The impact of PACS on clinician work practices in the intensive care unit: a systematic review of the literature

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ABSTRACT

Objective To assess evidence of the impact of Picture Archiving and Communication Systems (PACS) on clinicians' work practices in the intensive care unit (ICU).

Methods We searched Medline, Pre-Medline, CINAHL, Embase, and the SPIE Digital Library databases for English-language publications between 1980 and September 2010 using Medical Subject Headings terms and keywords.

Results Eleven studies from the USA and UK were included. All studies measured aspects of time associated with the introduction of PACS, namely the availability of images, the time a physician took to review an image, and changes in viewing patterns. Seven studies examined the impact on clinical decision-making, with the majority measuring the time to image-based clinical action. The effect of PACS on communication modes was reported in five studies.

Discussion PACS can impact on clinician work practices in three main areas. Most of the evidence suggests an improvement in the *efficiency of work practices*. Quick image availability can impact on *work associated with clinical decision-making*, although the results were inconsistent. PACS can change *communication practices*, particularly between the ICU and radiology; however, the evidence base is insufficient to draw firm conclusions in this area.

Conclusion The potential for PACS to impact positively on clinician work practices in the ICU and improve patient care is great. However, the evidence base is limited and does not reflect aspects of contemporary PACS technology. Performance measures developed in previous studies remain relevant, with much left to investigate to understand how PACS can support new and improved ways of delivering care in the intensive care setting.

INTRODUCTION

> Printing CT and MRI exams for interpretation is like printing your email in order to read it (Hirschorn, p 3[1])

Picture Archiving and Communication Systems (PACS) are a unique technology which provide a 'centralised repository for all imaging data' (Faggioni, p 254[2]) and deliver diagnostic images (eg, x-rays, CT scans, MRI scans) and radiology reports electronically to clinicians at the point-of-care, negating the requirement for a film-based system. PACS was expected to revolutionize and streamline the delivery of healthcare, assisting communication between radiologists and clinicians, improving clinical decision-making, and facilitating more efficient patient care processes.[3–6] The last 30 years has seen PACS evolve from in-house radiology systems to fully fledged hospital-wide commercial systems integrated with electronic medical records and incorporating technologies such as voice recognition and computer-aided diagnosis as hospitals establish paperless systems.[2 5 7 8] In the USA 76% of hospitals reported using PACS in 2008,[9] and in England and Scotland a national roll-out of PACS has been completed with the remainder of UK hospitals implementing it by 2012.[10] Despite its widespread use and the great technological advances, the question remains, has PACS simply automated the process of imaging in healthcare, as the introduction of email initially did to written communication, or has it revolutionized clinical practice and led to new ways of working?[11] Although PACS has been in existence for 30 years, this question has received little research attention.

A number of studies have been conducted to determine if PACS achieves its goals of improving efficiency and effectiveness within health systems. These studies focus on its impacts on workflow, roles, patient outcomes, and costs, with variable conclusions.[12–22] Much research attention has focused on gains in workflow efficiencies associated with PACS, particularly in radiology departments.[12–15 22] With the integration of PACS into a number of medical units outside radiology, the intensive care unit (ICU) is one clinical area where PACS has the potential to significantly change work practices.[23] The ICU is a 'complex' and 'data-rich environment'[24 25] where clinicians continuously multi-task and utilize multiple information sources in order to provide optimum care for critically ill patients. Images are integral to patient care,[26–29] with high volumes of imaging studies conducted in ICUs daily.[30–32] Rapid access to these to support decision-making can be of crucial importance. With the potential for imaging results to impact dramatically on a patient's care, the ICU provides a good setting to assess how PACS can impact on and lead to innovation in clinical work practices. To date no synthesis of the evidence to investigate the effects of PACS in the complex and demanding environment of the ICU has been performed.

We aimed to conduct a systematic review to assess evidence of the impact of the introduction of PACS on clinicians' work practices in the ICU, published between 1980 and 2010. This 30-year period provides an opportunity to examine changes in the nature and outcomes of studies over time

within a context of evolving technology. A further objective of our review was to synthesize the employed core indicators, assess their validity, draw conclusions about their value for contemporary studies of PACS and clinicians' work in the ICU, and identify areas for future research.

METHODS

Search strategy

We searched Medline, Pre-Medline, CINAHL, EMBASE, and the SPIE Digital Library (http://spiedigitallibrary.org) between 1980 and September 2010 using Medical Subject Headings and keywords. The full search strategy is shown in table 1. We used multiple terms to identify clinician work practices. We restricted the search to English articles and hand searched the reference lists of included articles.

Study selection and exclusion criteria

Our initial search yielded 222 articles (figure 1). Two reviewers independently undertook a title and abstract review of 166 articles after the removal of duplicates (n=56) to determine if papers met the inclusion criteria. If no abstract was available, the full text was reviewed. At this stage, 118/166 articles were excluded for the reasons shown in figure 1. The full texts of the remaining 48 papers were reviewed and consensus reached as to their inclusion. Study authors were contacted for further information if necessary. Only 16 articles met the inclusion criteria (figure 1).

Data extraction and synthesis

The following details for each paper were abstracted (if available): study design and methods, setting, country, participants, sample size, aims, outcomes, and results. Additionally, we also noted if the authors discussed integration of PACS with other systems, clinicians' attitudes toward PACS, and any limitations of the studies. Where the same data were reported across multiple manuscripts, these were combined and reported as one study. We assessed a number of potential factors that are often associated with bias, for example, the study origin and setting, when the study was conducted, and any comments made by the authors discussing why the study context may have affected particular results.

Due to the heterogeneous nature of the data, it was not possible to combine the results in a meta-analysis and so the results are reported according to the individual outcome measures described by the authors.

RESULTS

Sixteen papers met the review criteria (figure 1), representing 11 studies, for the reasons shown in table 2.

Study characteristics

Three articles were published after 2000,[33 40 45] but all were conducted prior to 2000. The majority were undertaken in the USA,[34–39 41–48] primarily by two research groups at the University of Pennsylvania Medical Center[36–39 45–48] and Duke University Medical Center,[34 35 42–44] with the remainder in the UK.[33 40] Study designs included three before-and-after studies,[40 41 44] two surveys,[33–35] two observational studies,[42 43 46] and one cohort design.[45] Additionally, three studies collected alternating film-only and PACS data.[36–39 47 48] Full study characteristics and results are shown in supplementary online appendix 1. Table 2 summarizes the outcome measures reported by each study.

Table 1 Search strategy

Database	Search terms
Medline, Pre-Medline	Intensive care units* OR intensive care* OR critical care* OR intensive care$ OR critical care$ OR ICU AND Radiology information systems* OR PACS OR 'picture archiving and communication system$' AND Physician's practice patterns* OR practice pattern$ OR communication* OR professional role* OR interprofessional relations* OR workflow* OR 'task performance analysis'* OR workload* OR workload OR workflow OR work flow OR work load OR evaluation studies as topic* OR evaluation OR efficiency, organizational* OR efficiency* OR efficiency OR productivity OR time factors* OR 'time and motion studies'* OR time* OR time OR attitude of health personnel* OR attitude to computers* OR attitude$ OR professional practice* OR clinical practice OR delivery of healthcare* OR decision making* OR decision making OR behavio?r
CINAHL	Intensive care units* OR intensive care units, neonatal* OR critical care* OR intensive care$ OR critical care$ OR ICU AND Picture archiving and communication systems* OR 'picture archiving and communication system$' AND Practice patterns* OR practice pattern$ OR communication* OR communication OR interprofessional relations* OR professional role* OR 'task performance and analysis'* OR workload* OR workload OR workflow OR work flow OR work load OR evaluation research* OR evaluation OR organizational efficiency* OR productivity* OR efficiency OR productivity OR time factors* OR 'time and motion studies'* OR time* OR time OR attitude of health personnel* OR attitude to computers* OR attitude$ OR professional practice* OR medical practice* OR nursing practice* OR clinical practice OR healthcare delivery* OR decision making* OR decision making OR behavio#r
EMBASE	Intensive care unit* OR intensive care* OR intensive care OR critical care OR ICU AND Picture archiving and communication system* OR 'picture archiving and communication system' OR PACS AND Communication* OR communication OR clinical practice* OR professional practice* OR practice adj1 pattern OR practice pattern$ OR clinical practice OR evaluation* OR evaluation research* OR evaluation OR productivity* OR organizational efficiency* OR efficiency OR productivity OR task performance* OR workload* OR workload OR workflow OR work flow OR work load OR time* OR time OR health personnel attitude* OR attitude to computers* OR attitude$ OR healthcare delivery* OR clinical decision making* OR decision making* OR decision making OR behavio?r
SPIE Digital Library‡	'Picture archiving and communication system' OR PACS AND 'Intensive care' 'Picture archiving and communication system' OR PACS AND ICU 'Picture archiving and communication system' OR PACS (searched within the results for 'intensive care')

For each search we also included 'NOT pulmonary artery catheter OR peripheral artery catheter' as these terms are also commonly abbreviated to PACS.
*Medical Subject Headings terms or subject headings, exploded where possible.
‡A number of similar searches were carried out in this database to capture all possible articles.

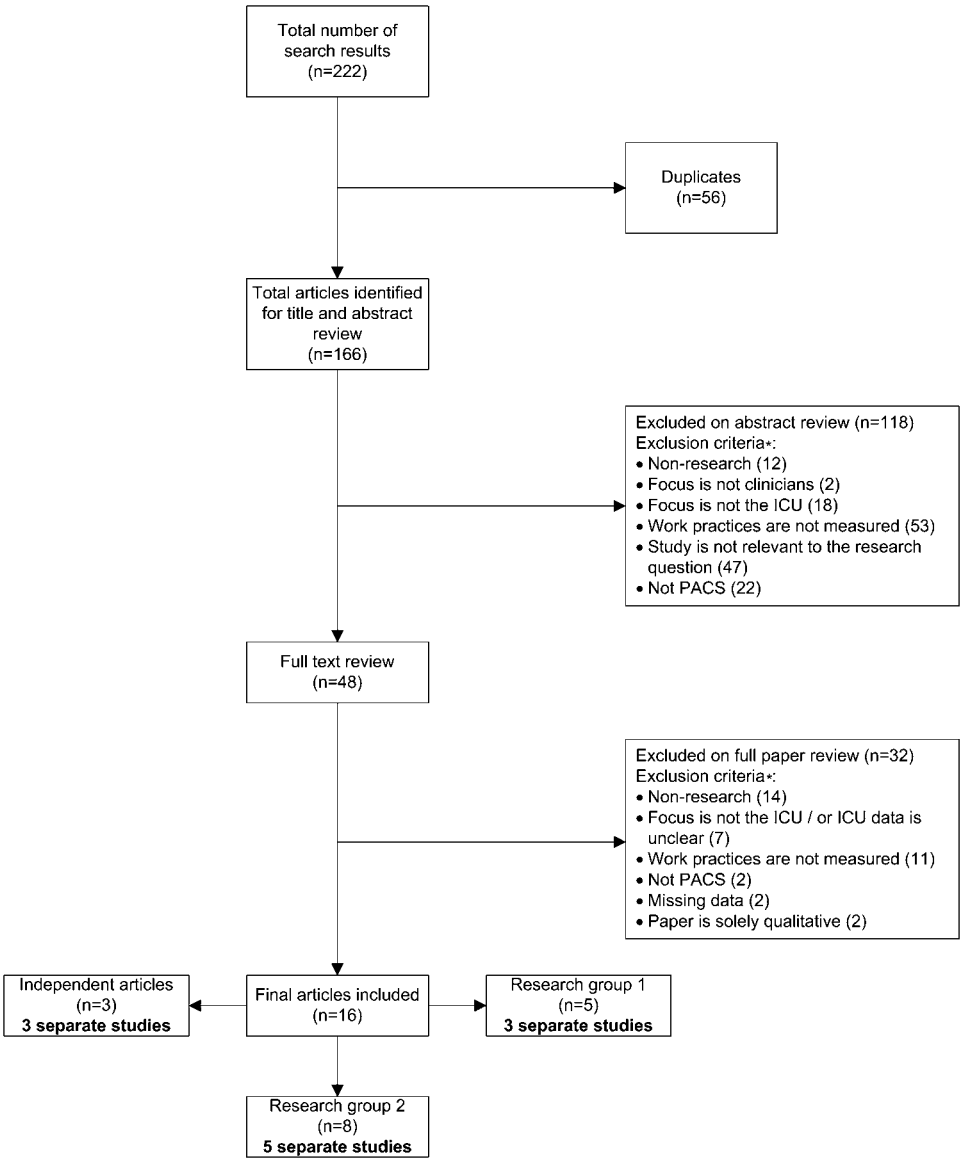

Figure 1 Process by which studies were included in the review. *Some papers were excluded under more than one exclusion criterion. PACS, Picture Archiving and Communication Systems.

Availability of images

Of the five studies that reported on image availability,[33–40] all but one found that access to images was quicker with PACS. The studies by Kundel *et al*[36–38] and Redfern *et al*[39] involved four data collection periods (analog film, first PACS, computed radiography (CR) film and second PACS). Kundel *et al*[36–38] focused on *non-routine* (for specific problems that can sometimes be urgent) chest examinations and Redfern *et al*[39] on *routine* images. Both reported a reduction in the median time to image availability with PACS. A survey administered by Cox *et al*[33] to evaluate ICU staff perceptions of the impact of PACS found that 90% of users thought images were available more quickly and 72% perceived there were no longer problems due to lost images. Humphrey *et al*[34 35] measured clinicians' perceptions of PACS utility via a questionnaire, with the majority of respondents reporting that images arrived faster in soft copy rather than with a hard copy film. A significant decrease ($p<0.01$) in the time to image availability for *routine* examinations from 30 and 45 min in the baseline periods to 15 min in the PACS period was found by Watkins *et al*[40] in their pre- and post-PACS implementation study, but there was no difference for *non-routine* images.

Time to imaging information review by ICU physician

The time from when an image was taken until the imaging information was accessed by an ICU physician was considered in six studies,[36–38 41–46] with four reporting a decrease in this time following the introduction of PACS.[41–45] Andriole and colleagues[41] carried out a before-and-after study to examine the impact of PACS on physician behavior and determined that the average time from image exposure to image review decreased from 2 h 32 min to 1 h 35 min. A decrease was similarly observed in the study by Redfern *et al*[45] which looked at the time to review of *non-routine* images. This study also investigated the review times according to the workload of the physician using variables such as unit occupancy, severity of illness, and APACHE III score. There was a statistically significant association between an increased workload and the length of time it took for an image to be viewed without PACS. While this time decreased with PACS, it was not statistically significant.

In their observational study, Humphrey *et al*[42 43] compared two ICUs in the same hospital with and without PACS (a surgical intensive care unit, SICU, and a medical intensive care unit, MICU, respectively). The mean time from image exposure to image viewing in the SICU was 39 min compared to 78 min

Table 2 Outcome measure summary

Outcome measure	Definition(s)	Studies (n=11)	Papers
Availability of images	The time period from when an image is taken to the availability of the image	5	Cox *et al*[33] Humphrey *et al** [34 35] Kundel *et al** † [36–38] Redfern *et al*† [39] Watkins *et al*[40]
Time to imaging information review by ICU physician	The time period from when an image is taken until the imaging information (image and/or report) is accessed by an ICU physician	6	Andriole *et al*[41] Humphrey *et al** [42 43] Humphrey *et al*[44] Kundel *et al*[36–38] Redfern *et al*† [45] Shile *et al*[46]
Viewing patterns	The time(s) of day clinicians access images	3	De Simone *et al*[47] Humphrey *et al*[42 43] Redfern *et al*[39]
Time associated with clinical decision-making	1. The time period from when an image is taken until a clinician takes an image-based clinical action 2. Perceptions of ICU clinicians on the impact of PACS on decision-making	7	Andriole *et al*[41] Arenson *et al*‡ [48] De Simone *et al*‡ [47] Cox *et al*[33] Humphrey *et al*[34 35] Kundel *et al*[36–38] Redfern *et al*[39] Watkins *et al*[40]
Communication modes	Frequency and types of communication between ICU clinicians and the radiology department	5	Andriole *et al*[41] Arenson *et al*‡ [48] De Simone *et al*‡ [47] Kundel *et al*[36–38] Redfern *et al*[39] Shile *et al*[46]

*These authors each published preliminary or the same data across a number of articles.
†Different aspects of the same study were reported on by these authors.
‡Both papers report on the same study data and so are counted as one study.
ICU, intensive care unit; PACS, Picture Archiving and Communication Systems.

for the MICU. The authors commented that the maximum time for which an image could be 'useful' to the clinicians was 1 h and determined that SICU clinicians were 9.5 times more likely to access imaging results within 1 h compared to MICU clinicians (p=0.0425). The authors followed this study by looking at the MICU following PACS implementation and found the mean time to viewing dropped to 55 min.[44]

Kundel *et al*[36–38] looked at the time imaging information was first accessed via usual channels (looking at the image, asking a radiologist, or reading the radiologist's report) or the PACS workstation and stratified according to the reason for the examination (pulmonary and pleural problems, or position of tubes and catheters), although the authors did not specify which information channel was used. During the first PACS period there was a significant difference in the median time to physician access between *CR film* (3 h 48 min) and PACS (1 h 24 min). For position of tubes and catheter images, the time until imaging information was viewed was not significantly less when PACS was available. Similarly, in the study conducted by Shile *et al*,[46] physicians had the choice to obtain images and reports through their usual communication channels (going to visit the radiology department or at a daily ICU conference) or through a PACS workstation. Only 44% of *non-routine* images were first viewed using PACS. The authors noted that 19% of films were not digitized and so could not be viewed using PACS and for those that were, they were not all available within 3 h due to the slow digitization process. Almost 50% of reports were received in the first 3 h following the examination, although for those reports that were viewed alongside the image, this occurred in hard copy rather than at the PACS workstation. For images first viewed at the workstation, 34% of reports were received at least 1 h later and thus not viewed simultaneously, due to the time required for report transcription.

Viewing patterns

Three studies reported on changes to the viewing pattern of images by ICU clinicians following PACS availability.[39 42 43 47] De Simone *et al*[47] found clinicians viewed images earlier in, and more evenly during, the day when images were available electronically. The authors commented that without PACS the majority of films were viewed at the daily radiologist conference in the ICU at 15:00 h. However with electronic images, these could be viewed by physicians on the morning ward rounds and they incorporated this into their routine. Similarly, in the study reported by Redfern *et al*,[39] 19% and 27% of images were accessed before the daily radiology conference (09:15 h) in the two PACS periods compared to 0% for the film periods (p<0.001). The observational study by Humphrey *et al*[42 43] of the SICU and MICU found that in the SICU all images were viewed evenly over the hour following the examination, however in the MICU (no PACS), apart from urgent results, image viewing was scattered over a 2.5-h period.

Time associated with clinical decision-making

Seven studies reported on the impact of PACS on the time associated with image-based clinical decisions.[33–41 47 48] Five discussed the time to clinical action, with two studies reporting an overall *significant* decrease in the time it took for a physician to take image-based clinical action as a result of the image being available in PACS.[39 47 48] In one of these, De Simone and Arenson[47 48] comment on the discovery of a pneumothorax when clinicians viewed the digital image, which allowed the patient to receive prompt treatment. Additionally, Andriole *et al*[41] found that the time to clinical action decreased from an average of 3 h 21 min to 2 h 6 min following PACS introduction. Kundel *et al*[36–38] also reported a significant decrease (p=0.03) in the time before a primary clinical action (related to the reason for the examination) was taken for *non-routine* images. When they divided the time to clinical action into (a) the time to image review by the clinician and (b) the time from image review until clinical action, they found that the decrease was a result of the reduced time to image review. The before-and-after study by Watkins *et al*[40] found no difference between baseline and PACS

periods for the time to clinical action for both *routine* and *non-routine* images, although the authors commented on the limited data available for *non-routine* image-based clinical actions. The majority of clinicians surveyed by Cox *et al*[33] and Humphrey *et al*[34 35] believed PACS led to quicker decision-making.

Communication modes

Communication with the radiology department was reported in five studies.[36–39 41 46–48] Three found that PACS use led to a decrease in communication between physicians and radiologists.[36–39 47 48] Kundel *et al*[36–38] observed a significant reduction in the input physicians received from radiologists ($p<0.05$) in the first PACS period, with only 26% of images receiving radiologist input via the telephone, direct radiologist contact, or the radiologist's report. Similarly, the Redfern study[39] also found a significant decrease in the level of radiologist–physician communication. However, there was little change in 'film and report' encounters, with the authors commenting that while some images were viewed before the radiology conference, the reports for these were discussed alongside the images at the daily conference. While De Simone and Arenson[47 48] did not measure the significance of the changes, they did find there was less consultation with the radiologist. Physicians did, however, review the radiologists' reports, transmitted through PACS, for 50% of images, whereas the preliminary report was read for only 16% of images without PACS. These authors commented that the presence of PACS enhanced communication between physicians on the ward round through facilitating discussions regarding patient care. In contrast, Andriole *et al*[41] found no difference in the level of consultation pre- and post-PACS. Shile *et al*[46] reported that in the first 4 h after an image had been taken, physicians primarily visited the radiology department to verbally receive the radiologist's report. Only 25% of radiologist reports were first read on PACS and this occurred at least 2 h after the examination.

DISCUSSION

Studies to date identify a number of areas in which PACS impacts on clinicians' work practices in the ICU, however the current evidence base to determine if PACS delivers on its promises is weak, inconsistent in some areas, and leaves many questions unanswered. Despite searching databases for papers published in the last 30 years, we identified only 16 papers which reported 11 studies, with two US research groups responsible for eight. All studies were conducted at a single site and these factors are likely to play a role in the generalizability of the results. No randomized controlled trials were conducted, although three out of the 11 studies utilized a before-and-after methodology[40 41 44] and two alternated control periods with PACS periods.[36–39] The lack of control groups in other studies invites concern. Further, four studies did not report or test the statistical significance of their findings. Although PACS is now considered ubiquitous in many ICUs worldwide, no empirical studies have been conducted in over 10 years, limiting the ability to draw firm conclusions about its impact on contemporary practice. Many of the ICUs in this review were early adopters of PACS, utilizing basic systems, and some operated PACS in parallel with a film-based system during studies, which is less likely to occur today, particularly as the aim of PACS is to provide filmless imaging.[36–39 45–48] Much discussion has taken place surrounding the importance of PACS integration with electronic medical records and computerized provider order entry,[2 5 12] which are also becoming commonplace in the ICU.[49] The level at which PACS is used and how it is incorporated into clinical practice will be influenced by the extent to which it is integrated. None of the reviewed studies provided details of system integration for us to take this into account in our analysis.

Despite the limited number of studies, the evidence suggests a broad framework of relevance for future studies seeking to evaluate the influence of PACS on clinician work practices focusing on three core indicator areas: *efficiency of work practices*, *work associated with clinical decision-making*, and *communication practices*.

Efficiency of work practices

One of the many purported benefits of PACS is improved efficiencies in the delivery of healthcare.[4 50] All studies measured various aspects of efficiency. One study commented on the eradication of issues associated with lost images,[33] which is commonly cited as a benefit of PACS, negating the need for clinicians to spend time searching for images.[12 51 52] Four studies demonstrated a reduction in the time to access an image with PACS, improving the efficiency of a clinician's work. Other studies did not show this level of efficiency. The authors of one study[36–38] commented that the time to image availability included transport of the CR plates to an area away from the ICU, which then had to be scanned before being transmitted to the ICU PACS workstation. With the development of portable digital radiography, substantial improvements in efficiencies are likely to have been achieved.[53] A few studies demonstrated clinicians accessing and viewing images earlier, due to the ability to now view images when required on the ward round. This is consistent with recent literature.[51 54] A recent qualitative study conducted across three ICUs in Australia also reported positive, although varied, changes to the structure of ward rounds following the implementation of PACS.[55]

Work associated with clinical decision-making

Informed clinical decision-making is vital in an ICU where a critically ill patient's condition can rapidly change and quick information access is essential. Ready availability of images through PACS can have positive effects on clinical decision-making[16 52 54 56] and this was perceived to be the case in two studies.[33–35] When times to clinical action were measured in other studies, the results were inconsistent.[36–41 47 48] Many organizational factors in the ICU[57] can affect decision-making. Kundel and Watkins both discuss potential factors that may have influenced their 'negative' results,[36 40] such as the lack of a 'flag' to signify that the image was available. This could result in delayed clinical action, as also suggested by Peer *et al*.[54] The presence of PACS alone will not allow the ICU to reap the benefits of more timely decision-making if the work processes, such as a 'flag' to signal image availability, are not in place to allow clinicians to take advantage of results upon which clinical actions, such as changing medications or adjusting a tube position, are dependent.

Communication practices

Effective communication is of crucial importance in the delivery of healthcare generally[57 58] and also in the ICU.[59 60] However, as PACS has developed, concerns have arisen that it changes communication between clinicians and radiologists,[61 62] potentially causing clinicians to view and interpret images independently and without the aid of expert radiology advice.[56] Three studies in our review reported a decrease in clinician–radiologist communication after the introduction of PACS.[36–39 47 48] The

changes to image viewing patterns, as highlighted above, are likely to have altered the clinician's requirement to regularly visit the radiology department for film and/or report review, a common practice before the introduction of PACS. While communication processes have become more electronic in nature, some continue to encourage face-to-face conferences,[15 55] as highlighted by one ICU in our review.[39] Two studies displayed no changes in communication,[41 46] corresponding with the inconsistencies reported in the literature regarding PACS and communication processes.[15 52 54 63]

PACS also creates opportunities for enhanced shared decision-making and has been found to improve communication processes within clinician groups[12 51 64] and between clinicians and radiologists,[12 22 54 65] enhancing clinical discussions and decision-making. However, only one of our included studies commented on this.[47 48]

Implications for future research

Despite the ubiquitous presence of PACS in many ICUs, the findings from this review and others[66] suggest that more research is required. PACS are being integrated with electronic clinical information systems with increasingly sophisticated features including decision support functionalities, voice recognition, and image manipulation technologies, yet this review has starkly highlighted the absence of research on how practice changes, or fails to change, as a result of these technological advances.

Regardless of the marked improvements in PACS technology since the included studies were published, the three core indicator areas synthesized from the existing research evidence remain relevant and they should continue to be a focus for future studies. While the studies do not necessarily show profound innovative changes in the way clinicians undertake their daily work, the potential of PACS to increase efficiencies and influence clinical decision-making may only be realized, as Siegel *et al* suggest,[67] if an effort is made by clinicians to redesign their work flow, access images earlier than they previously would have, and integrate PACS into their work practice. A recent study conducted in three ICUs where PACS is integrated with clinical ordering and results systems (one ICU had access to PACS at the bedside), found that expected behaviors, such as integrating viewing of images during ward rounds at the bedside, did not occur at the site with point-of-care terminals.[55] This was despite clinicians reporting that bedside availability of PACS was a great advantage in their ICU. However, doctors from the site with only centralized PACS access consistently navigated between the bedside and the work station in order to view images during ward rounds. With the increasing use worldwide of mobile technologies such as tablets and iPads, great potential also exists for such technologies to be used within clinical areas such as the ICU to allow clinicians instant access to imaging information, particularly on ward rounds for example, where point-of-care terminals are not always available.[68] This would be an area worthy of future investigation.

Future research should prioritize the refinement of outcome measures utilized in the current studies and the design of new objective indicator measures to understand how PACS does indeed impact on efficiency, decision-making, and communication practices in the ICU, as well as the implications for patient care. The context and organizational nature of the ICU will influence how PACS and their associated technologies impact and transform work practices. A literature review carried out by Maslove *et al* on the use of computerized provider order entry in the ICU environment concluded that a 'lack of compelling evidence demonstrating its value' was apparent and highlighted the importance of taking a socio-technical approach for future evaluations.[69] Such conclusions are no less true for PACS and further research should take the context of the ICU into account when developing and refining these indicators. However, it will likely be difficult to conduct any before-and-after studies with PACS now commonplace in many ICUs. Thus the early studies presented in this review provide some useful indicators of baseline experiences of ICUs pre-PACs which can assist in the interpretation of future findings.

The challenge for future researchers is to examine how the definitions of some of the specific outcome measures (table 2) require refinement to take account of the changes in PACS technology. While the majority of the measures continue to be relevant, there is no doubt that contemporary PACS allows for quicker availability of images and image review than that in the included studies and so a measurement such as 'availability of images', as quantified by Kundel *et al*[36] for example, is not likely to be as important today. However, the inclusion of technologies such as voice recognition software, ought to impact on the availability of imaging reports alongside images and thus refinement of the 'availability' measure would be a worthy adaptation.

Limitations

Despite using a broad search strategy, we found only 16 papers, which reported on a total of 11 studies. It is possible we may have missed papers that were indexed under other terms, used different key words, or were published in the gray literature or in languages other than English, resulting in a publication bias. Due to the heterogeneous nature of the studies, we were unable to conduct a full quality assessment and so synthesized the results according to the outcomes presented by the authors, rather than a meta-analysis. We only included quantitative studies, however these can often be one-dimensional and, as suggested above, there is a need to look beyond quantitative studies in future work.

CONCLUSION

Our review highlights that within the ICU setting limited evidence exists to suggest that 'the perceived benefits of PACS match well the proclaimed benefits'.[51] Certainly, it is difficult to draw firm conclusions on how PACS may have significantly changed clinical practice on a large scale. Evidence of change exists in some specific areas of work and PACS has great potential to improve clinical work practices in the ICU, thus improving patient care.[12 16] The framework of three core indicator areas synthesized from the key outcome measures and results provides the basis for much needed further investigations of the impact of PACS in supporting new and improved ways of delivering quality, safe, and efficient care.

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