Chapter 21

Evaluation of Picture Archiving and Communications Systems

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21.1 Introduction

Picture Archiving and Communication Systems (PACS) present an opportunity to radically change film-based radiology services both inside and outside the hospital setting. In the past, the usual medium for capturing, storing, retrieving and viewing radiology images was hard-copy film. The idea to replace film with digital images was first conceptualized in 1979 (Huang, 2003). However it was not until the early 1980s that advances in technology made introducing PACS into radiology departments feasible (Duerinckx, 2003). PACS replaces the film environment with an electronic means to seamlessly communicate and share radiology images and associated reports between health professionals.

21.2 Current State of Evidence

In evaluating the benefits of PACS there are many approaches and methodologies that can be employed. The approaches generally employed (i.e., formative versus summative or subjective versus objective) are basically different perspectives on how one can measure specific benefits. When reviewing the literature on PACS evaluations, it was rare that the author actually stated the approach taken in terms of evaluation perspectives. One must review the methodology closely to determine if, for example, the approach utilized was formative or summative. As well, in the majority of papers the methods section is limited to identifying the specific methods of data collection (e.g., surveys). In reviewing the literature, the methods most often used in evaluating PACS were: (a) questionnaires/surveys, (b) data collection sheets, (c) administrative data/project doc-

uments, (d) time and motion studies, (e) direct observation, (f) video recording, and (g) interviews. The environments in which PACS were most often evaluated were private clinics, radiology departments, and other hospital departments outside radiology.

21.2.1 Synthesis of Current Evidence

Many PACS evaluations published in the literature are not specific to a setting, but rather address a specific issue related to PACS. These include evaluations that investigated the following: financial benefits, pre-implementation planning, system integration, image quality, integration of voice recognition, and technical issues.

Financial benefits – Financial benefits that can be realized through the implementation of PACS fall into two areas, cost savings and increased revenues. In Canada, cost savings are achieved through the elimination (or reduction) of ongoing expenses related to the film environment, and are a direct result of the implementation of PACS. In the American health system if efficiencies are achieved with PACS over hard-copy film, additional revenues result for the given institution if the number of patients receiving radiology services is increased (i.e., increased patient throughput).

Pre-implementation planning – Planning for the implementation of PACS has drawn considerable interest from the research community in recent years. Pre-implementation planning studies have various degrees of scope, ranging from looking at the complete process, to carrying out a gap analysis and developing a Request for Proposals (RFP), to selecting the vendor (Ortiz & Luyckx, 2002; Swaton, 2002; Lepanto, Carrier, Gauvin, Dieumegarde, & Delage, 2002; Farnsworth, 2003; Bedel & Zdanowicz, 2004; Lawrence, 2005). Other implementation studies are even more specific, such as studies that investigate the role of a PACS Committee, the value of marketing PACS to end users (Viau, 2004), the challenge in linking PACS to external clinics (Arreola & Rill, 2003), and the degree of implementation of PACS in other countries (Foord, 2001; Inamura et al., 2001; Burbridge & Bell, 2004).

System integration – The maximum benefit of PACS is achieved when it is integrated into both the Hospital Information System (HOIS) and the Radiology Information System or RIS (Carrino et al., 1998; Reiner, Siegel, & Scanlon, 2002; Siegel & Reiner, 2003). A basic PACS architecture generally starts at the HOIS, as this is where patient demographic information is held and, in most cases, where the service order originates. Both patient demographic and order information is sent from the HOIS to the RIS, which distributes this information to the appropriate modality in the Radiology Department (e.g., chest X-ray). Once the image is created, it is sent from the RIS to the PACS for reviewing by the radiologist, who can then append the image report to the PACS (Mulvaney, 2002). The benefits of PACS integration into the RIS and HOIS systems include the elimination of redundant data entry, the availability of more accurate information in PACS, and a reduction in workload for radiology and clerical staff (Levine, Mun, Benson, & Horli, 2002).

Image quality – An increase in productivity and a reduction in costs are only beneficial if there is no loss of image quality when compared with traditional film. Given the massive amounts of computer memory (storage) required to store, transfer and retrieve digital images, earlier versions of PACS were disadvantaged simply because they were too expensive to operate (Agarwal, Rowberg, & Kim, 2003; Erickson, 2002). A relatively recent solution to the large amounts of space needed for digital imaging is to compress (or shrink) the image so that it does not require as much space for storage/transfer.

Integration of voice recognition – The installation of a voice recognition system that interfaces with PACS has been found to reduce the percentage of lost or unreported examinations (Hayt & Alexander, 2001) and improve report turnaround time (Azevedo-Marques, Carita, Benedicto, & Sanches, 2004). Voice recognition technology allows the radiologist to dictate an oral report via the voice recognition system, which is then attached to the appropriate image(s) in the PACS. The radiologist performs all the editing and corrections either by voice command or by manual typing (Marquez & Stewart, 2005). While voice recognition technology has made considerable advances in recent years, it still has some disadvantages. A particular concern is the potential for decreased face-to-face consultations between radiologists and physicians, given physicians have more immediate access to images and reports (Hayt & Alexander, 2001), and issues related to change management for both physicians and radiologists from multiple organizational perspectives.

Technical issues – Technical problems are always a possibility when new technology is introduced, and PACS is no exception. Problems with reliability of the system (Strickland, 2000) and delayed access to images (Inamura et al., 2001; Reed, Herzog, & Reed, 1996; Bryan, Weatherburn, Watkins, & Buxton, 1999) were identified in early studies of PACS. The issue of storage also garnered quite a bit of interest in the late 1980s and early 1990s, mainly because the digital image was so large and the storage capabilities were limited. Recent advances in technology have resolved the issue of storage (Naul & Sincleair, 2001), but other challenges still remain. These include access to historic images (Gamsu & Perez, 2003; Gaytos, Speziale, Bramson, & Treves, 2003), access to monitors and logging on to the system (Pilling, 2003), user friendliness (Cox & Dawe, 2002; Watkins, 1999; Krupinski, McNeill, Haber, & Ovitt, 2003), and overall IT support (Bedel & Zdanowicz, 2004; Hasley, 2002; Hayt, Alexander, Drakakis, & Berdebes, 2001).

21.2.2 Summary of Key Findings

The approaches to evaluating PACS are as diverse as the environments in which it is found. Areas that are usually studied focus in on increased efficiencies (e.g., increased report turnaround times — TAT) and productivity (e.g., more exams reported) and cost reduction. Cost is particularly important in the United States where a fee-for-service model is most prevalent.

21.3 Selected Case Study: Does PACS Improve Report Turnaround Times?

21.3.1 Introduction

In the fall of 2005, Canada Health Infoway and the Province of Newfoundland and Labrador (Canada) partnered on a $23 million initiative to implement one of the first province-wide Picture Archiving and Communication Systems in Canada. Prior to 2005, PACS implementations in Canada were funded either by provincial governments, regional health authorities, or such individual institutions as hospitals and clinics. In 1998, Newfoundland and Labrador initiated a project-based approach to implementing PACS, such that by 2005 approximately 70% of the service areas in the province had PACS capability. The challenge with the project-based approach was that these PACS were not interconnected and could not communicate beyond the local installation. To address these gaps, the 2005 PACS initiative in Newfoundland and Labrador was undertaken with two goals in mind: (a) to implement PACS in selected rural sites where no PACS currently existed, and (b) to address gaps in those regions where PACS was currently operational.

This section of the chapter describes a study specific to the impact that PACS had on turnaround times (TAT) for radiology reports. The Report TAT evaluation was carried out on the island portion of the province with a focus on hospitals in the two health authorities located on the east and west coasts.

21.3.2 Materials and Methods

This PACS Report TAT study was designed as a pre/post comparative benefits study. The majority of TAT data was collected from the hospitals' Radiology Information Systems (RIS), the Hospital Information System (HOIS), and the PACS: (a), each month, for minimum of three months pre-PACS implementation, and (b) each month, for minimum of nine months post-implementation, for a total of 12 data points. The mean TAT was derived for each pre/post period, excluding the month that PACS was implemented. A one-way analysis of variance (ANOVA) was used to determine if there was a statistically significant difference between the pre-PACS and post-PACS periods on the mean report TAT. The TAT was considered the dependent variable and pre/post time periods the independent variable. A p-value of < 0.05 would signify a significant difference in TAT between pre- and post-PACS.

21.3.3 Study Setting

The Province of Newfoundland and Labrador consists of two major geographical areas, the island of Newfoundland and a mainland section, Labrador. The province encompasses an area of 405,720 square kilometres with Labrador comprising 72% of the land area of the province, but containing only 5% of the population. The province is separated into four health authorities: Eastern Health Authority, Central Health Authority, Western Health Authority and the

Labrador/Grenfell Health Authority. The Eastern and Western Authorities were chosen for this study, given they had recently implemented PACS and pre/post exam data was available. The total population of Newfoundland and Labrador is approximately 525,000 (as of 2014), with the majority (300,000) residing in the Eastern Health Authority.

21.3.4 Report Total Turnaround Time

Defining an appropriate measure to study report TATs presented several challenges to the research team. Initially, we had hoped to measure the time the request for the exam was logged into the Radiology Information System (RIS), to the time the final report was posted back to the Hospital Information System (HOIS). However, several challenges became evident early into our study:

1. It was discovered that physicians sometimes utilized only the exams (or the draft reports) when providing patient care, thus minimizing the urgency of the radiologist to sign off on draft reports in a timely manner.

2. Some radiologists were known to verify all reports generated over an extended period of time on a particular day (e.g., every Friday afternoon).

3. Perhaps most importantly, check-in time was captured differently for inpatients and outpatients; that is, all inpatient "registrations" were recorded at 8:00 a. m. the morning after the physician had requested the exam. Conversely, outpatient "registrations" were recorded as the actual time the person registered in the hospital's radiology department.

Given the problems associated with our TAT measure, a modified measure was developed that excluded inpatient exams, and used the average monthly TAT for exams originating at outpatient registration to when the draft report was posted to the HOIS. At the time of the study, transcriptionists in many of the hospitals utilized a high-end tape recorder that was not interfaced with the HOIS. The transcriptionist reviewed the audiotape and typed the draft report directly into the HOIS. The radiologist then reviewed the draft report in the HOIS, made the necessary changes, and signed off on the report electronically.

Data for this modified TAT measure was collected for CT, echocardiography, MRI, nuclear medicine, general radiograph and ultrasound. In most cases, the collection period encompassed three (3) months pre-PACS implementation, and nine (9) months post-PACS implementation.

21.3.5 Results

Western Health Authority – Administrative data for all draft report TATs for outpatients was collected from the RIS and HOIS for each modality within scope in the Western Health Authority from September 2005 to December 2006 (N = 112,667). As a result of staggered implementation dates for PACS at the seven sites in the Western Health Authority, not all sites had complete data for three months pre- and nine months post-PACS implementation.

Eastern Health Authority – Administrative data for all draft report TATs for outpatients was collected from the RIS and HOIS for each modality within scope in the Eastern Health Authority for the period June 2004 to August 2005 (N = 177,855). As a result of staggered implementation dates for PACS at the three sites in the Eastern Health Authority, the pre-implementation and post-implementation periods differ depending on the month of implementation: June, July, or August 2004.

21.3.6 Discussion

The results of our study found that report TATs in some sites increased after PACS had been implemented, most notably in the Western Health Authority. In advance of discussing this anomalous finding, it is important to first consider PACS in the context of the enterprise of information systems that exist in today's modern hospitals. That is, there are a multitude of factors that need to be considered when investigating the benefits of PACS as it relates to report TATs. One needs to look at the entire enterprise, rather than PACS as a stand-alone system. Inamura and colleagues (1998) suggest the evaluation of PACS needs to look at the interaction between PACS, the Hospital Information System and the Radiology Information System, and how these systems interact with other information systems within the hospital. Foord (1999) concluded, "Installing PACS has very wide implications and it is important that these are well understood within the organisation and that acquiring a PACS is not seen as like buying another piece of imaging hardware, which has little functional impact on the radiology department and hospital as a whole" (p. 100). Reiner and Siegel (2002) identified several external factors to PACS which can impact on report TATs, such as facility type and size, HOIS/RIS/PACS integration, training, support staff, and patient population.

Another issue to be considered is what constitutes an acceptable TAT. The measure itself may be objective, however its interpretation is very subjective and can include many factors, such as the urgency of the event, the type of exam, hospital policy, staffing levels, exam volume and service environment (e.g., emergency department versus a chronic care unit). To put this into perspective, is a TAT of 100 hours for a non-urgent report any different than one of 50 hours? As one radiologist pointed out in follow-up to this issue, there is a big difference between statistical and clinical significance, and while there might be a statistically significant difference in an average TAT of 100 hours and one of 50 hours, as a physician treating a patient, the reduced time of 50 hours in the context of

100 hours may not be clinically significant if the case is non-urgent. The issue of clinical versus statistical significance is illustrated in a study carried out by Weatherburn, Bryan, Nicholas, and Cocks (2000) which found the rate of misdiagnosis pre-PACS was 1.5%, whereas the rate post-PACS was only 0.6%. The small difference raised this question: Regardless of whether the difference is statistically significant, is it clinically significant? The 1.5% rate of misdiagnosis suggests an efficiently run film environment existed in the emergency room prior to PACS being implemented. Following the implementation of PACS there was a statistical benefit realized, evident by the drop in misdiagnosis to 0.6%; however, this drop was not deemed to be clinically significant.

Western Health Authority – An analysis of the data obtained from the hospital information system at Hospital_A found that all six modalities under study experienced a significant increase in report TAT for the nine months following the implementation of PACS. This increase, as measured by the average TAT per month, was not entirely attributable to the initial high TATs for those months immediately following implementation. That is, it would be expected that longer TATs would be experienced immediately following the implementation of PACS given the inexperience of users. While there may be several reasons that contributed to the increased report TAT post-PACS at Hospital_A, an ongoing shortage of transcriptionists is believed to be the primary cause. At the time of the study, there was no voice recognition system at Hospital_A and all reports were recorded to a stand-alone recording system.

Of interest, many of the smaller peripheral sites in the Western Health Authority experienced decreases in report TATs following the implementation of PACS. Upon further investigation, it was determined that the most likely reason for this decrease was that before PACS was implemented, these sites would batch all their non-urgent exams (i.e., film) taken over a two- to three-day period, and then send them to Hospital_A via taxi for interpretation and reporting. Following the implementation of PACS, these exams were now available immediately to the radiologists at Hospital_A for reporting, thus eliminating the time previously taken in having the film transported over the road.

An important point to consider is that all sites within the Western Health Authority, with the exception of Hospital_A, have relatively small volumes of exams performed annually. To put this in context, the total exams within scope performed at the six peripheral sites in the Western Health Authority for the year under study was only 35,011, ranging from 1,134 to 16,727 per site. Adding in the volume of exams from Hospital_A (n = 77,656), the total volume of exams for the Western Health Authority was only 112,667.

Eastern Health Authority – In the Eastern Health Authority there were three hospitals for which TAT data was collected pre- and post-PACS implementation. Hospital_H carried out 97,922 exams for those modalities within scope, Hospital_I 73,428, and Hospital_J 6,505.

Hospital_H provided report TAT data pre- and post-PACS for CT, echocardiography, MRI, nuclear medicine, general radiograph, and ultrasound. All modal-

ities, with the exception of nuclear medicine, experienced a reduction in average TAT for the three months pre-PACS implementation compared to the 12 months post-PACS. Similar to Hospital_A in the Western Authority, Hospital_H also experienced issues related to a lack of transcriptionists. However, given the larger size of Hospital_H compared to Hospital_A, the impact of a reduction in transcriptionists was partially mitigated by the fact Hospital_H had more transcriptionists on staff to share the workload. In addition, the administration at Hospital_H introduced short-term measures to address the delay in TATs, including increasing overtime and contracting with retired transcriptionists.

Hospital_I exams within scope included CT, echocardiography, nuclear medicine, general radiograph, and ultrasound. Only TATs for nuclear medicine and general radiographs experienced a decrease from pre- to post-PACS, whereas the average TAT for the other three modalities remained statistically the same. In investigating why some modalities experienced a decrease in TAT, while others apparently did not, no one cause was identified. The problem the research team experienced in carrying out such investigations was that administrative databases are limited when one wants to study cause and effect. However, one explanation put forward by one Director of Radiology was a likely reduction in human resources (i.e., radiologists and transcriptionists) available, either through retention or illness, for extended periods of time for the year that TAT data was collected. During these times of staff shortages, it is possible that the reporting of some types of exams were given priority over others. Another reason may be specific hospital policies that dictate which exams are given priority for reporting

Hospital_J is a psychiatric hospital that also provides general radiographs to the general public through a pre-appointment outpatient setting. Over the study period, there were 6,505 general radiology exams performed at this site, with a decrease in report TAT found from pre- to post-PACS. Hospital_J has two technologists on staff, and no radiologist. In the film environment, a radiologist would visit Hospital_J twice a week to report on all exams taken since the previous visit. In the PACS environment, the technologists now only need to call a radiologist at one of the other sites and let them know that the exam is now posted on PACS and request a consult. The ability to post exams on PACS for external review was the most significant factor in reducing report TATs at Hospital_J.

21.3.7 Conclusion

The implementation of PACS in two of the four health regions in Newfoundland and Labrador had mixed results with respect to Report TATs. Our study found that increases in report TATs in some smaller sites following the implementation of PACS was due mainly to a lack of support staff (transcriptionists), rather than the PACS itself. In the larger sites studied, a lack of transcriptionists was also evident; however, the impact on TATs was less profound given the reductions in support staff in the Radiology Department could be mitigated through other resources available in the larger sites.

21.4 Issues, Guidance and Implications

Where sites are paid for each radiology service provided to a patient (e.g., the United States), PACS can provide an opportunity to increase revenues. This is made possible when radiologists become more efficient in reviewing digital exams (images) and preparing reports for referring physicians. With this increased efficiency, hospitals can accommodate more new patients (i.e., increase productivity) from their pool of referring physicians (Reed et al., 1996; Chopra, 2000; Kim, Park, Chun, & Nam, 2002; Andriole, Rowberg, & Gould, 2002; Hunt, 1998). In Canada, the delivery of health services is funded through the Canada Health Transfer (CHT), which provides universal health care insurance to all residents of Canada. Therefore, PACS provides limited opportunity for hospitals in Canada to generate revenues by increasing the number of patients seeking radiology services. Nevertheless, from an accountability perspective, investments in health information systems are costly and it is necessary to quantify the success of such systems and the degree to which the investment was justified (Protti, 2002). Challenges to addressing these concerns include:

1 Efficiency (doing things right) is easier to measure than effectiveness (doing the right thing).

2 New systems are intended to change difficult-to measure actions.

3 Strategic systems elude measurement.

4 Infrastructure investments are difficult to justify on a return on investment (ROI) basis.

Adding to the challenge is that the literature is not conclusive on whether PACS can actually result in savings and/or increase revenues and profits (Strickland, 2000; Maass, Kosonen, & Kormano, 2001; Maass et al., 2002; Grosskopf, 1998; Terae, Miyasaka, Fujita, & Shirato, 1998; Cartier, 1999; Andriole et al., 2002; Colin et al., 1998; Nitrosi et al., 2007), given that the level of benefit achievement depends on a multitude of confounding factors, such as the funding model in place, the degree of HOIS/RIS/PACS integration, the level of training and support staff, the size and type of the PACS site, and the population served (Reiner, Siegel, Carrino, & Goldburgh, 2002), and how efficient the film site was before PACS was implemented (Lepanto et al., 2002).

The volume of exams performed in a site, and its relationship to the expected benefits of PACS, can also impact on the level of benefits achieved through introducing PACS. While installing PACS in a site that only averages 10,000 exams per year may not be a practical investment for most sites, it nevertheless raises the question of what constitutes the necessary volume of images before an investment in PACS becomes feasible. An earlier study by Bauman, Gell, and Dwyer (1996) stated that a large PACS installation required a minimum of

20,000 examinations per year to ensure the feasibility of PACS, whereas seven years later Siegel and Reiner (2003) reported the cut-off was at 39,000 exams. In classifying sites, Cartier (1999) carried out a study in a "small" hospital that produced 15,000 exams a year, while Hayt et al. (2001) carried out a study in a "large" hospital that produced 116,000 exams per year. While these studies classified the size of a site either in relation to the number of beds, or the actual volume of exams, there is no consensus on standards for such classifications. Nevertheless, such studies do raise the question of how to interpret the benefits of PACS within the context of exam volume.

Capital and operational factors associated with the implementation of PACS in the Western Health Authority were very costly. The most significant contributors to the cost of PACS, and the main reason for not realizing a financial return on investment, were equipment and maintenance costs. In the Western Health Authority total cost of PACS was $4.1 million, of which $2.4 million was for hardware (58%). In addition to hardware costs, annual licensing and maintenance costs usually run about 10% to 15% of capital costs, which in the case of the Western Health Authority came to $229,000 per year. One potential opportunity to reduce PACS equipment costs is for multiple sites to partner and offer a joint request for proposals (RFP), thus taking advantage of any economies of scale. The overall cost for the provincial implementation and/or enhancement of PACS was $23 million, not an insignificant amount, even nationally. Yet even with this expenditure, there were no major savings realized, and the costs of the PACS equipment resulted in most hospitals in the province not achieving a return on investment. Until PACS hardware, software and licensing fees comes down in price, it is unlikely, except in the largest urban hospitals, that there will be any financial return on investment for the majority of PACS implemented in Canada.

21.5 Summary of Evaluation Issues

The real challenge is not in determining revenues and/or savings, although both are important and relatively easy to measure. The challenge is determining the indirect benefits of PACS that even today continue to elude meaningful measurement. That is, how can one quantify in financial terms benefits such as improved patient care or outcomes, improved access, or clinician satisfaction? In spite of the 25-plus years of PACS research, there still is no consistent evidence that supports the financial benefits across the many diverse environments in which PACS operates. Sites having high exam volumes, inefficient film environments, and opportunities to generate revenues, offer the best likelihood of achieving a financial return on investment. In contrast, the Western Health Authority had a moderate exam volume, an efficiently run film environment, and no opportunities for generating revenue. This environment resulted in the cost per case analysis in Western Health Authority concluding that unless the planning horizon is lengthy, PACS is more expensive to operate than within the traditional film environment.

21.5.1 Guidance for Future Directions

While this study focused on a report TATs for PACS, it is recognized that the true benefits of PACS are quite far-reaching. There are many other benefits of PACS that need to be considered in the broader context of patient care. Improved efficiency and productivity, which are achieved in part through improved report turnaround times (Azevedo-Marques et al., 2004; Reiner & Siegel, 2002; Mackinnon, Billington, Adam, Dundas, & Patel, 2008) and immediate access to reports and images from multiple sites 24 hours a day, seven days a week (Watkins, 1999; Mackinnon et al., 2008; Bryan et al., 1998; Ravin, 1990; Srinivasan, Liederman, Baluyot, & Jacoby, 2006; Hurlen, Ostbye, Borthne, & Gulbrandsen, 2010; Bolan, Guimaraes, & Mueller, 2008) are but two benefits of PACS considered to offset any higher costs for PACS.

21.5.2 Policy and Practice Implications

From a clinical practice perspective, many of the aforementioned benefits feed into the decision of a hospital/clinic to budget for the changeover from film to PACS, as such costs generally come for the hospital/clinic's operating budget. Policy really does not have as big an influence on moving to PACS at the institutional level as that of clinical benefits. One area that would have broader interest beyond the pure clinical piece is when PACS is considered a valuable tool for recruiting and retaining hard-to-find radiologists in a very competitive national and international market. It is understandable that a radiologist looking for employment will likely go to an environment where the latest technology is available (and stay there), and PACS certainly delivers in that sense.

21.6 Summary

PACS has been available for more than a quarter of a century yet it is still difficult, if not impossible, to measure its true benefits, given the differences in evaluation approaches and clinical environments. It is also difficult to separate PACS from all the other information systems that operate within any environment. Perhaps even more difficult is to attempt to evaluate PACS (as with any health information system) from a financial perspective, given the difficulty in quantifying and defining a price on improved quality of care for our patient population. Most PACS evaluations examine improved efficiencies or productivity, and these then become proxies for improved quality of care and, ultimately, improved health outcomes. For now, we will have to take that assumption on faith.

References

Agarwal, A., Rowberg, A. H., & Kim, Y. (2003). Fast JPEG 2000 decoder and its use in medical imaging. *IEEE Transactions on Information Technology in Biomedicine, 7*(3), 184–190.

Andriole, K. P., Rowberg, A. H., & Gould, R. G. (2002). Workflow assessment of digital versus computed radiography and screen-film in the outpatient environment. *Journal of Digital Imaging, 15*(1), 124–126.

Arreola, M., & Rill, L. N. (2003). Enterprise-wide CR implementation: The Shands Healthcare System experience. *Journal of Digital Imaging, 16*(2), 173–179. doi: 10.1007/s10278-003-1653-z

Azevedo-Marques, P. M., Carita, E. C., Benedicto, A. A., & Sanches, P. R. (2004). Integrating RIS/PACS: the web-based solution at University Hospital of Ribeirao Preto, Brazil. *Journal of Digital Imaging, 17*(3), 226–233.

Bauman, R., Gell, G., & Dwyer, S. (1996). Large picture archiving and communication systems of the world — Part I. *Journal of Digital Imaging, 9*(3), 99–103.

Bedel, V., & Zdanowicz, M. (2004). PACS strategy for imaging centers. *Radiology Management, 26*(5), 24–29.

Bolan, G. W., Guimaraes, A. S., & Mueller, P. R. (2008). Radiology report turnaround: Expectations and solutions. *European Society of Radiology, 18*(7), 1326–1328.

Bryan, S., Weatherburn, G., Watkins, J., & Buxton, M. (1999). The benefits of hospital-wide picture archiving and communication systems: a survey of clinical users of radiology services. *The British Journal of Radiology, 72*(857), 469–478.

Bryan, S., Weatherburn, G., Watkins, J., Roddie, M., Keen, J., Muris, N., & Buxton, M. (1998). Radiology report times: Impact of picture archiving and communication systems. *American Journal of Roentology, 170*(5), 1153–1159.

Burbridge, B., & Bell, C. (2004). The digital readiness of imaging facilities in Saskatchewan. *Canadian Association of Radiologists, 55*(5), 311–314.

Carrino, J. A., Unkel, P. J., Miller, I. D., Bowser, C. L., Freckleton, M. W., & Johnson, T. G. (1998). Large-scale PACS implementation. *Journal of Digital Imaging, 11*(3), 3–7.

Cartier, M. (1999). The challenge of PACS in a small hospital. *Radiology Management, 21*(4), 23–28.

Chopra, R. M. (2000). Why PACS is no longer a four-letter word. *Radiology Management, 22*(5), 44–48.

Colin, C., Vergnon, P., Guibaud, L., Borson, O., Pinaudeau, D., Perret Du Cray, M. H., Pasquier, J. M., & Tan-Minh, V. (1998). Comparative assessment of digital and analog radiography: diagnostic accuracy, cost analysis and quality of care. *European Journal of Radiology, 26*(3), 226–234.

Cox, B., & Dawe, N. (2002). Evaluation of the impact of a PACS system on an intensive care unit. *Journal of Management in Medicine, 16*(2/3), 199–205.

Duerinckx, A. (Ed.). (2003, March). Introduction to two PACS '82 panel discussions: "Equipment manufactures' view on PACS" and "The medical community's view on PACS". *Journal of Digital Imaging, 16*(1), 29–31.

Erickson, B. (2002). Irreversible compression of medical images. *Journal of Digital Imaging, 15*(1), 5–14.

Farnsworth, T. J. (2003). PACS for imaging centers. *Radiology Management, 25*(3), 36–41.

Foord, K. (1999). PACS: the second time around. *European Journal of Radiology, 32*(2), 96–100.

Foord, K. (2001). Year 2000: status of picture archiving and digital imaging in European hospitals. *European Journal of Radiology, 11*(3), 513–524.

Gamsu, G., & Perez, E. (2003). Picture archiving and communication systems (PACS). *Journal of Thoracic Imaging, 18*(3), 165–168.

Gaytos, D., Speziale, J., Bramson, R., & Treves, S. T. (2003). The PACS pre-implementation process at a major teaching hospital: A multi-disciplinary approach. *Journal of Digital Imaging, 16*(Suppl 1), 73–80.

Grosskopf, E. J. (1998). On the road to PACS: Confronting the issues. *Radiology Management, 20*(5), 26–33.

Hasley, T. (2002). PACS support: The radiology approach. *Radiology Management, 24*(6), 26–30.

Hayt, D. B., & Alexander, S. (2001). The pros and cons of implementing PACS and speech recognition systems. *Journal of Digital Imaging, 14*(3), 149–157.

Hayt, D. B., Alexander, S., Drakakis, J., & Berdebes, N. (2001). Filmless in 60 days: the impact of picture archiving and communications systems within a large urban hospital. *Journal of Digital Imaging, 14*(2), 62–71.

Huang, H. K. (2003). Some historical remarks on picture archiving and communication systems. *Computerized Medical Imaging and Graphics, 27*(2/3), 93–99.

Hunt, D. (1998). Making PACS the present, not the future. *Radiology Management, 20*(5), 35–38.

Hurlen, P., Ostbye, T., Borthne, A., & Gulbrandsen, P. (2010). Introducing PACS in the late majority: A longitudinal study. *Journal of Digital Imaging, 23*(1), 83–94. doi: 10.1007/s10278-008-9160-x

Inamura, K., Umeda, T., Sukenobu, Y., Matsuki, T., Kondo, H., Takeda, H., … Kozuka, T. (1998). HIS/RIS contribution to image diagnosis and maximization of efficacy of PACS when coupled with HIS/RIS. *Computer Methods and Programs in Biomedicine, 57*(1-2), 41–49.

Inamura, K., Konishi, J., Nishitani, H., Kousaka, S., Matsumura, Y., Takeda, H., & Kondoh, H. (2001). Status of PACS and technology assessment in Japan. *Computer Methods and Programs in Biomedicine, 66*(1), 5–15.

Kim, S. A., Park, W. S., Chun, T. J., & Nam, C. M. (2002). Association of the implementation of PACS with hospital revenue. *Journal of Digital Imaging, 15*(4), 247–253.

Krupinski, E., McNeill, K., Haber, K., & Ovitt, T. (2003). High-volume teleradiology service: focus on radiologist satisfaction. *Journal of Digital Imaging, 16*(2), 203–209.

Lawrence, P. (2005). Preparing a cultural strategy for PACS. *Radiology Management, 27*(1), 21–26.

Lepanto, L., Carrier, R., Gauvin, A., Dieumegarde, M., & Delage, M. (2002). Planning an enterprise-wide PACS: the Centre Hospitalier de l'Université de Montréal experience. *Journal of Digital Imaging, 15*(Suppl 1), 252–253.

Levine, B. A., Mun, S. K., Benson, H. R., & Horli, S. C. (2003). Assessment of the integration of a HIS/RIS with a PACS. *Journal of Digital Imaging, 16*(1), 133–140.

Maass, M., Kosonen, M., & Kormano, M. (2001). Cost analysis of Turku University Central Hospital PACS in 1998. *Computer Methods and Programs in Biomedicine, 66*, 41–45.

Maass, M., Kosonen, M., Kormano, M., Chan, L., Trambert, M., Kywi, A., & Hartzman, S. (2002). PACS in private practice — effect on profits productivity. *Journal of Digital Imaging, 15*(Suppl 1), 131–136.

Mackinnon, A. D., Billington, R. A., Adam, E. J., Dundas, D. D., & Patel, U. (2008). Picture archiving and communication systems lead to sustained improvements in reporting times and productivity: results of a 5-year audit. *Clinical Radiology, 63*(7), 796–804.

Marquez, L. O., & Stewart, H. (2005). Improving medical imaging report turnaround times: The role of technology. *Radiology Management, 27*(2), 26–31.

Mulvaney, J. (2002). The case of RIS/PACS integration. *Radiology Management, 24*(3), 24–29.

Naul, L. G., & Sincleair, S. T. (2001). Radiology goes filmless. *Postgraduate Medicine, 109*(6), 107–110.

Nitrosi, A., Borasi, G., Nicoli, F., Modigliani, G., Botti, A., Bertolini, M., & Notari, P. A. (2007). Filmless radiology department in a full digital regional hospital: Quantitative evaluation of the increased quality and efficiency. *Journal of Digital Imaging, 20*(2), 140–148.

Ortiz, A. O., & Luyckx, M. P. (2002). Preparing a business justification for going electronic. *Radiology Management, 24*(1), 14–21.

Pilling, J. R. (2003). Picture archiving and communication systems: the users' view. *The British Journal of Radiology, 76*(908), 519–524.

Protti, D. (2002). What can the American electronic health record (EHR) pioneers tell us about what it takes to be successful? *Healthcare Management Forum, 15*(2), 33–35.

Ravin, C. E. (1990). Initial experience with automatic image transmission to an intensive care unit using picture archiving and communications system technology. *Journal of Digital Imaging, 3*(3), 195–199.

Reed, D. H., Herzog, D. G., & Reed, G. (1996). A visual guide to PACS. *Radiology Management, 18*(4), 20–22.

Reiner, B., Siegel, E., Carrino, J., & Goldburgh, M. (2002). SCAR radiologic technologist survey: Analysis of the impact of digital technologies on productivity. *Journal of Digital Imaging, 15*(3), 132–140.

Reiner, B., Siegel, E., & Scanlon, M. (2002). Changes in technologist productivity with implementation of an enterprise wide PACS. *Journal of Digital Imaging, 15*(1), 22–26.

Reiner, B. I., & Siegel, E. L. (2002). Technologists' productivity when using PACS: comparison of film-based versus filmless radiography. *American Journal of Roentology, 179*(1), 33–37

Siegel, E. L. & Reiner, B. I. (2003). Filmless radiology at the Baltimore VA Medical Center: a 9-year retrospective. *Computerized Medical Imaging and Graphics, 27*(2), 101–109.

Srinivasan, M., Liederman, E., Baluyot, N., & Jacoby, R. (2006). Saving time, improving satisfaction: the impact of a digital radiology system on physician workflow and system efficiency. *Journal of Healthcare Information Management, 20*(2), 123–132.

Strickland, N. H. (2000). PACS (picture archiving and communication systems): filmless radiology. *Archives of Disease in Childhood, 83*(1), 82–86.

Swaton, N. (2002). Learn from experience: insight of 200+ PACS customers. *Radiology Management, 24*(1), 22–27.

Terae, S., Miyasaka, K., Fujita, N., & Shirato, H. (1998). A hospital-wide PACS: 7 year experience and new development. *Computer Methods and Programs in Biomedicine, 57*(1-2), 5–12.

Viau, M. A. (2004). PACS — and beyond. *Radiology Management, 26*(3), 36–40.

Watkins, J. (1999). A hospital-wide picture archiving and communication system (PACS): the views of users and providers of the radiology service at Hammersmith Hospital. *European Journal of Radiology, 32*(2), 106–112.

Weatherburn, G., Bryan, S., Nicholas, A., & Cocks, R. (2000). The effect of a picture archiving and communications system (PACS) on diagnostic performance in the accident and emergency department. *Journal of Accident and Emergency Medicine, 17*(3), 180–184.