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The Effectiveness of Service Delivery Initiatives at Improving Patients' Waiting Times in Clinical Radiology Departments: A Systematic Review

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Abstract We reviewed the literature for the impact of service delivery initiatives (SDIs) on patients' waiting times within radiology departments. We searched MEDLINE, EMBASE, CINAHL, INSPEC and The Cochrane Library for relevant articles published between 1995 and February, 2013. The Cochrane EPOC risk of bias tool was used to assess the risk of bias on studies that met specified design criteria. Fifty-seven studies met the inclusion criteria. The types of SDI implemented included extended scope practice (ESP, three studies), quality management (12 studies), productivity-enhancing technologies (PETs, 29 studies), multiple interventions (11 studies), outsourcing and pay-for-performance (one study each). The uncontrolled pre- and post-intervention and the post-intervention designs were used in 54 (95 %) of the studies. The reporting quality was poor: many of the studies did not test and/or report the statistical significance of their results. The studies were highly heterogeneous, therefore meta-analysis was inappropriate. The following type of SDIs showed promising results: extended scope practice; quality management methodologies including Six Sigma, Lean methodology, and continuous quality improvement; productivity-enhancing technologies including speech recognition reporting, teleradiology and computerised physician order entry systems. We have suggested improved study design and the mapping of the definitions of patient waiting times in radiology to generic timelines as a starting point for moving towards a situation where it becomes less restrictive to compare and/or pool the results of future studies in a meta-analysis.

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Abbreviations

PEWT	Pre-examination waiting time
RTAT	Report turnaround time
TRWT	Total radiology waiting time
SDIs	Service delivery initiatives
ER	Electronic requesting
DR	Digital radiography
CPOE	Computerised physician order entry
PACS	Picture archival and communication system
EPOC	Effective practice and organization of care
CR	Computed radiography
ESP	Extended scope practice
TR	Teleradiology
PNS	Pager-notification system
QM	Quality management
HIS	Hospital information system
WMS	Workflow management system
SRR	Speech recognition reporting
IT	Information technology
EMR	Electronic medical records
RCT	Randomised controlled trial
ITS	Interrupted time series
CBA	Controlled before and after
RIS	Radiology information system

QMMs Quality management methodologies
PETs Productivity-enhancing technologies

Background

Patients' experiences of radiology services centre on the key issues of availability and waiting times [1]. The three key measures of patients' waiting times within radiology departments are the time intervals between: (1) referral and examination, i.e. the pre-examination waiting time (PEWT); (2) examination and finalised radiology report, i.e. the report turnaround time (RTAT) [1] and (3) referral and finalised radiology report, i.e. the total radiology waiting time (TRWT), which is 1 and 2 combined. Unless otherwise stated patients' waiting time is used to represent all three aspects of patients' waiting experiences from now on in this paper.

There is a time boundary within which the radiology examination (report) is of clinical importance [2]. Increasing financial, political and clinical pressures to reduce the waiting times for radiology examinations have meant that many radiology departments are implementing a variety of service delivery initiatives (SDIs). The breadth of SDIs is wide, ranging from small scale inexpensive changes to practice, to large costly initiatives. There is a dearth of literature on how best to evaluate these SDIs within radiology departments, where pragmatic constraints often mean that randomised controlled trials are not feasible. Consequently, the methods and quality with which SDIs are evaluated within radiology settings is often mixed. In spite of, and perhaps even because of these constraints, a review of the type of SDIs, methods of evaluation used, and evidence of effectiveness, would be a useful addition to the literature. There has been no synthesis of evidence on the effectiveness of the frequently adopted SDIs at reducing patients' waiting times within radiology departments. A few reviews on the causes of elongated hospital waiting times and the impact of various improvement strategies have been published [3–5]. However, many of these reviews were unsystematic [6] and have only focused on the waiting lists for surgical care.

Our aim was therefore to systematically review the literature to address how effective SDIs implemented within radiology departments are at reducing patients' waiting times. Evidence of this form will allow for a more effective guidance to radiology service managers who are keen to improve their services and, those designing and conducting studies evaluating the effectiveness of SDIs within radiology departments.

The Global Radiology Workflow

The radiology workflow starts with the request for a radiology examination by a clinician and ends with the finalised radiology report (Fig. 1). The radiology workflow steps can be optimised with different type of SDIs, for example, the traditional hardcopy imaging request form is often replaced with a computerised physician order entry systems (CPOE). This should reduce the requests delivery times and intuitively lead to quicker turnaround times. A key workflow step is the transcription of radiology reports. The human transcriptionist might be replaced with a speech recognition reporting (SRR) system which converts dictated report to written text.

Methods

A systematic review is a protocol-driven attempt to discover, evaluate and synthesize all the empirical evidence that meet pre-specified criteria, to address a given research question, using explicit methods to minimise bias, with an objective of producing a more reliable findings that can be used to inform decision making [7]. This review incorporates methods from the Cochrane Collaboration [7], Centre for Reviews and Dissemination [8] and the PRISMA statement [9]. The general structure of this review, organisation of search and the risk of bias assessment followed the Cochrane guideline. Data synthesis followed the Centre for Review and Dissemination guideline. We adopted the PRISMA guideline for reporting systematic reviews. The PRISMA guideline is widely endorsed [10]. These guidelines were combined because preliminary literature search revealed a diverse study designs and settings and we did not wish to impose a highly restrictive inclusion criteria.

Data Sources

We searched MEDLINE, EMBASE, CINAHL, INSPEC and The Cochrane Library for relevant articles published between 1995 and February, 2013. The search was organised in line with the PICO framework: *P*opulation/*P*roblem; *I*ntervention, *C*omparison (optional) and *O*utcome. The search strategy implemented on MEDLINE is shown on appendix I. The strategy combined Medical Subject Heading (MeSH) with free text terms.

Inclusion and Exclusion Criteria

We included articles that reported objective measures of the impact of SDIs on patients' waiting times within routine clinical settings. This is expressed as the time waited from referral to either examination or finalised radiology report, from examination to finalised radiology report or the number/proportion of patients that waited above or below a specified time.

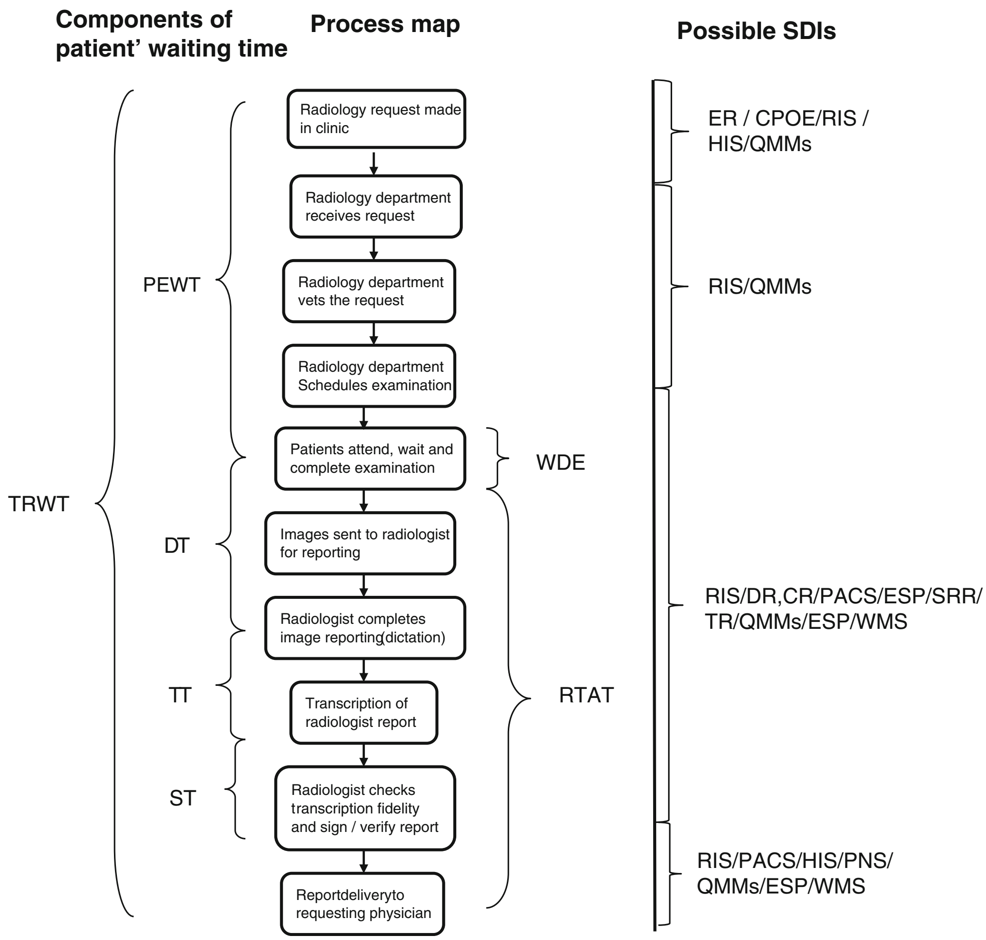

Fig. 1 Global radiology workflow and possible workflow improvement strategies. *TRWT* total radiology waiting time; *PEWT* pre-examination waiting time; *DT* dictation time; *TT* transcription time; *ST* signature time; *WDE* waiting on the day of examination; *RTAT* report turnaround time; *SDIs* service delivery initiatives; *ER* electronic requesting; *CPOE* computerised physician order entry; *RIS* radiology information system; *DR* digital radiography, *CR* computed radiography; *PACS* picture archival and communication system; *ESP* extended scope practice; *TR* teleradiology; *PNS* pager-notification system; *QMMs* quality management methodologies; *HIS* hospital information system; *SRR* speech recognition reporting; *WMS* workflow management system

The type of SDIs included extended scope practice (ESP), quality management, SRR, electronic requesting etc. (Fig. 1). Only English language articles were included.

Studies which addressed diagnostic performances without reference to patients' waiting times, clinical interventions, simulation, opinion, editorials and other non-empirical studies were excluded.

Study Selection Process

All identified articles were imported into EndNote X6™ and duplicates removed (Fig. 2). One of the reviewers (BO) screened the list of unique articles by title and abstract. The full text articles assessed as 'potentially relevant' were retrieved.

The inclusion and exclusion criteria were independently applied to the potentially relevant articles by BO and YFC and reasons given for exclusions. Disagreements were resolved by discussions. Opinions were sought from a third reviewer (KH or AG) when required. The reference lists of the included articles were hand searched and identified articles were added to the review database. Data were extracted from the included studies by BO and YFC. We stratified and sub-stratified the studies by the type of SDIs and study design, respectively.

Risk of Bias Assessment

Risk of bias assessment addresses the key question of the extent to which the results of a study can be believed [11].

> A bias is a systematic error, or deviation from the truth, in results or inferences … meaning that multiple replication of the same study will reach the wrong answer on average [11].

Tools have been developed to assess the risk of bias in studies, however these tools are developed for studies meeting certain minimum research design requirements. The Cochrane Collaboration Effectiveness of Practice and Organisation of Care (EPOC) review group risk of bias tool [12] was used to assess the risk of bias on studies that were: either randomised controlled trials (RCT), non-randomised controlled trials, controlled before-after (CBA) with 2 control and intervention sites or interrupted time series (ITS) [13]. The risk of bias was not assessed on studies that used either the uncontrolled before-and-after or

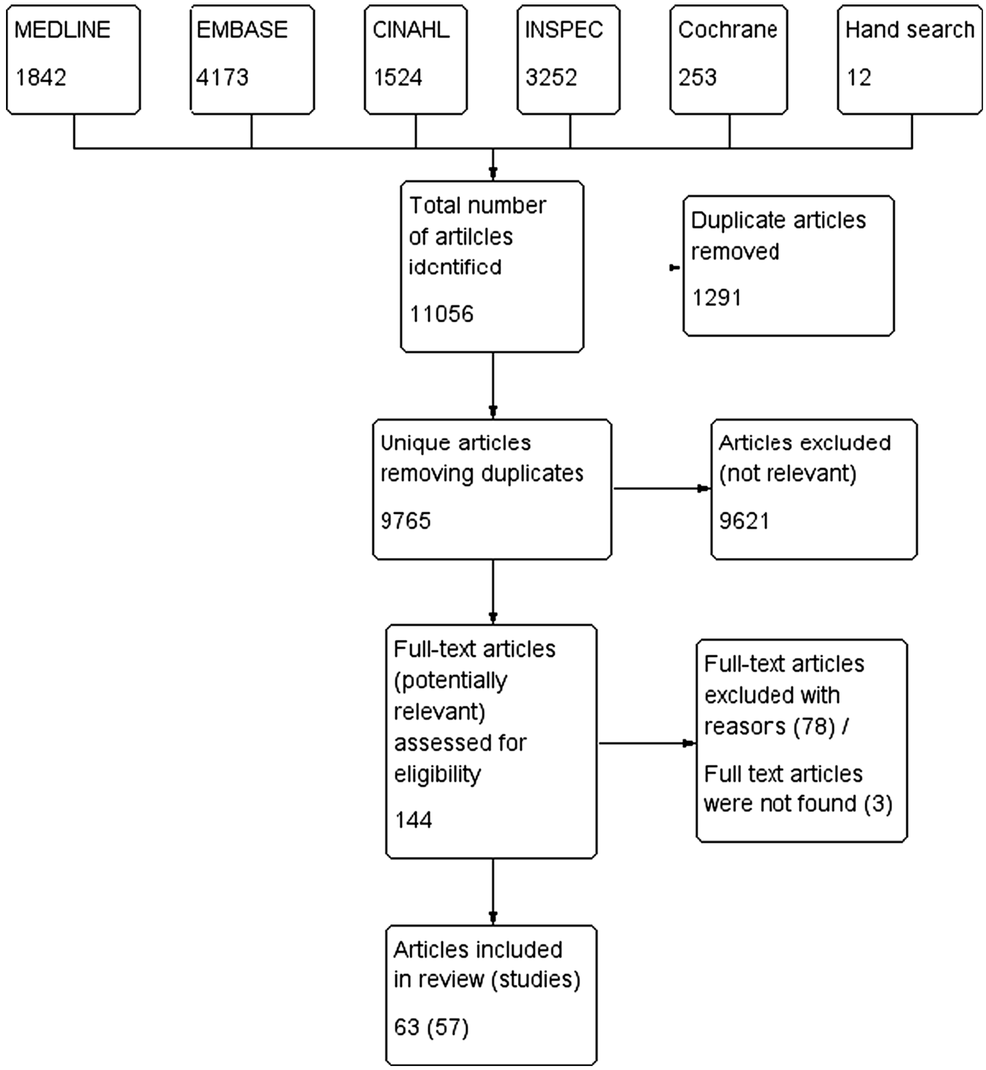

Fig. 2 Articles filtration process

post-intervention only designs because these designs are already known to be inherently susceptible to a high risk of bias [7, 13].

Data Synthesis

Data synthesis involves the collation, combination and summary of the results of individual studies included in a systematic review. Data synthesis can be done quantitatively using formal statistical procedures such as meta-analysis, or if formal pooling of results is unsuitable, through a narrative approach [8]. Pooling of results obtained from diverse non-randomised study types is not recommended [14]. Similarly, meta-analysis of poor quality studies could be seriously misleading as errors or biases in individual studies would be compounded and the very act of synthesis may give credence to poor quality studies [11]. Pooling of results in a meta-analysis is inappropriate for the current review due to a high level of heterogeneity. The narrative synthesis is widely used in this situation [15, 16]. Therefore, we present a narrative synthesis of our findings. This is a textual approach that provides an analysis of the relationships within and between studies and an overall assessment of the robustness of the evidence [8].

Results

Our search yielded 11,056 articles (Fig. 2). We screened 9,765 articles by titles and abstract after removing duplicates (n=1,291). We excluded 9,621 as not relevant leaving 144 articles eligible for full text review. Full text for 3 articles could not be obtained from the British Library and were therefore excluded. Seventy-eight articles were excluded with reasons: did not report the outcome measures of interest [17–68]; did not report objective measure of patients' waiting times, is an opinion piece, an editorial or theoretical paper [69–83]; did not report any intervention [84–89] and was withdrawn from publication [90]. Sixty-three articles (57 studies) met the inclusion criteria.

Table 1 Included studies stratified by type of intervention, research design and component of patients' waiting times reported (percentage in parenthesis)

Type of intervention	Number of studies	Study design				Waiting time component		
		Post-intervention designs	Uncontrolled pre- and post-intervention designs	Controlled pre- and post-intervention designs	Structural time series	Pre exam waiting time (PEWT)	Report turnaround time (RTAT)	Total radiology waiting time (TRWT)
Extended scope practice	3 (5)	.	2		1	1	3	
Quality mgt./service re-design	12 (21)	1	10	1		10	2	2
Outsourcing	1 (1.75)	1				1		
Pay-for-performance	1 (1.75)	.	1				1	
Productivity-enhancing technologies[a]	29 (51)	5	22	1		4	24	2
Multiple intervention	11 (19)	2	10			1	7	2
Total number of studies	57 (100)	9 (15.8)	45 (78.9)	2 (3.5)	1 (1.8)	17 (30)	37 (65)	6 (11)

[a] Productivity-enhancing technologies reported included: speech recognition reporting (SRR), picture archival and communication system (PACS), radiology information system (RIS), computed radiographer (CR), computerised physician order entry (CPOE), digital radiography (DR). The waiting time components do not add up to 57 because some studies measured more than one component of the patients' waiting times

Most of the studies (61 %: 35/57) were performed in the USA, 14 % (8 of 57) each in the UK and EU, respectively and 6 (11 %) within rest of the world. The majority of the studies (60 %: 34/57) were published between years 2000 and 2009, 17 % (10/57) before the year 2000 and 23 % (13/57) from and including years 2010 to February 2013. Forty-five studies (79 % of 57) used the pre- and post-intervention design while 15 % (9/57) used the post-intervention only design (Table 1). The RTAT outcome measure was reported in 65 % (37/57) of the studies while PEWT was reported in 30 % (17/57) (Table 1). The characteristics and main findings of the included studies are summarised in Appendix II. The results of the studies by type of SDIs are presented below.

Extended Scope Practice

An ESP radiographer is one who has significantly extended their role and accordingly has supplementary clinical proficiency in a specified area of practice [91], e.g. image reporting. Three (5 %) of the 57 included studies evaluated ESP and all were performed in the UK. Two of these studies used the uncontrolled pre- and post-intervention design and covered different patient groups: accident & emergency (A&E) [92], inpatients and outpatients [93]. The third study used a time series design on A&E patients [94]. Different components of the patients' waiting times were reported: RTAT [92, 94] and PEWT [93]. All three studies reported improved patients waiting times. For example, regression analysis suggests that increased proportion of A&E examinations reported by ESP radiographers is associated with 36.8 % reduction in RTAT, $p<0.001$ [94], and there was a 75 and 62 % drop in the mean PEWT for inpatient and outpatient video fluoroscopy, respectively following ESP implementation [93].

Quality Management Methodologies

Quality management is a general approach to delivering services that meet service users' needs with a more effective use of resources [95]. There are different approaches to quality management. Twelve (21 %) of the 57 studies investigated quality management strategies including the Lean, Six Sigma and continuous quality improvement methodologies [96–101] and process/service re-design [102–107]. The type of study designs used include the controlled pre- and post-intervention [99], the post-intervention [104] and the remaining 10 studies adopted the uncontrolled pre- and post-intervention design. The PEWT were reported in seven studies [96, 98, 100–102, 104, 107], one study reported the RTAT [103] and two studies reported the TRWT [99, 106]. Two studies failed to define the timelines used in computing the outcome measures [97, 105].

Most of these studies reported improved outcomes [96–105, 107]. For example, the mean PEWTs were 56 (90 % CI 54, 57) and 36 (90 % CI 34, 38)min pre- and post-intervention with the Lean methodology, respectively [100]. However, one of these studies reported that the improvements were not sustained [99]. One study found increased waiting times following service re-design [106]: the TRWTs were 51 and 69 min for CT head; 69 and 82 min for body CT pre- and post-service re-design, respectively.

Outsourcing

Outsourcing is a situation where the radiology department (not the referring physician) contracts an examination or parts of it (e.g. reporting) to an outside agency [108]. One study evaluated the impact on PEWT of outsourcing radiology examinations [108]. This study used the post-intervention only design to compare the PEWT of outsourced examination with those performed in-house. The study found no statistically significant difference between the groups, in either the number of examinations that were not performed within the preferred time or the number of days that exceeded the preferred waiting time target. However, for examinations without a preferred timeframe, the waiting time was shorter for outsourced investigations than those not outsourced.

Pay-for-Performance (PFP)

Pay-for-performance (PFP) is a financial incentive intended to inspire providers to deliver higher-quality care [109]. A PFP programme comprising $5,000 annual bonus payment to radiologists who met specified RTAT targets was evaluated for its impact on RTAT [109]. This study found that the mean RTATs were 43 (SD 99), 32 (SD 78) and 16 (SD 54)h before, after and 2-year follow-up periods, respectively, $p<0.0001$.

Productivity-Enhancing Technologies (PETs)

Productivity-enhancing technologies (PET) is a collection of technologies for optimising the radiology workflow steps. The effectiveness of PETs at reducing patients' waiting times was investigated in 51 % (29/57) of the studies. The technologies examined included speech recognition reporting, picture archival and communication systems, teleradiology, radiology information systems, computerised physician order entry systems and other.

Speech Recognition Reporting (SRR)

The SRR system works by converting spoken words into digital signal which is then transformed into written text. SRR was evaluated in 11 (19 % of 57) studies [110–121]. Two of the studies used the post-intervention design [119, 121] and the remaining nine studies used the uncontrolled pre- and post-intervention design. All 11 studies evaluated different patient populations and measured the RTAT with different time lines. All 11 studies reported varying degrees of improvement in RTAT. One of the studies noted that 2 of 30 radiologists did not experience improvement in their individual workflow following SRR implementation [114].

Picture Archival and Communication System (PACS)

The picture archival and communication system (PACS) is a structure of hardware and software system for handling, storing, organising and distributing digital images within the health care environment. Five (9 %) of the 57 included studies evaluated PACS [122–127]. The uncontrolled post-intervention design was used in one study [123] and the remaining four studies used the pre- and post-intervention design. Different patient populations were included: these were based on imaging modality [124, 126, 127], or referral sources [122, 125]. The definition of outcome measures also varied. The results for PACS is mixed, for example one study [124] found that the mean RTAT increased from 4 to 7 days for MRI, $p<0.001$, remained stable at 2 days for CT and dropped from 4 to 3 days for plain X-rays. However, the overall departmental RTAT improved from 6 to 5 days $p<0.001$. Another study found a 9 % improvement in RTAT [126, 127]. Yet another study reported that the median PEWT was significantly longer for plain X-rays after PACS implementation: increasing from 20 to 25 min for A&E patients and three to 42 min for patients on intensive care [125].

Teleradiology

Teleradiology is the method of sending digital radiology images from one location to another for the purpose of consultation and interpretation. Two (3.5 % of 57) studies on teleradiology met the inclusion criteria. Both studies found that teleradiology improved RTAT [2, 128]. For example, the proportion of reports completed within 40 min increased from 34 (95 % CI 29, 38) to 43 % (95 % CI 39, 47) pre- and post-intervention, respectively, $p<0.01$ [2]. The two studies used different research designs: controlled pre- and post-intervention design [2] and controlled post-intervention design [128]. Both studies measured RTAT in using different timelines.

Radiology Information System (RIS)

The radiology information system (RIS) is a software system for managing and keeping permanent records of patients' journeys through the radiology department. Two (3.5 % of 53) studies investigated the RIS and both used the pre- and post-intervention design. Both studies investigated different components of patient waiting times: the TRWT for orthopaedic patients [129] and the RTAT for MRI and mammography [130]. The results were mixed. One study found that the mean RTAT for mammography improved from 4.06 (SD 2.34) to

2.17 (SD 1.43)h while the RTAT for MRI increased from 3.11 (SD 1.87) to 3.20 (SD 1.85)h pre- and post-intervention, respectively [130]. These results were statistically significant at 5 %. The earlier study found that the mean TRWT reduced from 26.8 (SD 6.8) to 3.6 (SD 2.5)h following the RIS implementation [129].

Computerised Physician Order Entry (CPOE) Systems

CPOE is a system for requesting radiology examinations electronically instead of the papers-based methods. Four (7 % of 57) studies assessed the impact of CPOE on patients waiting times. All four studies used the uncontrolled pre- and post-intervention design. One study measured the TRWT [131] while the rest measured the PEWT [132–134]. The study populations varied: patients that presented with chest pain in the A&E department and subsequently had chest a X-ray [131], patients on adult Intensive Therapy Unit (ITU) who had urgent CT or plain imaging [133], patient referred for either plain chest/abdominal X-rays or abdominal ultrasound from the transplant service [134], the fourth study included only very low birth weight (VLBW) babies on the Neonatal Intensive Care Unit (NICU) who had abdominal or chest X-rays [132]. Three of the studies reported positive findings: The adult ITU study [133] found reduced median PEWT from 96 to 29 min $p<0.001$ with less variation around the median, while the study involving patients referred from the transplant unit found that PEWT reduced from 7 to 4 h (49 %) $p<0.05$ [134]. It was not specified if these were mean or median values. The VLBW study reported reduced mean order-to-image-display time from 42 to 32 min [132]. The fourth and most recent study reported no improvement in patient waiting times: TRWT remained stable at 80 min, $p=0.49$ despite increased volume of requests [131]. Two of the four studies [132, 134] were from the same institution.

Other Technologies

The remaining 5 of 57 (9 %) studies investigated a wide range of productivity-enhancing-technologies. These technologies included pager-notification systems [135–137], digital imaging [138], computer coded reporting [139], workflow management system [140]. Two studies used the controlled post-intervention design [138, 139] while the remaining studies used the uncontrolled pre- and post-intervention designs [135–137, 140]. All five studies measured the RTAT with different timelines and included different patient population as well. Most of the studies reported positive findings [135–137, 139, 140], however one study noted that the gains were not sustained beyond 1 week post implementation of a pager-notification system [136, 137]. Mixed results were reported on a digital radiography system [138].

Multiple Interventions

We identified 11 (19 % of 57) studies where more than one type of intervention was evaluated. Most of the studies combined multiple PETs [141–150]. The remainder combined quality management methodologies (QMMs) with PETs [151–154]. The studies used varied research designs including the post-intervention only design [147, 148] and the uncontrolled pre- and post-intervention design. In terms of outcome measure, most of the studies reported RTAT [141, 142, 146–148, 151–154], two studies measured TRWT [143–145] and one study reported the PEWT [149].

Most of the studies reported positive findings [141, 142, 145, 146, 150, 152–154]. For example, the average RTATs were 115 and 23 h pre- and post-intervention, respectively [141, 150]. However, one study reported that the improvements were not sustained [152]. Another study reported negative findings [149]. This study reported that implementation of PACS and automated scheduler increased the PEWT from 0.12 to 0.27 h. Three studies reported mixed results [143, 144, 147, 148, 151]. For example one study [151] evaluated a combination of interventions and found that better staffing level, technology (use of SRR) improved RTAT while proposed sanction on non-compliance with RTAT target and education of staff on the need to comply with RTAT requirements did not improve RTAT.

Risk of Bias Assessment

Only one study [94] fully met the minimum design standard for a Cochrane review. Two studies [2, 99] used the controlled pre- and post-intervention design without the recommended minimum of two control and two intervention sites thereby meeting the standard only partially [13]. The Cochrane EPOC risk of bias tool [12] was used to assess the risk of bias on these three studies (Table 2). We did not assess the risk of bias on the remaining studies for two reasons: as earlier stated, the studies used research designs that are already known to be inherently susceptible to a high risk of bias [7], and we did not find any assessment tool either.

Discussion

Patients' waiting times are a major indicator of the quality of care within radiology departments [155, 156]. Several type of intervention are being implemented by radiology departments to improve waiting times. Some individual study estimates of the impact of the SDIs on waiting times have been published but there is yet no synthesis of the evidence of their effectiveness. Recent systematic reviews have examined the impact of

Table 2 Risk of bias assessment on the three studies that met the minimum design requirement for a Cochrane EPOC systematic review

	Controlled pre- and post- (CBA) studies		Time series (ITS) study	
CBA Domains	[99] Quality management	[2] Teleradiology	ITS Domains	[94] ESP
Was the allocation sequence adequately generated?	High risk of bias All CBA studies are considered high risk on this domain	High risk of bias All CBA studies are considered high risk on this domain	Was the intervention independent of other changes	High risk of bias The study is silent on the medical informatics and other productivity-enhancing technologic environment of the department/any changes within the time period
Was the allocation adequately concealed?	High risk of bias All CBA studies are considered high risk on this domain	High risk of bias All CBA studies are considered high risk on this domain	Was the shape of intervention effect pre-specified	Low risk of bias Time of intervention was specified
Were the baseline outcome measures similar?	Low risk of bias Number of chest X-rays performed on the two sites were similar	Low risk of bias Differences were adjusted for by analyzing percentage drop in RTAT	Was intervention unlikely to affect data collection?	Low risk of bias Radiographers reporting should not affect data retrieval from the RIS.
Were baseline characteristics similar?	High risk of bias The two sites have different workflow processes	Low risk of bias The same site as control	Was the knowledge of the allocated intervention adequately prevented during the study?	Low risk of bias Objective outcome data
Were incomplete data adequately addressed?	Unclear Not discussed	Unclear Not discussed	Were incomplete data adequately addressed	Unclear Not discussed
Was the knowledge of the allocated intervention adequately prevented during the study?	Low risk of bias Objective outcome data	Low risk of bias Objective outcome data	Was the study free from selective outcome reporting?	Low risk of bias No evidence of selective reporting
Was the study adequately protected against contamination?	Low risk of bias Based on institution which were far apart	Low risk of bias Based on episodes of care	Freedom from other risk of bias?	Low risk of bias None detected
Was the study free from selective outcome reporting?	Low risk of bias No evidence of selective reporting	Low risk of bias No evidence of selective reporting		
Freedom from other risk of bias?	High risk of bias different methods of data collection on both sites, Data obtained from the RIS on one site (OUH) and by questionnaire at the other site (HUCH)	Low risk of bias None detected		

a single SDI on a range of outcome measures. For example, CPOE system was found to impact on imaging requesting behaviours, adherence to guidelines, length of hospital stay, mortality, readmission rates and radiology turnaround times [157]; PACS within the intensive care setting was found to impact on image availability, image viewing patterns, clinical decision, etc. [158]. These reviews have not focused on patient waiting times. We have used a different approach in the current review by evaluating the impact of popular SDIs implemented within radiology on an outcome measure of topical interest (patients' waiting times). The studies included this review are highly heterogeneous and most (95 %) of them used study designs that can potentially lead to biased estimated of effect size and the reporting quality was poor. In the next sections, we discuss each type of intervention in terms of the theory behind how it works, why it might work for which type of organisation, the results and relationships between the studies with a focus on the studies with lower a risk of bias. The subsequent sections examine the robustness/ quality of the evidence and the causes of heterogeneity in the studies.

Extended Scope Practice

ESP radiographers reporting has been employed by NHS organisations experiencing increased demand and shortage of radiologists [159], with attendant increased RTAT. ESP allows radiographers to extend their roles into some tasks traditionally undertaken by radiologists (e.g. plain film reporting) as means of increasing (reporting) capacity [159, 160]. A previous review [15] of the evidence on the effectiveness of ESP concluded that most of the studies explored the acceptance of these roles by other professional colleagues; however, their impacts on services were not evaluated. We found three ESP studies, all performed within the NHS, UK. This is not surprising given that the NHS is one of the first healthcare systems to implement ESP [160, 161]. Only one of the three studies [94] used a robust research design [13] and we performed a risk of bias assessment on it. Table 2 shows that, generally, this study has a low risk of bias. All three studies reported positive findings, suggesting that where appropriate ESP might be an effective strategy to reduce RTAT for A&E plain film. However, amongst other considerations for implementing EPS, an assessment must be made that increasing RTAT is due to shortfall in reporting capacity.

Quality Management Methodologies

The objective of QMMs is to identify and remove wastage from a system. QMMs appear to have a huge potential to improve the global radiology workflow processes especially when combined with PETs [152–154]. Implementing PETs without QMMs is unlikely to yield the optimum results [112, 145, 152]. It is not surprising therefore that the NHS is paying a greater attention to the Lean and Six Sigma methodologies [162, 163]. Only one [99] of the 12 included studies partially met the Cochrane EPOC study design requirements. This study implemented a seven-step continuous quality improvement (CQI) strategy on the intervention site and a 'traditional' management technique on the control site. The seven steps included using expert team to map the process, identify and understand the problems, select, design, implement and monitor the process improvement. This led to 18 % reduction in the proportion of chest X-ray examinations breaching the 2 h target. One [106] of 12 reported negative results. These two studies differ; in terms of population, imaging modality, methodology and type of intervention. Whereas the latter was done in an A&E department the former was done in an outpatients setting. The second study involved a barrage of interventions but did not follow a problem identification procedure. This might explain the difference in results between this two studies. Any radiology department will benefit from QMMs because the radiology workflow processes is particularly suited to process improvement. However, sufficient time must be invested in identifying and understanding the problem as well as its root cause(s).

Productivity-Enhancing Technologies

PETs include a host of technologies employed to improve process flow within the radiology departments. PETs were evaluated in 51 % (29/57) of the studies of which only one study [2] evaluating teleradiology partially met the minimum design standard for a Cochrane EPOC review. Teleradiology is mainly used by NHS hospitals for outsourcing routine reporting to cover shortfall in reporting capacity and provide cover for remote communities [164]. Kennedy et al. [2] found that teleradiology improved RTAT. A second [128] teleradiology study also reported positive findings. The results of both studies suggest that teleradiology might improve RTAT, however, this must be balanced against other quality parameters such as costs and referring clinicians' satisfaction [164].

The importance of SRR is limited to addressing the time delay between report dictation and its transcription. Theoretically, SRR should improve the speed of report production by instantly transforming dictated reports into text. Therefore, the SRR intervention might only be useful to an organisation struggling with its transcription workload, as opposed to a shortfall in reporting capacity. Some researchers have argued that SRR only shifted the burden of transcription to the radiologists with detrimental effects on their productivity, which might result in higher aggregate costs [55, 63]. Other concerns included high error rates [63] and the brevity of reports generated with SRR (24–39 % shorter in length) compared to conventional dictation [55, 57]. All the 11 SRR studies included in this review reported varying degrees of improvements on RTAT. Some reported cost savings as well [112, 117], others reported that SRR had not improved the RTAT of some radiologists within the practice [114]. It was therefore thought that human behaviour might play a significant role on the extent of improvements observed. Although all 11 studies used designs with a high inherent risk of bias. The results suggest that a 'total' (100 %) SRR implementation might be more effective than partial implementation [111] and even better when combined with QMMs [112]. However 100 % SRR adoption might be a difficult proposition for organisations with teaching commitments [113].

PACS and RIS are the bedrocks of any modern radiology department. Both technologies impact patient waiting time by improving process flow; reducing time wasted on tracking films, patients' records and appointments. The impact of PACS on patient waiting times is mixed. One study reported mixed results depending on referral sources [124]. Other studies observed no impact on waiting times [126, 127], deteriorated waiting times [125] and positive results [122, 123]. The situation is similar with the RIS: two studies with mixed results. We have found the evidence of the impact of PACS and RIS on patients waiting times to be both inconsistent and insufficient. A previous review on PACS reached similar conclusion [16]. However, we feel that the overall importance of these two systems to a large radiology department might outweigh any considerations of their empirical impact on reducing waiting times. The dynamics might be different for smaller departments processing only a few thousand cases per year.

Other Interventions

We found a few other promising technologies including electronic requesting [145], CPOE [131–134, 142]. CPOE improve waiting time by ensuring that requests are received by radiology departments almost instantaneously. Again, this technology might be useful for large departments having problems of not receiving requests in a timely manner/ loosing requests forms. The earlier the requests are received, the sooner the examinations can be arranged. Of the four CPOE studies, only one [131] reported no improvement in waiting times. This is probably because the study examined chest X-ray requests in the A&E settings. Care in the A&E is usually fast paced, usually with X-rays performed in adjacent rooms. Therefore, CPOE might not make a drastic impression on this setting.

We found one study each evaluating PFP [109] and outsourcing [108]. PFP might be useful when routine QMMs fail and an organisation decides that staff needed additional incentive to improve quality [109]. The PFP study reported statistically significant improvement in RTAT. This is a single study estimate. The implications of PFP are a current debate topic in many health economies [165, 166]. Some think that there are too many obstacles for it to work in radiology [167], others feel that it can be easily abused [168] but most importantly there are insufficient outcome studies [169]. The study that evaluated outsourcing [108] found no difference in waiting between outsourced examinations and those performed in-house, when a preferred time frame was specified. We feel that a predictable consequence for the development of teleradiology is the potential for the outsourcing of radiology reporting. In 2009, 37 % of UK radiology department were already outsourcing parts of radiology reporting as a means of increasing capacity [164]. This review has found insufficient evidence that either PFP or outsourcing of radiology examinations improved patients' waiting times.

Robustness/Quality of the Studies

Only one of 57 studies [94] fully met the minimum design standard for a Cochrane EPOC review. Two studies [2, 99] partially met the standard by using the controlled pre- and post-intervention design. These two studies do not have the recommended minimum two control and two intervention sites [13]. The pre- and post-intervention and the post-intervention only design were adopted in 95 % (54/57) of the studies (Table 1). There is empirical evidence that these study designs produce biased estimates [11, 170–172] and are prone to overestimating the effect size of an intervention [172, 173].

Reporting quality was generally poor. For example, many of the studies that reported positive findings did not test and/or report the statistical significance of their findings [93, 97, 98, 101, 102, 105, 121, 122, 126–128, 142, 146]. Only a few studies reported the confidence interval on their results [2, 100, 104]. Many of the studies did not define the timelines used in computing the outcome measures [92, 94, 97, 105, 115, 116, 120]. Virtually all the included studies failed to give any information on the technical features of the implemented systems or the IT infrastructure and the levels of integration within these settings. The IT infrastructure and levels of integration have a significant impact on the effectiveness of radiology SDIs [114, 141, 150]. The results of the studies must be viewed with the above quality issues in mind.

Exploration of Heterogeneity

The results of the studies could not be pooled in a meta-analysis due to a high level of heterogeneity. The causes of heterogeneity included varied research design, the breadth/combination of SDIs and variation in the study population and setting. The study population included patients who had specified examinations e.g. chest X-rays [99], CT pulmonary angiogram [2]; patient referred from specified sources like A&E [94], or imaging modalities [152]. Most importantly, we also found inconsistent definition of the outcome measures. The importance of consistent outcome measure definition has been highlighted [174]. We illustrate the inconsistent definition of the RTAT outcome measures: the time interval between the examination and the finalised report. This was measured by different studies to start from the: time a patient arrived the X-ray reception desk [138], start of examination [122, 154], completion of image acquisition [135–137], completion of the examination on the RIS [126, 127] and time the image became available on the PACS [140] to the time of final radiology report. Many studies failed to define the timelines used in computing RTAT [92, 94, 97, 105, 115, 116, 120]. The time interval between the completion of image acquisition and completion of the examination on the RIS is frequently more than 1 h [175]. Given that many of the studies reported improvements in minutes [2, 112], it is easy to see how inconsistent outcome measure definitions might affect the results of any comparison. We have therefore proposed generic timelines for defining patients waiting times in clinical radiology (Table 3). In addition, the IT environment within which the evaluated systems were implemented and the levels of integration were different and/or not discussed.

Implications for Future Research

Evidence of effectiveness is clearly paramount in the implementation of appropriate SDIs in radiology as a means to improve the patients' experiences. Studies to date have been mostly of low quality and future studies need to be of a higher quality. Higher quality studies might consist of interrupted time series evaluations [170. p 171–172] or, randomised designs. As there is obviously a need for pragmatic evaluation, one possible appealing randomised design might be the stepped wedge study [176]. The stepped wedge design is a cluster study, and so would involve multiple sites or modalities, which would sequentially be randomised to receive the SDIs. In addition, there is a need to harmonise the definitions of the timelines used in computing patients' waiting times to reduce the level of heterogeneity in the studies. We propose that the timelines should be defined as shown in Table 3. We also recommend that future studies should include basic details of the IT infrastructure and levels of integration. We think that this will make both comparison and meta-analysis less restrictive.

Limitations

It is possible that we have missed articles indexed under different MeSH headings or key words. We excluded non-English language papers. This might lead to language bias.

Conclusions

This review has highlighted the type of SDIs implemented to improve patients' waiting times in radiology departments. Most of the studies used the post-intervention only design and the pre- and post-intervention designs without a control group. These designs are prone to overestimating effect size. It is therefore not surprising that majority of the studies had positive results. There is a need for higher-quality studies to improve the evidence base.

We found the studies to be highly heterogeneous and the reporting quality was poor. We understand that SDIs within radiology departments will impact on more than one quality

Table 3 Proposed generic timelines for defining patients waiting times in clinical radiology

Total radiology waiting time (TRWT)	The time elapsed from the moment a request for radiology investigation is received on the RIS to the time when the finalised radiology report was available on the RIS.
Pre-examination waiting time (PEWT)	The time elapsed from the moment a request for radiology investigation is received on the RIS to the time when the examination was completed on the RIS.
Report turnaround time (RTAT)	The time elapsed from when the radiology examination was completed on the RIS to the time when the final radiology report was available on the RIS.

measure. Therefore, we suggest that interested parties should critically appraise the studies for their designs, results, and the description of the elements of the evaluated systems that they think are critical to achieving their objectives. We propose that the definitions of patients' waiting times should be mapped to generic timelines as a starting point for moving towards a situation where it becomes less restrictive to compare and/or pool the results of future studies.

Appendix I Search Strategy Implemented on MEDLINE

Population Terms

#1 *diagnostic imaging/

#2 *radiology department, hospital/or *radiology/or *radiology, interventional/or *radiology information systems/

#3 *radiography, interventional/or *radiography, dental/or *radiography, panoramic/or *radiography, bitewing/or *radiography, thoracic/or *radiography, dental, digital/or *radiography, abdominal/or *radiography/ or *radiography, dual-energy scanned projection/

#4 medical imaging.mp.

#5 or/1–4

Intervention Terms

#6 *"appointments and schedules"/

#7 health care rationing.mp. or *health care rationing/

#8 quality improvement.mp. or *"quality of health care"/or *total quality management/or *quality improvement/or *practice guidelines as topic/or *health services research/or *quality assurance, health care/

#9 *quality indicators, health care/

#10 *efficiency, organizational/or six sigma.mp.

#11 (speech or voice recognition).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

#12 reminder systems.mp. or *patient compliance/or *reminder systems/

#13 (organi?ation and innovation).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

#14 *workload/or *"personnel staffing and scheduling"/or staffing level.mp. or *personnel management/

#15 *"health services needs and demand"/or *decision support techniques/or capacity planning.mp. or *"utilization review"/

#16 extend* work* hour*.mp.

#17 24 h service.mp.

#18 *after-hours care/or after hour care.mp.

#19 *organizational innovation/or radiology planning.mp.

#20 *medical order entry systems/or *data collection/or computerized order entry system.mp. or *hospital information systems/

#21 exp *teleradiology/or exp *outsourced services/or outsource radiology.mp.

#22 *delegation, professional/

#23 (radiographer* and radiologist*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

#24 radiographer* role*.mp. or exp *inservice training/or exp *staff development/

#25 (radiographer* and report*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

Outcome Terms

#26 *health services accessibility/or *waiting lists/or wait* list*.mp.

#27 (wait* and time*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, protocol supplementary concept, rare disease supplementary concept, unique identifier]

#28 *time factors/or turnaround time.mp. or *"time and motion studies"/

#29 exp *patient satisfaction/or exp *consumer satisfaction/or customer satisfaction.mp. or exp *"marketing of health services"/

#30 *patient compliance/

#31 or/6–30

#32 5 and 31

#33 limit 32 to (humans and yr="1995 -Current")

The numbers '#' show the progression of the search (sequences), the search strings shown as '*…/' are MeSH, those strings shown as '....mp' are free text s. As there are a wide variety of service delivery interventions which may not be well indexed in the database, we adopted a more 'sensitive' (rather than 'specific') strategy by combining general terms related to radiology (lines 1–4) with any terms related to either service delivery interventions or outcomes of interest (lines 6–30), as shown in line 32 of the search strategy. Similar strategies were implemented on the other databases.

Appendix II

Characteristics and main findings of the included studies

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
[94]	Extended scope practice (ESP)	Time series regression model	5/7	RTAT: Not defined.	The study used monthly data collected from Feb 1993 to June 1998 comprising 2 and 3 years pre- and post-intervention data segments, respectively. The RTAT was averaged yearly and presented in a pre- and post-intervention format as well. The impact of ESP radiographers' reporting was assessed using 3 separate time series regression models. (1) Proportions of examinations reported, (2) RTAT for A&E examinations and (3) RTAT for GP examinations. The mean RTATs for A&E plain film examinations during the baseline periods were 94.6 and 115.1 h for 1993 and 1994 respectively. The post-intervention RTATs were 112.3, 155.6 and 100.8 h for 1995, 1996 and 1997 respectively. Regression analysis suggests that: increased proportion of A&E examinations reported by ESP radiographers reduced the RTAT by 36.8 %, $p<0.001$; ESP radiographers' reporting was associated with 12 % (per month) increase in the proportion of reported A&E examinations after controlling for increased workload, $p=0.05$.
[2]	Teleradiology	Controlled pre- and post-intervention (intervention and control were on one site)	6/9	RTAT: time from the completion of examination to the time of finalised report.	This study evaluated the impact of teleradiology on the RTAT for CT pulmonary angiograms performed between 6 PM and 12 AM on weekdays and 2–7 PM on weekends. The control group comprises CT brain done within the same time brackets. The proportion of reports completed within 40 min in the intervention group were 34 % (163/485; CI 29, 38) and 43 % (268/617; CI 39, 47) pre- and post-intervention, respectively, $p<0.01$. Stratified analysis of individual shifts did not reveal uniform improvement. No significant changes were noted in the control group.
[99]	Continuous quality improvement (CQI)	Controlled pre- and post-intervention (one intervention and one control site)	4/9	TRWT: Time elapsed from when the patient leaves and returns to the outpatient department with the finalised radiology report and film.	CQI was implemented in the intervention site while a "traditional" management method that consisted of calling for assistance when the queue of waiting patients is elongated was used in the control site. CQI was associated with a drop in the percentage of chest X-ray examinations with TRWTs over 2 h: from 34 to 16 % pre- and post-CQI intervention, respectively. However, a follow-up measurement at 8 months post-intervention showed that the improvement was not sustained. The proportion of examinations with TRWTs over 2 h remained unchanged at the control site.
[110]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: time elapsed from the completion of the examination to the availability of the finalised radiology report.	Data was collected on 6 radiology sub-specialties (CT, MRI,NM, FLUO, US and IR) from July 2007 to July 2008 (dicta phone period) and June 2009 to May 2010 (SRR period). The percentage of radiology reports completed within 24 h improved across all

(continued)

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					imaging modalities following SRR implementation. For example, the proportions were 63.9 and 71 % for CT pre- and post-SRR, respectively, $p<0.001$.
[96]	The Six Sigma methodology	Uncontrolled pre- and post-intervention	NA	TRWT: time elapsed from "examination order to end of procedure".	This was a process improvement project in an academic radiology department that performs about 68, 000 inpatient CTs annually. The mean inpatient TRWTs were 20.7 (SD, 23.03) and 11.6 (SD, 15.2)h pre- and post-intervention, respectively. The improvement was sustained over the subsequent 18 months.
[101]	Quality management	Uncontrolled pre- and post-intervention	NA	TRWT: time elapsed from "examination order to end of procedure".	The study was performed in a radiology department that performs about 6000 CTs/month using 4 static and one portable CT scanners. The study reports on a process re-design involving bringing staff schedule in line with variations in CT demand. The average TRWT dropped from 8.2 to 6.5 h (weekdays) and 13 to 8 h (weekends). An improvement of 20 and 38 % for weekdays and weekend examinations, respectively.
[136, 137]	Pager-notification system (PNS)	Uncontrolled pre- and post-intervention	NA	RTAT: the difference between the actual times imaging was completed and when radiology report was faxed to ED.	The study was performed in an academic radiology department with PACS installed. The mean RTATs for A&E examinations were 90.05 (SD 77.47; range 9–299) and 40.05 (SD 20.86; range 15–78)min pre- and post-PNS, respectively. However, the gains were not sustained beyond I week post PNS as the radiologists either lost the pager or stopped responding.
[141, 150]	RIS/PACS	Uncontrolled pre- and post-intervention	NA	RTAT: time interval between the completion of examination and the finalised radiology report.	The study assessed the value of implementing large scale information systems in a radiology department by examining a range of outcome measures including revenue, waiting times and satisfaction levels. The average RTATs were 115.6 and 23.81 h pre- and post-intervention, respectively.
[92]	ESP	Uncontrolled pre- and post-intervention	NA	RTAT : Not defined	The study combined quantitative and qualitative methods to assess the impact on RTAT of ESP radiographers' reported images of appendicular skeleton on the accident and Emergency department of an NHS hospital. The mean RTATs were 10.23 (SD 7.65) and 5.62 (SD 4.27) days pre- and post-ESP, respectively. In addition, the proportion of appendicular images reported were 37.9 % and 80.4 % pre- and post-intervention, respectively. The percentage of the entire A&E plain images that were reported increased from 38.4 to 54.4 % pre- and post-intervention, respectively.
[109]	Pay-for-performance (PFP)	Uncontrolled pre- and post-intervention	NA	RTAT: time interval between the completion of an examination and the finalised radiology report.	The PFP programme comprises a $5000 bonus payment annually to radiologists who met specified report approval target. The mean departmental RTATs were 42.7 (SD 99.3), 31.6 (SD 78.2) and 16.3 (SD 53.6)h before, after intervention and 2-year follow-up periods, respectively, $p<0.0001$. The changes were significant for all sub-specialties evaluated, except nuclear and neurovascular radiology.

(continued)

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
[97]	Lean Six Sigma	Uncontrolled pre- and post-intervention	NA	PEWT: not defined.	PEWT dropped from 25 days to 1–2 days following the intervention. It was not specified whether 25 days was median, mean or IQR.
[121]	The Six Sigma	Controlled Post-intervention	NA	RTAT: time from the end of examination to when the film and finalised report were available for delivery to the ward.	The study is set in a radiology department that performs about 90, 000 examinations annually and uses SRR and dicta phone systems in parallel. 78 % of the reports were produced using SRR. The median departmental RTAT was 49 h. The mean RTATs for reports generated with SRR and dicta phone were 45.75 and 95.97 h, respectively. Inpatient reports were generated 95 % of the times with SRR. Almost all inpatients' reports were delivered with 36 h. Authors concluded that radiologist should be encouraged to use SRR to reduce report delivery times.
[151]	SRR, interlinked with RIS and HISS, staffing, education and proposed sanctions	Uncontrolled pre- and post-intervention	NA	RTAT: time interval between the completion of examination and availability of the finalised radiology report on the HIS.	Study was performed in the radiology department of a 641-bed level 1 trauma Centre. The department performs about 250, 000 examinations annually. The interventions included SRR, specified radiologist to report A&E CT and plain film images, integration of RIS with HIS, staff education and proposed sanction. The RTATs for periods 1 to 5 were 86.4 (SD 31), 2.3 (SD 2.2), 2.6 (SD 3.6), 1.7 (SD 1.9) and 2.4 (SD 14.2)h, respectively. The following factors improved RTAT: (1) provision of on-call radiologist), use of SRR. The following did not improve RTAT: (1) staff education on the need to comply with RTAT requirements, and (2) proposed sanction on non-compliance with RTAT target.
[140]	Paperless workflow management system (WMS)	Uncontrolled pre- and post-intervention	NA	RTAT: time interval between when images were available on PACS and when the finalised radiology report.	The study reports on the development and implementation of a WMS in a RIS, PACS and SRR environment. The WMS is an automated system for prioritizing cases on PACS for reporting. Results were presented for three patients groups: A&E, inpatient and Outpatient. The mean RTATs were 7.72 and 6.18 h for A&E; 7.33 and 7.12 h for inpatient and; 6.73 and 5.03 h for outpatient pre- and post-intervention, respectively, $p<0.05$.
[122]	PACS	Uncontrolled pre- and post-intervention	NA	RTAT: time elapsed from when the examination was started to when images/report were returned to the requesting physician.	This study investigated the impact of PACS on RTAT for images done out-of-hours in a community practice. The images were reported by a radiologist in an academic radiology department some distance away. Before PACS, the images were sent by a pneumatic tube. The study found reduced average RTAT for urgent out-of-hours examinations from 128 to 32 and from 58 to 42 min for examinations done within regular clinic hours pre- and post-PACS, respectively.
[98]	The Lean Methodology	Uncontrolled pre- and post-intervention	NA	Waiting pre-examination and waiting post-examination: Not defined.	The Lean methodology was used to map and improve the workflow processes of a radiology department. The mean pre-examination waiting times were 4.1 and 1.2 while the post-examinations waiting times were 3.39 and 1.2 min pre- and post-intervention,

(continued)

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					respectively. This represents 64 and 69 % improvements in the pre and post-examination waiting times, respectively.
[111]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the total time between image acquisition and finalised report.	This study reports the implementation of SRR in a multi-site hospital that used different workflows before SRR implementation: site 1 used handheld dicta phone while site 2 used digital speech file. The study found statistically significant drop in RTAT for all 4 patient groups: Casualty, GP, outpatient and inpatients. The RTATs for site 1 were: casualty 6.29 (0.78) and 1.76 (0.32); GP 6.00 (0.70) and 1.84 (0.32); inpatient 9.10 (1.50) and 2.90 (1.39); outpatient 8.82 (1.29) and 2.75 (1.14) days pre- and post-intervention, respectively. The RTATs for site 2 were Casualty 4.53 (0.74) and 1.60 (0.46); GP 3.44 (0.56) and 1.44 (0.45); Inpatient 5.84 (1.43) and 1.66 (0.76); outpatient 4.87 (0.74) and 1.92 (0.66) days pre- and post-intervention, respectively, SD in parenthesis.
[107]	Service re-design	Uncontrolled pre- and post-intervention	NA	PEWT: The time elapsed between the date on request form and date of examination.	This study evaluates the impact on PEWT of providing same day ultrasound service (turn-up-wait-and-be-examined) in addition to the usual appointment system. Same day patient had to turn up 9–11 am or 2–4 pm to be examined in the morning or afternoon sessions, respectively. The median PEWTs for GP patient who choose to book appointment were 10 (IQR, 7–20) and 6 (IQR, 4–10) days pre- and post-implementation, respectively, $p<0.0001$, despite increased workload. While the median PEWTs for outpatient were 14 (IQR, 7–44) and 9 (IQR, 5–155) days pre- and post-implementation, respectively, $p<0.0001$. Both patient groups waited longer on the day of examination, however, the GP patients who did not book appointment waited longest.
[154]	PACS/24-h on site radiologist coverage/ SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the percentage of reports completed within 12, 24 and 48 h of examination.	This was a process improvement project comprising the implementation of PACS, SRR and 24-h radiologist coverage. The proportions of reports generated within 12 h of examination were 7.4–9.6, 40 and 65–66 % before, after implementation and follow-up periods, respectively. The proportion of examinations reported between 24–48 h dropped from 25 to 11 % and those reported over 48 h dropped from 47 to 27 % pre- and post-implementation, respectively.
[103]	Service re-design	Uncontrolled pre- and post-intervention	NA	RTAT: the interval between the last radiograph and report printing time.	The service was re-designed to reduce the total time delay for orthopaedic outpatients referred for X-rays examination. The changes involved the provision of an additional radiographer 15 min before the start of orthopaedic clinic, designating a duty radiologist to supervise the reporting room, an extra computer in the reporting room, and scheduling time intensive examination during off peak periods. The mean RTATs were 13 (range 0–71), 11 (range 0–93) and 11 (range 0–84) min before, after implementation and 12-

(continued)

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					months follow-up periods, respectively. However the percentage of patient spending more than 45 min in radiology dropped from 41 to 29 % between the baseline to the follow-up period, $p<0.001$. There were only marginal changes in volume of patients.
[149]	Service re-design, PACS and dedicated scheduler.	Uncontrolled pre- and post-intervention	NA	PEWT: time from faxing request to the start of examination.	Data collection was by a mixture of observation, interviews and RIS query. The number of examinations was counted rather than time intervals. Moving the film reading location from A&E to the main radiology department does not significantly affect the median PEWT: 0.07 and 0.08 h pre- and post-intervention, respectively. However implementing PACS and subsequently dedicated scheduler increased median PEWT from 0.12 and 0.27 h, respectively.
[100]	The Lean Methodology	Uncontrolled pre- and post-intervention	NA	PEWT: the time interval between request and completion of CT examination.	The study applied the Lean methodology to improve the PEWT for CT examinations in an academic trauma Centre. The key changes included encouraging radiographers to facilitate workflow by "pulling" patients, changing CT protocol, aligning radiographers' rota with variations in CT demand, improved communication between radiology and A&E and performance feedback to radiographers. Following these changes, PEWT dropped from 55.8 (90 % CI 54.1, 57.4) to 35.9 (90 % CI 34.4, 37.5)min, in parenthesis. This represents a 36 % improvement in PEWT.
[139]	Computerised reporting system	Post-intervention (with control)	NA	RTAT: the time from the moment X-ray films had been developed to when the finalised report had left the department.	The study describes the development and implementation of a computerised/coded reporting system which was compared with two conventional reporting systems for impact on RTAT. The mean RTATs were 5.9 (SD 2.3), 1.3 (SD 0.5) and 0.4 (SD 0.9)h for tape, the coded and handwritten reporting systems, respectively.
[152]	PACS and process re-design in a RIS environment	Uncontrolled pre- and post-intervention	NA	RTAT: time from image acquisition to the availability of the finalised report.	Activity data for CR, CT, US, MRI and interventional radiology were retrieved from the RIS. There was an initial improvement following implementation, this was not sustained over the post implementation periods. The median RTAT dropped from 22.78 to 12.78 h post PACS, 44 % reduction. Subsequent measurements were 13; 15, 19 and 21.65 at 8, 12, 16 and 20 months post PACS, respectively. The impact at modality level varied.
[129]	RIS in a HIS environment	Uncontrolled pre- and post-intervention	NA	TRWT: the time from radiology request to the time when the films/report returned to the ward/clinics.	This was a time and flow study. Data was collected using integrated circuits (IC) card, carried together with the imaging request card. The card is clocked at specified locations to track TRWT. The information is transferred to a central location. The mean TRWTs were 26.8 (SD 6.8) and 3.6 (SD 2.5)h pre- and post-RIS, respectively. The pre implementation distribution of system TRWTs was wide and bimodal while the post implementation distribution was keen and uni-modal, concentrated around 1 h.

(continued)

Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
[105]	Service re-design	Uncontrolled pre- and post-intervention	NA	PEWT: Not defined.	This is one of the earliest radiology modernisation projects implemented within the UK in response to long patients' waiting times for imaging examinations. This study found that although capacity was in excess of demand, PEWT was 22 weeks for barium enema. Following service re-design, PEWT dropped to 5 weeks for barium enema, and from 18 to 1 week for barium meal/swallow. These changes were sustained. On the other hand, demand for ultrasound exceeded capacity and extra capacity was provided.
[112]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the time between completion of examination and the finalised radiology report.	There were 2 and 3 data points pre- and post-intervention, respectively. The target RTAT of 30 min for A&E patients was achieved 3 % of the times during the baseline periods. This changed to 73, 85 and 85 % during the post-intervention periods. The proportions of reports that met the 90 min RTAT target for outpatient were 2 and 12 % pre-intervention and 79, 85 and 91 % during the post-intervention periods. Whereas the 120 min RTAT target for inpatient was met 4 & 18 % during the pre-intervention periods, this increased to 83, 90 & 95 % during the post-intervention periods.
[113]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the time from completion of imaging to the availability of finalised report on the RIS/online.	The study compared the RTAT using SRR with cassette-based reporting system in an academic health Centre that has implemented HIS/PACS. Data from MRI, CT, US, special examination, interventional radiology and plain X-rays were included. The mean RTATs were 24.77 (SD 76.52), 5.39 (SD 27.7) and 4.67 (SD 12.72)h before (cassette-based system), after (SRR system) and follow-up periods, respectively, $p<0.0001$.
[114]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the interval between when the images were available on PACS and the finalised radiology report.	The study was performed in the radiology department of a 700-bed academic hospital. Data from 8 radiology sub-specialties were collected for 9 months (Jan–Sept. 2006) pre- and post-(April–Dec 2007) implementation. The average departmental RTATs were 28 (range 4.6–65.9) and 12.7 (range 1.2–47.3)h, respectively. All the 8 sub-specialties experienced improved RTAT. Of 30 radiologists, 2 did not experience RTAT improvement. The extent of improvement varied with radiologists' work habit.
[128]	Teleradiology	Post-intervention (with control)	NA	RTAT: the time from receiving a case to when the report is generated and faxed back to sending site.	This was a retrospective data analysis of a 2-year teleradiology programme. Satellite site send images via dial-up link to an academic radiology department. The department logs all cases received. The average RTAT was 1.27 (SD 2.9)h. 69.5 and 96 % of the cases had RTATs under 1 and 6 h, respectively. The control group (cases sent by courier) has average RTAT of 6 h. No statistical test was performed.
[123]	PACS	Post-intervention	NA	RTAT: the interval between when the image was generated and when the	The study evaluated the impact on RTAT of implementing PACS in a HIS/RIS/fee-for-service environment. Data was collected between Oct 1999 and Sept 2000 by stratified random sampling (using a

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Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
				written report was made available on PACS and HIS.	random number table) of patient episodes from angiography, CT and specialized examinations. The median RTATs during working hours were 98 (170,251), 105 (124,135) and 105 (134, 89) min for radiography, CT and special examination, respectively, mean and SD in parenthesis. These times are within acceptable limits for the hospital. The mean RTATs for the out-of-hours period ranged from 306 to 1,769 min in CT and radiography, respectively.
[130]	RIS	Uncontrolled pre- and post-intervention	NA	RTAT: the time elapsed from the end of examination to the finalised report	The study evaluated the impact of implementing a commercially available RIS on the RTAT in a network of 7 free-standing imaging Centres (4 included in this study). The network performs about 125, 000 examinations annually. The mean RTATs were 4.06 (2.34) and 2.17 (1.43) for mammography; 3.11 (1.87) and 3.20 (1.85)h for MRI pre- and post-intervention, respectively, SD in parenthesis. These results were statistically significant at 5 %.
[147, 148]	Comparison of 4workflow types: Films/manual transcription, Film/SRR, PACS/manual transcription and PACS/SRR	Uncontrolled Post-intervention	NA	RTAT: the time interval between the completion of an examination and the finalised report.	This is a one off survey of 40 radiology practices in North America for RTAT and productivity. The average RTATs in hours/normalized productivity for the different workflows were 48.2 (50 %)/16.2 for film & manual transcription; 15.5 (93 %)/2.27 for film and SRR; 13.3 (119 %)/21.8 for PACS & manual transcription; and 15.7 (98 %)/30.6 for PACS & SRR. The uncertainties for RTAT in parenthesis. Film/SRR have the best productivity and largest uncertainty. The high uncertainty is due to small number of respondents.
[138]	CR	Post-intervention (with control)	NA	TRWT: the time from patient' arrival at the X-ray reception desk to the finalised radiology report.	This study compares the efficiency of digital and conventional systems. 220 examinations were included: 111 and 109 in the digital and conventional arms, respectively. The examination process is the same for both arms except for the image acquisition technology. The mean TRWTs were 4.65 and 1.03 h for A&E chest X-rays, 1.80 and 2.24 for A&E orthopaedic examinations, 9.83 and 21.11 for inpatient chest X-rays, 22.72 and 4.71 for inpatient orthopaedic examinations, 10.39 and 57.26 outpatients chest X-rays, 41.53 and 90.57 h for outpatient orthopaedic examinations for digital and conventional systems, respectively.
[115, 116]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: not defined.	The study reports the design and implementation of SRR in a RIS environment. The department was using remote digital dictation system before this time. Activity data for CT, MRI, ultrasound and nuclear medicine were included in the study. The average RTATs were 120, 5 and 3.5 min before after SRR and follow-up periods, respectively.
[124]	PACS/RIS	Uncontrolled pre- and post-intervention	NA	RTAT: the time elapsed from examination completion to the issuing of finalised report.	This study evaluated the impact on RTAT of PACS/RIS implementation. 5 blocks of 3-month data (Feb–April, 2002–2006) for Plain radiographs and, specialist examinations (CT, MRI, US

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Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					and nuclear medicine) were retrieved from the RIS. There results were mixed at the level of imaging modalities. The mean RTATs were 6.8 and 5 days for radiographs; 4.2 and 3.1 days for specialist examinations, $p<0.001$, pre- and post-intervention, respectively. The mean RTAT for CT remained stable at 2 days. RTAT for MRI increased from 4.6 to 7.5 days, $p<0.001$. RTAT decreased at department level despite 30 % increase in patient episodes.
[142]	RIS/SRR/MS in a PACS environment	Uncontrolled pre- and post-intervention	NA	RTAT: the time interval between the start of examination and final report.	There was 100 % adoption of SRR. The average departmental RTATs were 9.38, 1.72 and 1.18 h before, after RIS/SRR and WMS, respectively. Modality level data were also reported.
[143, 177]	CR/PACS	Uncontrolled pre- and post-intervention	NA	(1) PEWT: Time from request to beginning of examination, (2) TRWT: Time interval between request and when film and final report reaches the physician.	This small study involving 215 patients was performed in the radiology department of a no-appointment ambulatory care hospital. The study examined the impact of switching from cassette/film based plan film examination to complete electronic imaging system. The mean PEWT increased from 0:15:54 (0:03:31) to 0:26:47 (0:03:37), $p=3.5^{-5}$. The TRWT reduced from a mean 4:21:54 (1:17:15) to 0:55:09 (0:07:06) $p=8.98^{-7}$, pre- and post-intervention, respectively, 95 % CI in parenthesis.
[126, 127]	PACS in a RIS/HIS/SRR environment	Uncontrolled pre- and post-intervention	NA	RTAT: the time interval between the examination completion on the RIS and the availability of finalised report on the HIS.	RTAT data for CT (only abdomen/pelvis) were retried from the RIS for two 1-year periods (March 1 1997–March 1 1998 and March 1 1998–March 1 1999) representing the periods pre- and post-PACS implementation, respectively. The mean RTATs were.5.49 (3.6, 0.04–28.6) and 5.97 (3.2, 0.005–65.5) days pre- and post-PACS, respectively, representing 9 % increase, median and range in parenthesis.
[93]	Extended scope practice	Uncontrolled pre- and post-intervention	NA	PEWT: time elapsed between referral and completion of the examination. RTAT: not defined.	The impacts of ESP on PEWT and RTAT for video fluoroscopy were investigated. Data were retrieved from the RIS for April 2003 to Mar 2004 and April 2009 to March 2010 representing the pre- and post-implementation periods, respectively. There was 75 % decrease in the mean PEWT for inpatient from 8 (range 1–14) to 2 (range 0–6) days and 62.5 % for outpatients from 32 (range 15–95) to 11 (range 0–26) days pre- and post-implementation, respectively. The combined average RTATs were 7 and 0–1 day pre- and post-implementation, respectively.
[145]	PACS in a RIS/HIS/SRR environment	Uncontrolled pre- and post-intervention	NA	TRWT: the time elapsed between imaging request and finalised radiology report. PEWT: Not defined.	The study was performed in a radiology department that performs about 180, 000 examinations yearly. Study data were retrieved from the RIS for 15/10/2002 to 15/4/2003 and 15/1 2003 to 15/4/2004 representing the pre- and post-implementation periods, respectively. The mean inpatient TRWTs were 29.6 (SD 32.36) and 13.5 (SD 24.75)h for CT, 33.9 (SD 56.25) and 9.62 (SD 26.09) for chest X-rays and 38.35 (SD 28.5) to 24.9 (SD 31.6)h for MRI pre- and post-intervention, respectively, $p<0.001$ for all three modalities. The

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Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					average outpatient PEWT reduced from 90 to 40 days for nun-urgent CT and from 90–180 to 30–60 days for nun-urgent ultrasound examinations pre- and post-intervention, respectively. But this was thought to reflect the impact of separate interventions: reminder system and improved scheduling.
[135]	Pager notification	Uncontrolled pre- and post-intervention	NA	RTAT: the time interval between completion of the examination and the finalised radiology report.	This paper reports a pager-notification system (PNS) project designed to inform radiologist when reports have been transcribed and ready for signature as means of reducing the RTAT. This study was designed to evaluate the signature times using same site controlled pre- and post-intervention. The intervention group comprised 26 voluntarily enrolled radiologists. The control group comprises 8 radiologists who did not enroll. Signature time was not an outcome of interest in this review. However, the study reported the departmental RTAT pre- and post-intervention. Therefore the study is being used as a pre- and post-design for a not fully subscribed PNS intervention. The RTATs pre- and post-intervention were 46.56 and 36.3 h, respectively. A reduction of 14.91 h (32 %).
[104]	Service re-design	Post-intervention (with control)	NA	PEWT: the time interval between referral (community group)/receipt of request (NHS group) and the date of examination.	This was a retrospective cross sectional study of the PEWT of patients attending for ultrasound scan in the community and a local NHS Trust. Sample size calculation was done. A random sample of 200 patient episodes was taken from the two patient populations. Data on PEWT were taken from computerised patient records management systems. The PEWTs were 17.44 (95 % CI 15.86, 19.02) and 44.53 (95 % CI 38.83, 50.23) days for the community and hospital services, respectively. Monthly mean PEWTs were also reported.
[106]	Service re-design	Uncontrolled pre- and post-intervention	NA	TRWT: The time interval between imaging request and finalised radiology report.	This structured abstract reports clinical audit of CT head CT body. The target TRWTs were <60 and <90 min for CT head and body, respectively. The following changes were made: second dedicated A&E CT scanner, prompt CT examination request by A&E doctors, wireless telephone for radiology registrars, dedicated CT portering staff. The mean TRWTs were 51 and 69 min for CT head; 69 and 82 min for CT body pre- and post-intervention, respectively.
[125]	PACS	Uncontrolled pre- and post-intervention	NA	PEWT: time elapsed from request to image dispatch.	This study assessed changes in radiology workflow and efficiency following PACS implementation. The study included 31, 000 examinations requested by A&E and Medical intensive care unit (MICU) over a 5-year period. Data were downloaded from the RIS. The PEWT increased from 20 to 25 min and 34 to 42 min for A&E and MICU, respectively, $p<0.0001$.
[117]	SRR	Uncontrolled pre- and post-intervention	NA	RTAT: the time elapsed between completion of examination and finalised radiology report.	This study evaluated the impact of SRR on RTAT in an academic radiology department. Two blocks of 1-week data for musculoskeletal radiology activity were collected representing the pre- and post-intervention periods. RTAT dropped from 62 to 24 h

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					(61 % improvement). Again, it is not certain if these represents mean, median e.t.c values.
[153]	Multiple	Uncontrolled pre- and post-intervention	NA	RTAT: time from completion of examination to the finalised report.	The study was set in a teaching hospital that performs 250, 000 radiology examinations annually. Different interventions were implemented within different radiology sub-specialties: home signing, buddy signing system, accelerated transcription, SRR, structured reporting etc. The mean RTAT decreased from 81.2 to 36.2 h (55 % change) following the interventions, p=0.001.
[118]	SRR in a RIS/electronic requesting environment	Uncontrolled pre- and post-intervention	NA	RTAT: the time from examination completion to finalised report.	The study was performed in a multi-site hospital with annul procedure volume of 360, 000. SRR was implemented with 100 % adoption by radiologists. 2-year pre implementation and 1-week post implementation data were used. Although it was a multi-site intervention results were presented for only one site: The Lehigh Valley Hospital. The proportions of reports with RTATs less than 24 h were 41 and 78 % pre- and post-SRR, respectively.
[102]	Service re-design	Uncontrolled pre- and post-intervention	NA	PEWT: time elapsed from imaging request to completion of examination.	The process re-designs involved creating a centralised patient scheduling system for each imaging modality. The PEWT dropped from 12 h to 33 min after implementation Again it was not specified if 12 h represents mean or median value.
[108]	Outsourcing	Post-intervention (with control)	NA	PEWT: time in days that patients had to wait for examination.	All MRI examinations requested by the oncology department within the first trimesters of 2005 and 2006 which were outsourced to an external MRI service provider were included in the study, n=97. These were matched for organs with MRI examinations performed in-house within the same periods, n=97. Preferred examination time frames were specified by the referrer in 59/93 and 65/93 for the in-house and outsourced groups, respectively. The specified time frames were not met in 39 and 36 % for the in-house and outsourced groups, respectively. In these cases waiting exceeded the requested time by an average of 18.2 (SD 20) and 22.1 (SD 21) for the in-house and outsourced groups, respectively, p=0.4. Referrers did not specify time in 34/93 and 28/93 for the in-house and outsourced groups. PEWTs for these were 55 (SD 23.3) and 36 (SD 21) days for the in-house and outsourced groups, respectively, p<0.001.
[146]	SRR in a RIS/PACS environment	Uncontrolled pre- and post-intervention	NA	RTAT: not explicitly defined, however, included the availability of final reports online.	This is a report about a not-for-profit stand-alone imaging Centre that performs 450, 000 cases per year. The practice had SRR and RIS that were not integrated with PACS. The intervention involved switching to a more functional SRR and PACS integration. Radiologists edited 70–80 % of their reports. The average RTAT reduced from 24 to 6 h.
[119]	SRR	Post-intervention (with control)	NA	RTAT: the time from image acquisition to finalised radiology report.	UCLA was expecting to install PACS and SRR. A baseline analysis was done comparing the current status with LAVA which already

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Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
					has functional SRR. UCLA outsources its report transcription service. Data for musculoskeletal (MSK) X-ray and chest X-ray were collected for three weeks period by observation. The mean RTAT for the MSK division at the UCLA (no SRR) and West LAVA (SRR) were 37.1 (2.1) and 10.6 (1.9)h, respectively; whereas the values for chest X-ray were 32.3 (3.2) and 6.3 (0.94)h for UCLA and West LA VA, respectively, standard error in parenthesis.
[120]	SRR in a RIS/PACS environment	Uncontrolled pre- and post-intervention	NA	RTAT: not defined.	This is report was about the implementation of SRR in a facility with procedure volume of 85, 000. The SRR was implemented in 3 phases The RTAT averaged roughly 60 h before SRR. Following SRR 50, 80 and 90 % of reports have RTATs within 1, 3 and 5 h, respectively.
[131]	CPOE	Uncontrolled pre- and post-intervention	NA	TRWT: the time from order writing to results availability.	The study population consists of A&E patients with chest pain for which a chest X-ray was done. Data was collected for 3 months pre- and post-intervention on 150 randomly selected patients. Method of randomisation was not disclosed. Statistical analysis was based on *t* test and chi-square test. The study found that examination turnaround times remained stable at 80 min despite an increase in the volume (18 to 135) of examinations P=0.49. It was suggested that this increase might be the result of better documentation resulting from CPOE implementation.
[133]	CPOE	Uncontrolled pre- and post-intervention		PEWT: the time from order to completion of examination.	The study was base in an ITU of a 400-bed tertiary hospital. Only patient who had urgent/"stat" request for CT or plan film imaging were included in the study. Data was collected during two 1-month periods (10 months pre- and 2 months post- CPOE implementation. The pre-intervention data were obtained from patients' charts. The study included 26 and 46 episodes within the pre- and post-intervention periods, respectively. Statistical analysis was based on Kruskal-Wallis test. This study reported that CPOE was associated with a decrease in the median time interval from request to the completion of examination, 96.5 to 29.5 min $P<0.001$. There was less variation around the media value following CPOE implementation.
[134]	CPOE	Uncontrolled pre- and post-intervention		PEWT: the time from physician order (manual or electronic) to the completion of the procedure.	This was hospital wide study including pharmacy radiology etc. However, we abstracted data for the radiology aspect only. Study population consists of patients referred from the transplant service. Data were included for the Chest and abdominal X-rays and abdominal ultrasound. Manual data collection was used in the pre-CPOE periods; 11 and 54 patient episodes in the pre- and post-CPOE periods, respectively. Statistical analysis was based in Students' *t* test. The study reported a 43 % reduction in the PEWT from 7 h 37 min to 4 h 21 min, pre- and post-CPOE implementation, respectively $p<0.05$. It was not stated whether these are mean or median values.

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Study ID	Type of Intervention	Study design	Risk of bias: # of low risk domains	Outcome measure & definition.	Main findings
[132]	CPOE	Uncontrolled pre- and post-intervention		PEWT: the time from order to image display	This study was performed in the Neonatal Intensive Care Unit (NICU) of an academic hospital. The hospital had already implemented PACS. The study population comprises very low birth weight (VLBW) infants born within two consecutive periods of 6-months pre- and post-implementation of CPOE: Only data from the first chest and abdominal X-ray taken following endo-tracheal intubation/umbilical catheter placement were included. The study measured time from order to arrival of radiology technician and to image display. Statistical analysis was based on unpaired *t* tests. Data from 107 pre and 99 post CPOE VLBW infants were included. The baseline characteristics were similar. The time interval from order placement to arrival of radiology technician were 28 (SD 13) and 17 (SD 12)min pre- and post-CPOE, respectively $p<0.001$. The order to image display times were 42 (SD 12) and 32 (SD 16)min. The times from technician arrival to completion of examination were similar 14 and 15 min pre- and post-CPOE, respectively.

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