Head of Nursing allocated funding to pay overtime to staff in the IT department to work on Q2. When the second prototype became available a small trial was set up to evaluate it. Positive results from this trial led to staged implementation across the trust.

The trust recognized the potential for commercializing the system but realised it did not have the in-house expertise to pursue this. Support was sought from a local NHS innovation hub and this resulted in a partnership between the trust and a specialist software house to develop Q2 further. A small grant from a regional development agency was used to fund this development so the commercial partner reworked the system to turn it into a scalable, robust, commercial product. Further refinement allowed the system to be provided as a software package and as a hosted-service. Involvement of the commercial partner at this stage was fundamental to Q2's commercial success. The partner effectively treated the original

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system as a "throw away" prototype that informed the rewrite. A distinct characteristic of this particular partner was its interest in and commitment to finding NHS innovations and commercialising them. This mode of activity formed a substantial element of its business model, with several of its products having been conceived within the NHS.

Q2 is accredited by the Department of Health and has now been implemented in four NHS trusts. Implementation on existing infrastructure is straightforward, especially because it stores no individual patient data. Configuration of the software is also straightforward with no need for local adaptations.

Limited evaluation has shown that Q2 reduces the time and cost of collecting data but there has been no detailed evaluation of the wider impacts of adoption. Within the trust that developed it, Q2 has produced the information needed to audit and monitor infection control and senior managers believe it has been beneficial in helping to change staff behaviour on wards.

Q3

Q3 is a quality assurance technology that was developed by the Medical Physics team at a teaching hospital's NHS trust. It allows dental surgeries and hospitals to bring the calibration of equipment in house at lower cost than using external contractors. The developers identified the opportunity for Q3 and developed a prototype version. With assistance from a local NHS innovation hub the technology was licensed to a manufacturer in early 2005. The commercial partner undertook design for manufacture work and brought Q3 to market within a little over a year of becoming involved.

The purchase cost of Q3 is £2100 and there are no ongoing additional costs other than staff time to actually use the technology. Adoption within the NHS is confined to one other trust but to date, ten machines have been sold overseas.

Q3
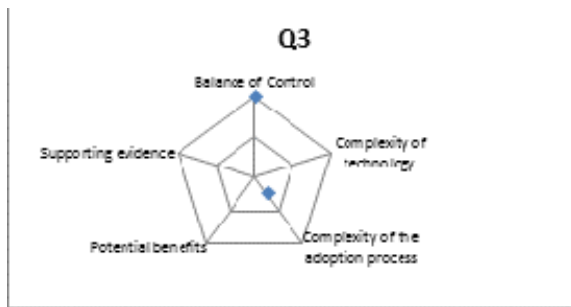
Q4

Technology Q4 is a software security interface that aims to prevent misdiagnoses that result from viewing poor quality diagnostic images. It was developed about six years ago by a senior medical physicist and a member of his staff as a technical solution to problems associated with the growing use of remote transmission of digitised images. It provides 'point of use QA', thus aiding clinical governance, but also goes beyond QA by incorporating a control element. It denies access to an image if that image does not meet quality standards. This control element can be over-ridden, but if the viewer insists upon seeing the image a record of the over-ride is generated.

Q4 is manufactured and sold by a commercial partner that was secured via assistance from the regional NHS innovation hub. Two versions of the technology are available: standalone; and server-based. For each version a detailed installation manual is supplied, together with an operating manual and first and second line technical support.

Q4 is in full use within the developer's trust and in a small number of other hospitals, but the level of adoption is low. Very few support issues have been raised by users though there can be minor technical difficulties in installing the system. Cost is also unlikely to be a major explanation of the low adoption rate. (Pricing was described by an interviewee as 'NHS friendly'.) One potential explanation that has been suggested is reluctance to accept that the problem it is designed to prevent exists. (This reluctance may result from the knowledge that if the problem is widespread in may mean that many of the monitors that are currently in use need replacing.) Another barrier to adoption is the reluctance of IT departments to install Q4 even when requested to do so by one or more departments. Installation has to be hospital-wide and so requires the support of IT.

There are certain eventualities that could lead to a big increase in take-up. One would be a high profile legal action where the mis-reading of an image was shown to have led to serious harm to a patient. Another would be incorporation of its use into care guidelines or the publication of a new edition of the 'Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems'. The current version, IPEM

Report 91, was issued at the start of 2005 so a revision may not be too far away.
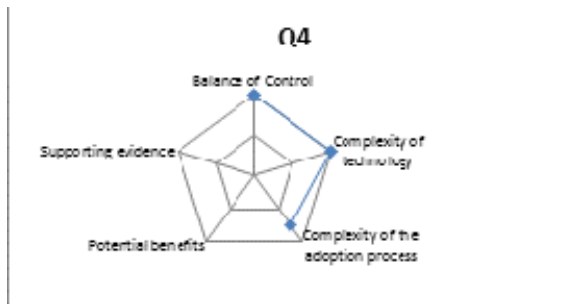
S1

S1 is a device used during surgery. The concept behind the technology originates from a surgeon who also saw its commercial potential and made a patent application to protect it in 2005. He then began to search for a commercial partner and in 2006 an NHS innovation hub helped him to formalise a licence agreement with a manufacturer. The manufacturer says 'We basically took the basic design that had been done by the surgeon who developed the concept, and we developed it into something that was manufacturable and went on to produce the tooling and to prototype the product and eventually developed the commercial item'.

S1 is registered with the Medical Devices Directive and between 20 and 25 hospitals have adopted it. The advantages it offers are that it reduces discomfort to the patient and dramatically reduces procedure times, thus allowing more patients to be treated within a given timeframe. However, S1 is competing with similar devices that some surgeons find easier to use but the cost of S1 is at the lower end of the range.
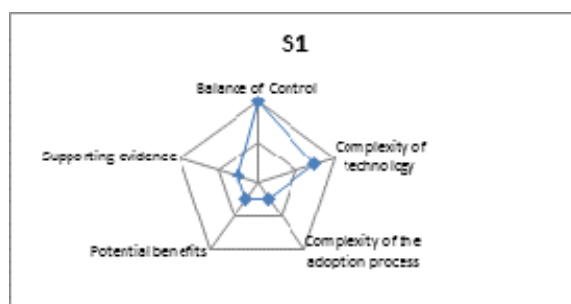

S2

S2 is a surgical instrument that allows a procedure to be carried out more precisely and with a lower risk of harm. It is a single use device costing a few pounds and replaces a conventional version of the device that costs less but is more difficult and risky to use. It was invented by a trainee clinician who had experienced difficulties in using the conventional version of the device.

The clinician's trust used a local NHS innovation hub to develop a partnership with small technology supplier with a view to commercialising the clinician's original idea. However, problems associated with the agreement between the trust and the supplier led to difficulties in allocating responsibility for funding development and as a consequence there were significant delays in the development process. It was several years before the device progressed from early prototype to working version. During this interval there were changes to the device's specification, difficulties in selecting appropriate materials and in designing production processes. Despite these difficulties the resulting device won an award which recognised the improvements it offers over the conventional device.

S2 underwent a rigorous clinical trial that validated the device for use in routine practice but holdups in the academic publishing process meant there was significant delay in publishing the trial's findings. Before the trial findings were published, S2 was launched at an international trade exhibition and was subsequently adopted by clinicians in a number of countries. However, S2 has had little success in the NHS market. Active marketing was delayed until the trial findings were fully published and has been described subsequently as 'modest'. The supplier believes that the purchasing process in the NHS militates against S2's adoption. Central to this concern is the supplier's belief that NHS purchasing processes emphasise minimising purchase costs and that lack of clinician involvement in purchasing can mean due regard is not given to the fact that purchase decisions can potentially mean sub-optimal devices are selected and that these in turn lead to complications or delays during surgical procedures.
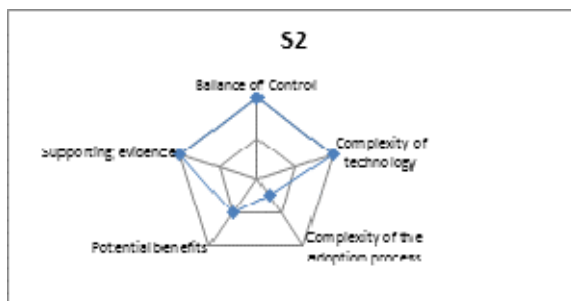
S3

Technology S3 enhances a pre-existing functional appliance used in orthodontistry. It was developed by a Technician, acting upon a request from the Consultant for whom he worked. Even though one adopter describes it as a "very neat solution and a very simple solution" its development was a substantial piece of work that included a number of design cycles to refine it.

An attempt was made to form a commercial partnership with a top international manufacturer of orthodontic products to manufacture and sell the product but this was not successful. Subsequently an agreement was

reached with an independent orthodontic supply company in the UK. This firm worked with the developer to improve the manufacturability of the product.

Although purchase of technology S3 increases the cost of the appliance supplied to the patient and increases the time the Technician spends working on it to prepare it for use, adoption is, at worst, cost neutral because of savings in Clinician time. It also brings advantages to the patient in terms of time spent in the clinic and allows treatment of more severe cases than would otherwise be possible.

The technology has been on the market for almost a decade. In the first few years the developer made substantial efforts to publicise his innovation, co-authoring a paper in a professional journal and attending conferences. The number of adoption sites rose but the increase stalled before use became widespread. The developer and industrial partner believe that once adopted the technology remains in use but there is at least one site where an attempt to adopt it failed. This may be the result of a training issue. An instruction leaflet is supplied with the product but no demonstration or training is supplied. Successful adopters are enthusiastic users, attesting to the reliability of the product and reporting failures as "very, very rare" but the unsuccessful adopter claims that each of the three items they tried to use failed.

S4

S4 is a surgical device used by eye surgeons. It was invented by the clinical lead for Ophthalmology at a major teaching hospital. He approached his local NHS innovation hub and they put him in touch with a Design Consultancy that had worked successfully to bring a number of innovative medical products to market. The project obtained a substantial amount of response-mode funding from a major charitable foundation to assist in the commercialisation of the technology.

S4 makes it much quicker and easier to perform the most crucial and challenging step of one of the most commonly performed operations in the UK and around the world. It is particularly useful when operating on children. (Children are the group of patients that has suffered the highest incidence of secondary complications in the past.)

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The devise is single use so has been designed to be manufactured at low cost. It also has other features that protect surgeons and patients from accidental sharps injuries during and after use.

S5

S5 is a low-cost, consumable item used during surgery. Before it was developed, the purpose it fulfils was met by the improvisational use of other items. S5 replaces them with a single, purpose-designed item that 'makes life easier'. It also improves patients' comfort during surgery and though no evaluation has been conducted to show it is the case, it is believed to reduce the chances of infection.

S5 was the idea of a surgeon. He heard about the local NHS innovation hub's call for innovative ideas approached them. After discussing the idea with the surgeon the hub contacted a supplier who then incorporated S5 into its product range. The hub has helped the inventor's trust to protect the intellectual property associated with S5 and negotiated a licence deal with the supplier on behalf of the trust. The trust receives royalties on sales.

The originating surgeon now uses S5 as part of his routine practice but adoption in the wider NHS has been minimal even though the procedure for which it is used is undertaken frequently in many trusts. Two possible explanations for the lack of adoption exist. First, the catalogue for the supplier is very large and S5 is one of many very similar sounding items. It is quite likely that potential adopters simply have not noticed that it is available. A second is another form of lack of visibility. The inventor is very pleased to have S5 available for his own use but does not really see the innovation as very significant and is not championing its adoption elsewhere.

S6

It has been shown that up to 20 per cent of patients receiving mechanical ventilation for more than 48 hours will develop a particular form of hospital-acquired infection. The consequences of this are very serious for the patients concerned (indeed, it doubles their risk of dying) and very costly for the NHS. S6 is designed to prevent patients from acquiring this infection. It is a highly innovative technology and was developed by a specialist in intensive care in an NHS hospital. The trigger for its development was repeated observation by nursing staff of problems associated with the technology they were using and which had been in use since the 1970s. The whole project from inception until it became available commercially in 2008 took a number of years. During this time substantial experimentation and testing was undertaken to perfect the technology and evaluate its performance. This evidence gathering culminated in a trial lasting 14 months that demonstrated the very substantial benefits of using the technology. Indeed, following this study it was possible to say that adoption led to substantial reductions in morbidity and considerable financial savings even though the cost of S6 is many, many times that of the technology it replaces. This is because the costs associated with the problem it prevents are so high. Indeed, at the site where the trial was conducted it was calculated that the cost of a single case of the infection S7 prevents is comparable to the annual costs of using it and without it there would be between five and ten cases during the course of a year.

There is some difference of opinion over the difficulty of using the technology. It is claimed in the literature that the procedure required to put S7 in place is as easy or easier than using the conventional technology but one adopter interviewed expressed a different view saying 'there is a lot of training involved in being able to handle it well'.
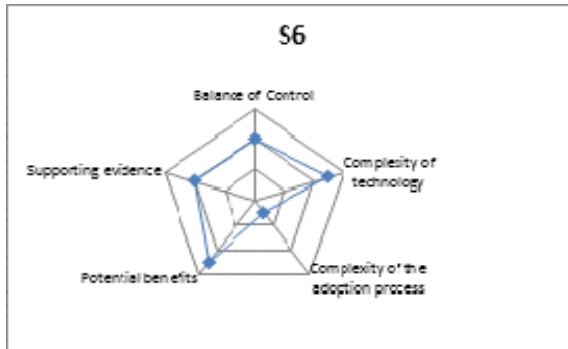
T1

T1 is a device to help radiographers to give repeatable and precise treatments to patients. It was developed by a clinical researcher working in a large teaching hospital. The clinical researcher's role was to manage a review of existing processes in the hospital's radiography department to check that they were underpinned by evidence. She was also tasked with identifying the need to undertake investigations where no such evidence existed and to implement more effective processes if the review showed they were needed. The specification for T1 was derived from one such review of processes.

The development of T1 was based on two successive prototypes produced by the hospital's engineering department. Each of the prototypes was used in the radiography department in turn and a large body of data was collected. Based on this data it was shown that T1 reduced the potential toxicity of radiotherapy, speeded up treatment time and improved the experience of patients during procedures. These very positive results caused the trust to decide to commercialise T1. This was done with support from an NHS innovation hub and in partnership with a large producer of medical devices.

The adoption of T1 is now widespread with most NHS radiology departments having bought at least one. However, as most radiology departments have several treatment suites, there is still scope for further adoption. The device has also been taken up widely in other countries including the US. T1's adoption within the NHS has occurred without its inclusion in any specific care guidelines, though it its use is included within certain clinical trial protocols.

The clinical researcher took a significant role in providing support to adopters. In addition to writing part of the device marketing brochure and the instruction manual, she also provided support and training to centres adopting the device. This has allowed her to encourage potential users of T1 and observe its use in different centres. The clinical researcher has been concerned that some adopters have not always used it effectively. When evaluating the performance of other centres where T1 has been adopted she has found they have not achieved the same levels of performance

improvement experienced elsewhere. Investigation has shown that the reason for this is that some centres fail to follow instructions given during training and in the instruction manual. Small but important differences in usage have led to suboptimal use. Several issues are raised by this. If centres do not know whether their use of T1 is effective then they will not know they need to take steps to improve practices. As a response to this, design of a newer version is underway which will include features that will reduce the possibility of wide variation in use. In particular, the low level of skills of some users will be addressed.
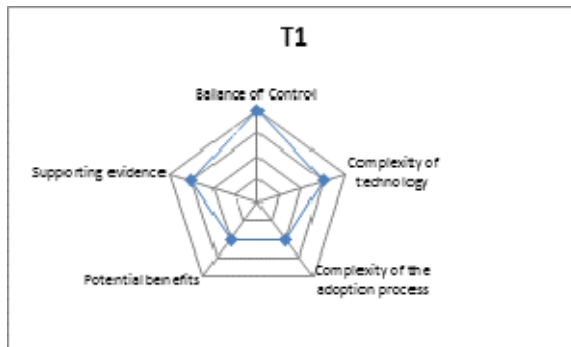

T2

Technology T2 was developed to prevent vaginal adhesions following radiotherapy or surgery. It was developed by a Clinical Nurse who specialises in Oncology and is actually a replacement for existing products that did the same job in the same way. However, it is claimed by those involved in the development that it is 'cheaper, easier and more comfortable to use than others currently on the market' and, in the words of one supplier, it 'offers exceptional design benefits [over competing products] and value for money'. Adopters report that the appearance of T2 is more appealing to patients than the alternatives that were already available. Because patients take the product with them when they leave hospital, packaging and ability to carry around discretely are also important and the product offers advantages here too.

The developer began working on her ideas in 1992 but T2 was not launched until 2005. It was estimated then that in the UK about 234,000 women per year could benefit from the technology and that the figure worldwide could be as high as 24 million. The late stages of development were supported by an NHS innovation hub. The hub helped in securing a contract involving the developer, the trust and a commercial partner that has a small stable of relatively low technology NHS-developed products.

Adoption is very straightforward and no different from the products that were already available. Adopters are split between those who know it is an NHS-developed technology and those that are unaware of its origins. Some of the former have been actively involved in its adoption and a sub-group within those have conducted their own informal trials. Where the latter are

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concerned, they were not aware of the adoption decision process and had just started using it because it had been made available to them. All of the adopters interviewed were very positive about T2 and felt it represented an improvement over the alternatives available.
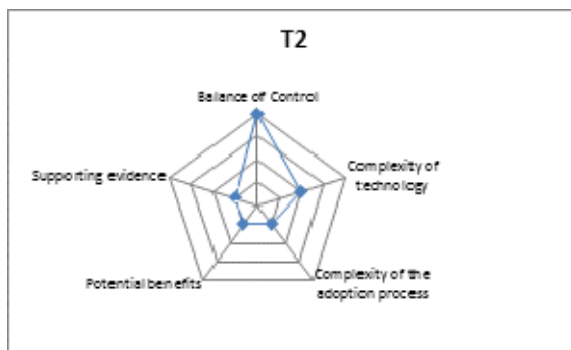

T3

Technology T3 is advertised as 'a rehabilitation product'. It is purchased by individual patients and by prevention programmes. For users it is a cheap, effective and portable product that allows them to exercise their legs whilst in a seated position. Essentially, adoption consists of no more than buying it and using it.

The technology was developed by a physiotherapist working with a non-NHS person who was looking for novel uses of a particular material he was already working with in an entirely non-health sphere. Having developed and tested the product the developer approached some large multi-national firms in search of an industrial partner. After coming close to giving up hope of success, she came into contact with a very small UK company that already had links with an NHS innovation hub. Acting on the advice of the company's Managing Director the developer approached the hub and her trust's R&D Manager. In 2006, five years after the initial idea for the product, a contract was signed by the developer, the trust and the commercial partner. The trust funded a trial to demonstrate the effectiveness of the technology and the partner made arrangements for manufacture, design of packaging, and the like.

By the summer of 2010 between 500 and 600 units had been sold. The developer is extremely disappointed by this low level of adoption and she feels that the marketing is to blame. One aspiration is to make the product available via a large chain of pharmacies, another is to sell the product at airports as a means of preventing deep vein thrombosis (DVT) on long flights, but neither of these is happening as yet.
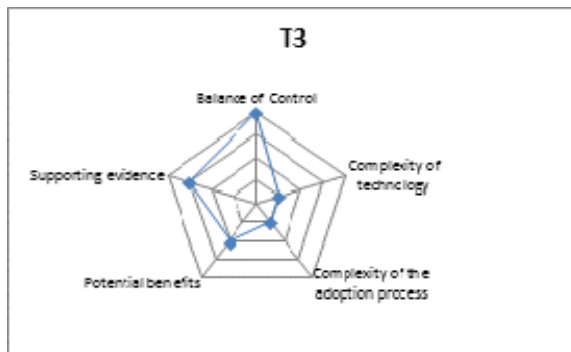
T4

Technology T4 is also a rehabilitation product. It is used under the guidance of physiotherapists and podiatrists by patients recovering from lower limb surgery or to treat foot problems in the hope that surgery can be avoided. It is also used to treat sports injuries. It treats conditions and injuries associated with over-pronation by allowing users to undertake exercise of specific muscle groups in the lower limbs that is controlled and reproducible and that can be increased in intensity as recovery proceeds.

The technology was developed by a specialist podiatrist with a particular interest in biomechanics who is employed by an NHS trust that provides acute and community health services. With financial support from an NHS innovation hub a prototype device was tested in a specialist laboratory at a local University, using 18 healthy volunteers undertaking lower limb stretching and squatting tasks, to see how they responded biomechanically when using the device. Data was collected using electromyography and photography and on the basis of those results the device was taken to a potential industrial partner and a contract was negotiated between the developer, the trust and a commercial partner that has a small stable of relatively low technology NHS-developed products.

The product was launched in the autumn of 2010 and can be purchased from the commercial partner or a leading supplier of rehabilitation equipment. The latter describe it as a piece of "practitioners' specific lightweight apparatus", thus drawing attention to the fact that it can be used to treat patients in their own homes as well as in clinic. It is marketed at the NHS and the private sector with attempts being made in publicity material to link it to the treatment of injuries sustained by premiership footballers and Olympic athletes. However, there is some scepticism amongst podiatrists that the technology offers advantages over simpler, and much less expensive, ramp devices. One commented "Whether it be calf stretching or eccentric loading of the patella tendon, these are things that the patient would need to be repeating at least once daily, and therefore they'd need one themselves" and expressed doubt as to whether patients would be willing/able to buy the device for themselves given it costs hundreds of pounds.
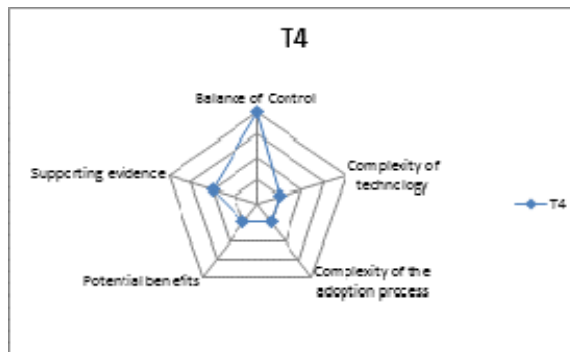
T5

T5 is a small, inexpensive device used by patients to self-treat a common skin condition. It can be used to treat a single episode of the condition but some evidence suggests that it effective in reducing the likelihood of future episodes. It is represents an alternative to pharmaceutical treatments and if effective represent a significantly cheaper treatment of the condition.

The device was developed by an NHS GP in his own time. Development took place over several years and included a number of small scale trials to prove the concept of the technology. The GP formed a company and developed partnerships with existing device manufacturers. Some key hurdles in the development of the commercial product were the design of specialised components and the refinement for manufacture of the device design. The funding of the development of the device was all sourced from outside of the NHS and though the GP worked within the NHS, no NHS organisations were involved with the project. The only relationship with the NHS was the involvement of NHS patients in a clinical trial to compare the device against pharmaceutical treatment. NHS nurses were also involved in running the trial and collecting outcome data. Data analysis was carried out by the medical research department of a local university. A significant amount of the development took place prior to the changes in the NHS to manage innovation and IP developed by NHS-staff. The device is now marketed by a UK-based company with manufacture taking place in Asia. Though it is marketed under a tradename in pharmacies, shops selling healthcare –related goods, and from internet-suppliers, it is also sold in some large pharmacy chains with their brand identity.T5 is also available in the UK on prescription but low levels of awareness of T5 on the part of GPs means that only a small number of devices are distributed this way. The majority of sales are directly to the public.

T5 is a technology that demonstrates the difficulty in defining 'NHS-developed technologies'. The concept for the device was developed before any significant management of IP was built into NHS organisations. The development of T5 was legitimately carried out separately from the NHS, though the experience of the GP involved was clearly rooted in his NHS work. Similarly the clinical trial that took place used NHS staff and patients. As such, the role of the NHS in the development of T5 was evident but the

IP associated with the technology is not even partially assigned to the NHS with the result that no revenue from the technology is received by the NHS.

A second point about T6 is the extent to which a technology can be deemed as 'adopted' by the NHS. The device is widely available for purchase directly by patients. Though clinicians may encourage use of the device or even provide one on prescription, the extent to which T5 can be seen as adopted by the NHS is unclear. T6 shows that the take-up by patients directly has potential to result in NHS patients no longer seeking further care.

Finally, providing definitive evidence that T5 is an effective technology is challenging. The technology needs to prove its effectiveness compared to pharmaceutical alternatives but also to the consequences of no treatment because the condition it treats is self-limiting. The skin condition is such that the use of T5 at an early stage is critical to its effectiveness, yet the likelihood of the patient noticing the condition and starting treatment early varies considerably. Claims that the technology reduces recurrence of the condition are also difficult to prove.

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