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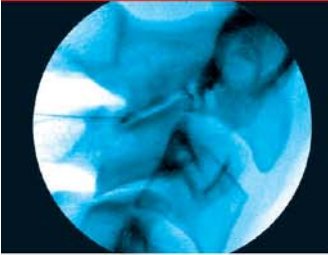
The implications of digital imaging for clinical practice

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Introduction

The introduction of digital imaging over 30 years ago has dramatically broadened the clinical applications of radiology. Not only have new radiological modalities emerged, making it possible to study finer anatomical details, elucidating pathology as well as function, but the workflow in radiology departments has also been revolutionized.

The Picture Archiving Communication System (PACS) concept was first proposed in 1982. The expectation was that it would solve most of the problems of conventional radiology by allowing efficient image management and thus achieving organizational and economic advantages, ultimately improving patient care. In reality, things were not so simple, mainly because the technology of the time was too immature to allow the implementation of filmless operations within hospitals.

PACS evolution

The paradox of first-generation PACS was that these systems were planned by a technologically motivated computer scientist at a time when information technology resources were still painfully inadequate for meeting the stringent requirements of the practice of radiology. Other reasons contributing to the failure of first-generation PACS were the legal framework in many countries (which were unprepared to cope with the novelties of the digital revolution in medicine), widespread customer dissatisfaction with the rudimentary systems that were initially introduced to the market and - last but not least - the high cost of the systems.

The evaluation of health care costs is not an easy subject and there are several areas of controversy. These include the determination of benefits (both payable and intangible) and the inclusion of indirect (or 'hidden') costs and benefits. When evaluating PACS,

the most common pitfall is to calculate costs and estimate savings taking into account only the radiology department. This narrow evaluation will reveal only that a changeover to digital systems entails additional costs, with very few savings to be expected (savings in films alone are of course insufficient to justify the massive investment needed to implement PACS from scratch). However, such an evaluation neglects the substantial savings in terms of the increased overall efficiency of the health care institution that can be achieved thanks to the integration of the digital management of all clinical data (including images).

Moreover, there is a rather intriguing and peculiar economic situation in medicine. In all other economic sectors, such as industry, banking or insurance, investments in information technology lead to an increase in productivity and ultimately to greater profits. In medicine, on the other hand, the investment in information technology seems only to increase the costs, since the revenues of hospitals are largely independent of their productivity.

Many things have changed since the early years of PACS. Today powerful personal computers have replaced the more costly UNIX machines and provide adequate computing platforms for almost all medical applications. Storage media have evolved, giving us the opportunity to archive a huge amount of data at only a fraction of the cost of a few years ago. Network technology has been revolutionized, with a marked increase in the available bandwidth and a progressive convergence of local area networks and wide area networks, as well as the introduction of wireless and mobile telecommunication. Standards such as Digital Imaging and Communication in Medicine (DICOM) and Integrating the Healthcare Enterprise (IHE) (Figure 1) have finally made it possible to achieve multi-vendor inter-operability across hospital information systems. Both national and European laws have evolved taking account of new issues such as digital archiving, the

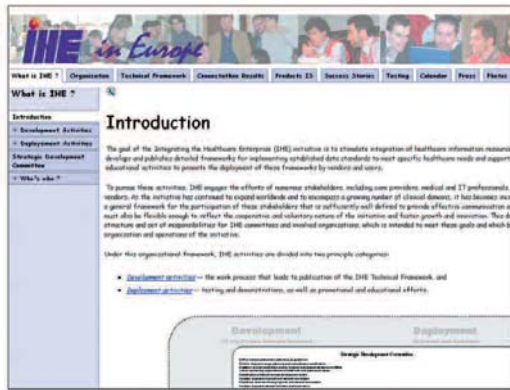


Figure 1. The Integrating the Healthcare Enterprise (IHE) website: www.ihe-europe.org

existence of databases containing confidential information and the importance of privacy and security in the digital environment.

All these important changes were prerequisites for the development of the second-generation PACS that have now proven successful in the clinical domain. Today technology is no longer a limiting factor, as high-performance networks are available, standards are universally accepted and national and international laws have been modified to meet the needs arising from the digital revolution.

Radiological reporting

The production of the report is one of the main goals of the entire radiological process and PACS has a relevant (and rapidly evolving) role in this area.

The introduction of soft-copy reporting and voice recognition has changed the way radiology is practised. However, there are still questions that need to be fully addressed, such as the diagnostic performance of the radiologist (i.e. reduction of mistakes) and ergonomics (i.e. workstation fatigue), among others.

Without soft-copy reporting, it would not be possible to read effectively the large volumes of data produced by up-to-date acquisition modalities, nor would we have experienced the seamless integration of advanced image processing, 3-4-5-D image analysis, multimodality image fusion, treatment planning and computer-aided diagnosis into the radiological workflow (Figure 2). Finally, reporting at the PACS workstation has made it possible to foresee the systematic use of structured reports, with the potential for reducing the indeterminate nature of many radiological reports, making the information included in our reports 'databasable' items that must be entered unambiguously in order to facilitate all kinds of 'data mining' at a later date.

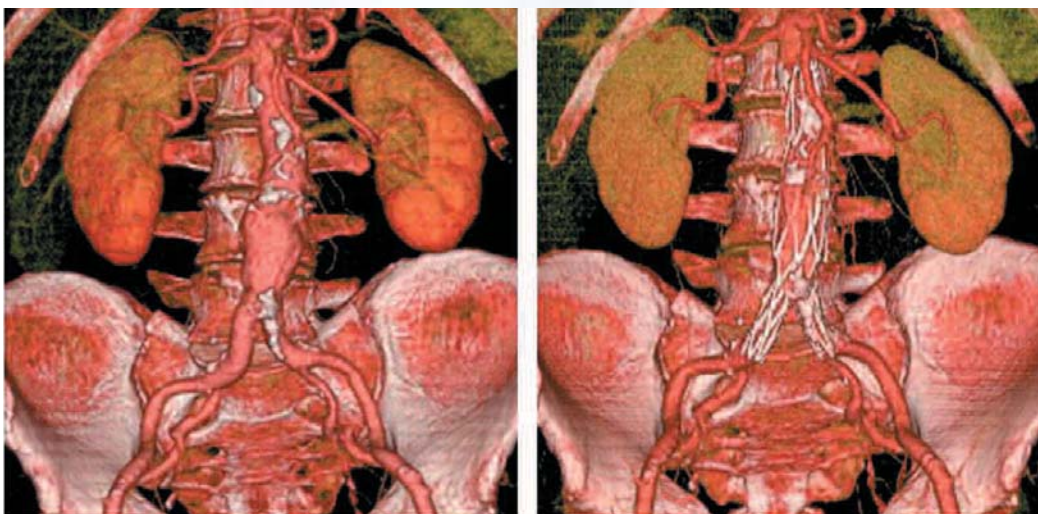
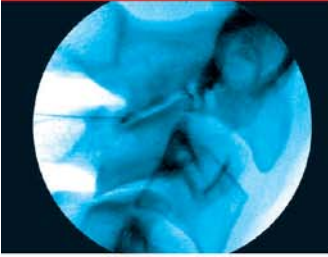


Figure 2. Image processing in vascular imaging and interventions.

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The impact of these structural changes on the outcome of the radiological process has not yet been fully understood. There is a risk that radiologists will be but passive acceptors of the changes being imposed by technology, rather than being active in planning for changes and steering their implementation. The structured report will change the way radiologists interact with referring colleagues, streamlining the information flow. PACS has already changed this complex relationship - for example, with the distribution of electronic images within hospitals it is clear that the pattern of utilisation of images by clinicians has changed but the details of these changes are still to be fully elucidated.

Radiologists may claim that they provide added value to clinicians by expediting the distribution of images and reports throughout the hospital. But how is this quantified? Have outcome studies been published that justify this assumption? Has the potential for more efficient hospital-wide PACS-mediated information-sharing to reduce medical errors and achieve better patient care been realized?

The distribution of radiological images is no longer confined within the hospital, since in many instances regional PACS are emerging as the best solution for a rapidly consolidating health care sector. This trend will make the term 'teleradiology' obsolete, since teleradiology is progressively becoming just another function of PACS. From a technical point of view, image distribution has been implemented using the web architectural model or the integration of off-line devices, such as CDs, which are often involved in communication with general practitioners. Moreover, many innovative products from the consumer market (e.g. latest-generation mobile phones, tablet PCs, hard drive-based devices) may be tested and adopted for improving the distribution of radiological data.

One interesting business model developed in the service industry (e.g. travel, insurance and banking) that is usefully being adopted by radiologists is ASP (Application Service Provider). An ASP operates software at its data centre that customers access on-line under a service contract. In radiology this can easily be applied to the archive, which can be 'outsourced' to an ASP vendor (Figure 3).

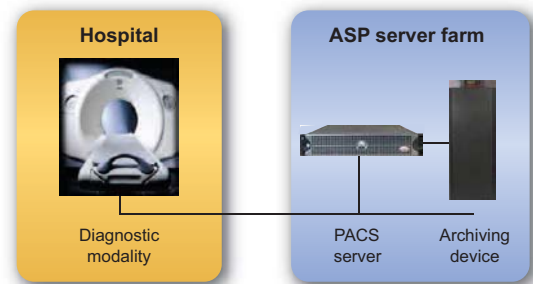
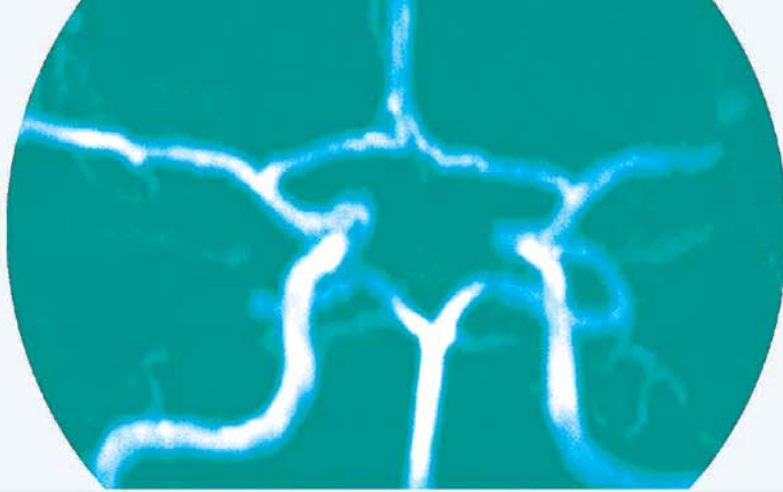


Figure 3. Outsourcing to an Application Service Provider (ASP)

Future of PACS

Radiologists are medical professionals who work with images. However, many other medical disciplines are based on imaging or require doctors to conduct image-intensive tasks (surgery, for example). Most PACS include nuclear medicine and radiotherapy, but a great deal of investigational effort will be necessary to define and then meet the specific requirements for integrating pathological images (interactive display of the microscopic fields), endoscopic images (video sequences) and dermatological images into the PACS environment. And still more research will be needed to specify and implement so-called 'surgical PACS'.

All hospitals with PACS have experienced their ability to improve the quality of teaching, both in terms of continuing medical education (e.g. clinico-radiological conferences) and in the specific area of radiological training. The availability of large numbers of images and



amounts of clinical data allows ready access to pathological examples, facilitates the construction of multimedia teaching files and prepares physicians to use the powerful resources of e-learning.

We have recently witnessed an impressive increase in the radiological resources available on the Internet, many of which are maintained by universities or by ad-hoc organizations that have gained great visibility on the Internet (examples include AuntMinnie.com, Medcyclopaedia™ [<http://www.amershamhealth.com/medcyclopaedia/medical/index.asp>] and CTIsus.com). There have been concerns about the diffusion of medical information on the Internet, mainly due to the potential presence of unchecked errors and to the possible misuse by patients of complex medical data. One interesting approach comes from EURORAD, the e-learning initiative of the European Association of Radiology. It has made over 1,500 peer-reviewed teaching files (many of them translated into French and Spanish) freely accessible at www.eurorad.org (Figure 4).

The local radiological archive has ceased to be solely a store for previous examinations kept for legal reasons but has become an active repository of our professional

knowledge that is updated at every encounter with the pathologies that we correctly diagnose. In the book *PACS and Imaging Informatics*, H K Huang has recently introduced the intriguing concept of a medical imaging informatics infrastructure that is designed to take advantage of existing PACS resources, and their image and related data, for large-scale horizontal and longitudinal clinical service, research and education applications that, due to insufficient data, were not previously possible.

This is the future of PACS: one in which traditionally separate decision-support modules will be fully integrated, as well as new developments in the areas of improved reporting strategies, optimized distribution of radiological information to referring doctors and knowledge management applications ranging from e-learning to computer-aided diagnosis.

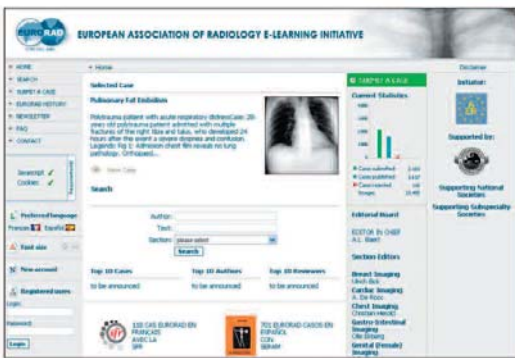


Figure 4. The website at www.eurorad.org