J HK Coll Radiol 2002;5:3-13

REVIEW ARTICLE

Digital Radiology: A Decade of Clinical Experience

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ABSTRACT

The world's first entirely digital radiology system was planned in 1988 and implemented in 1992 in the Danube Hospital of the Socio Medical Care Centre East in Vienna, Austria. An overview is provided of a decade's experience in digital radiology, and of the various considerations in implementing such a system.

This experience has proven that the principal advantage of digital radiology is reliable and rapid access to all relevant medical information. This saves time, speeds up report turnaround, and results in better diagnosis, since the timeliness of delivery of the diagnostic outcome is as important as its accuracy.

The last decade has shown that digital radiology is an excellent working clinical tool for improving healthcare delivery. Furthermore, it has the potential to become even more useful, as the focus shifts from simply saving film to increasing institutional productivity and efficiency.

Key Words: *Digital radiography, Information system, hospital, Hospital radiology department, Information system, management, PACS (radiology), Radiology information systems, Trauma centers*

INTRODUCTION

Clinical experience in digital radiology, including intra- and interhospital communication, has been documented in the literature since the late 1980s. The world's first strictly digital radiology system was planned in 1988 and implemented in 1992 at the Danube Hospital, part of the Socio Medical Care Centre East (SMZO) in Vienna. The objectives of this project were primarily to overcome the inherent problems of film-based systems, eg the loss of films, as well as to improve the efficiency and speed of patient data management, image acquisition, image distribution, archiving, and reporting.

The implementation of an integrated digital radiology system was expected to improve the quality of research and patient care, and to support administrative tasks in connection with the radiology (RIS) and hospital (HIS) information systems. Thus, not only the efficiency of the radiology department, but of the entire hospital, would be improved.

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Submitted: 17 July 2000; Accepted: 18 September 2001.

HISTORY OF THE PROJECT

The Danube Hospital is part of the Socio Medical Care Centre East (SMZO) in Vienna, which comprises, besides the hospital, a geriatric nursing home with 405 beds, a geriatric daily care centre, and a nursing school, as well as 500 personnel dwellings. The SMZO is the central authority for medical and social services in the eastern part of Vienna (Figure 1, Table 1).

Planning for the radiology department started in 1988. The decision to implement a strictly digital system was made in primary consideration of the qualitative benefit for the patient. A further objective was the improvement

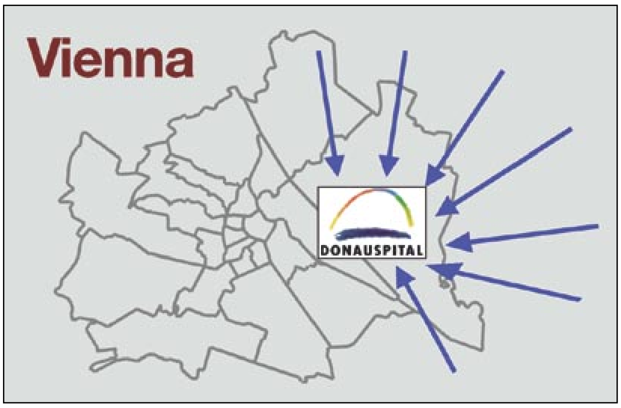


Figure 1. Service area of the Socio Medical Care Centre East (SMZO).

Table 1. General data on service delivery.

Metropolitan area (population)	1,800,000
Service area (population)	250,000
Average number of beds in system	933
Number of beds in the geriatric nursing home	405
Personnel	3,009

of departmental and hospital-wide efficiency, through the automated dispatch of image and examination report data. The potential for teleconsulting (eg for consultations between radiologists and referring physicians in cases with abnormal findings) was a strategic target pursued from the outset. Economic factors were of course also of key importance to the financial providers of the city of Vienna; as was subsequently demonstrated, the costs of digital radiology were, despite its substantial qualitative advantages, no higher than those of conventional radiology.

After determination of the medical and radiological specifications the project became subject to competitive bidding. From a technical point of view, 2 principal problems/challenges arose in the context of digital radiography, namely, the challenge for image data transmission and storage, and the challenge of interfacing all subsystems and modalities. From a medical point of view, the principal challenge was for reporting workstations and their software to be able to handle at least all tasks known from conventional film reading procedures. The main hardware prerequisites were sufficient spatial resolution and luminance intensity. The workflow (software) prerequisites were, for example, display of present and previous examinations in a way suited for comparison, display of patient demographics and clinical information, etc.

Installation began in the summer of 1991. Following the implementation phase, a 6-month test run was commenced as a phantom operation, the purpose of which being to optimise the newly applied technology for practice, and to check digitally-supported local organisations and communications for system consistency. A further goal of the test operation was the determination of parameters for quality control and quality assurance, and thus, the exact documentation of exposure doses in the context of digital radiography compared with film-screen radiography. These data were analysed and documented in relation to economic and ecological criteria, as well as legal requirements for radiation protection. Successful termination of this simulation was the prerequisite for introduction of the system into daily clinical practice.

NATURE OF THE SYSTEM

Today's Technology

A filmless radiology department within a filmless hospital has been achieved. Our current status is the result of constant adaptations to changing needs within the hospital, and to changes in information technology (IT) and the technology of imaging modalities. The structure of the network and archive configuration have remained unchanged since the initial planning period. New imaging devices have been added or replaced over the years.

Digital Archive

The digital archive (Figure 2) serves both the Picture Archiving and Communication System (PACS) and the Radiology Information System (RIS), and is the electronic counterpart of a conventional film archive, including radiological reports. The unique master of the digital archive is the so-called Patient Directory (PDIR) database. Following the PDIR database in hierarchy are 3 Information Management Systems (IMSs). The IMS form modules consist of an IMS database-workstation, a Redundant Array of Independent Disks (RAID), and up to 2 jukeboxes with Magnetic-Optical Discs

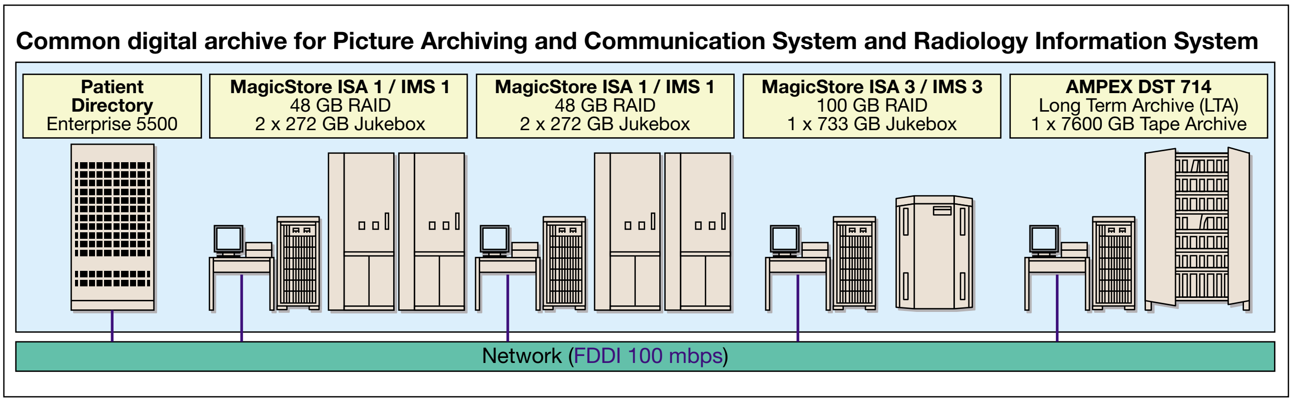


Figure 2. Digital archive in the radiology department.

(MODs). IMS modules can be added freely to the system, and this modular structure allows extension and adaptation of the archive to meet the increasing requirements of the radiology department. The last level of storage hierarchy — the recently-integrated Long Term Archive (LTA) — ensures additional availability and security of data.

In the PDIR, patient demographics, clinical information, and radiological reports are stored according to a relational database model (structured query language [SQL] database [Sybase, Inc., Dublin, CA 94568, USA]). The PDIR is normally used from the PACS and the RIS, and contains only the reference to the relevant digital images from every examination.

Modalities and Workstations

The extent and complexity of the hospital-wide digital network, as well as the digital modalities and workstations in use, are shown in Figures 3 to 5 and Table 2.

Radiology Department

In the main radiology department (Figure 3), RIS terminals (PCs) are installed in the reception, adjacent to all modalities, adjacent to all reporting workstations, and in the transcription office, allowing complete documentation of the radiological workflow.

Reporting workstations in the radiology department are equipped with 1, 2, or 4 monochrome landscape-size monitors, depending on the needs of the examination type assigned to them. All are integrated to the PACS via a fast fibre distributed data interface (FDDI) connection. Images from different modalities are auto-routed to specific reporting workstations, but are also available for retrieval from the digital archive, and can be retrieved from any workstation in the radiology department. In the main reporting room, one 4-monitor workstation is used for skeletal examinations, and 3 dual-monitor workstations are used for other conventional X-ray examinations. Several additional workstations in a second reporting room provide redundancy in the event of technical problems or high workload, and are also used by radiographers for quality control (ie review and preparation of images for reporting). Additional workstations are placed in the CT examination room, in the MRI room, in the ultrasound room, and in the radiographers' central working area. A demonstration workstation, connected to a video unit, is used for case conferences with referring physicians.

Table 2. Technical summary of the integrated hardware in the radiology department.

Diagnostic workstations	
6	MagicView 1004
22	MagicView 1002
17	MagicView 300
1	Leonardo AX Workstation
1	3D Virtuoso
Viewing workstations	
48	MagicView 50
Storage and archive	
1	PDIR Enterprise 5500
3	MagicStore RAID (2 with 48 GB each, 1 with 100 GB)
4	Jukebox (272 GB each, 1.7 GB WORM media)
1	Jukebox (733 GB, 4.8 GB WORM media)
1	Ampex DST 714 Long Term Archive (7,600 GB, 100 GB tape media)
Image documentation	
1	Camera server with Sterling LP400
2	MagicRead
2	Sterling Solid Inkjet 400 (Post Script Level 2)
Modalities (networked)	
Siemens Somatom Plus 4 Power (CT)	
Siemens Somatom AR.T (CT)	
Siemens Magnetom Impact Expert (MRI)	
Siemens Angiostar Plus, Polytron TOP (DS)	
Siemens Angiostar, Polytron 1000VR (DS)	
Siemens Sonoline Elegra (Ultrasound)	
Kretz-Technik VoluSon 530D (Ultrasound)	
2 Siemens Siregraph D1, Fluorospot H (DF)	
Siemens Iconos, Fluorospot TOP (DF)	
Siemens Thorax FD, Polydoros Lx50 Lite (Flat Panel Detector, CR)	
2 Siemens Digiscan 2 (CR)	
Siemens Digiscan 2C Plus (CR)	
Siemens Digiscan 2H Plus (CR)	
Siemens Polystar, Fluorospot H (DF)	
Siemens Uroskop D3, Fluorospot H (DF)	
Siemens Bicor (DS)	
Other	
48	SIENET MagicSAS RIS PCs
Interface to HIS of City of Vienna	

Abbreviations: CR = computed radiography; DF = digital fluororadiography; DS = digital subtraction angiography.

Images from all modalities are either sent directly to the PACS (eg CT, MRI, ultrasound, angiography, coronary angiography, digital fluororadiography [DF], etc), or are sent to the PACS semi-directly through the 2 computed radiography (CR) readers installed centrally near the radiographic rooms (eg digital radiography [DR], mobile DR, etc). One film digitiser and 2 film printers (laser and wax) are used for importing images from outside the hospital, and printing images for designated outpatients, respectively.

Trauma Centre

The trauma centre can be considered a high-speed microcosm of the radiology department including its referring departments (Figure 4).

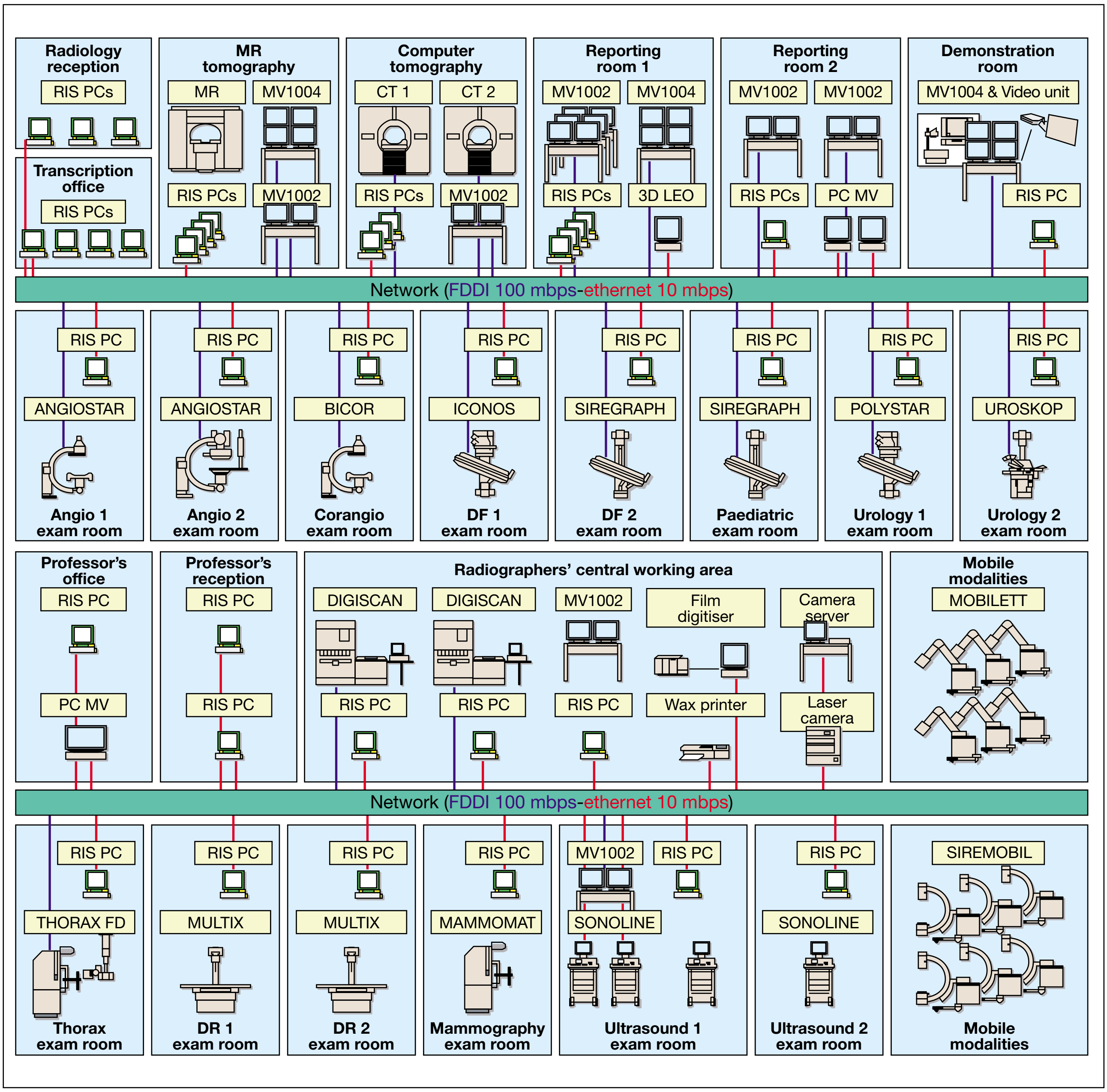


Figure 3. Digital network, modalities, and workstations in the radiology department.

The radiology sub-department in the trauma centre is equipped with 2 DR modalities and 2 CR readers, and is completely integrated within the PACS and the RIS of the main radiology department. This allows for image, report, and workflow communication between the main radiology department and its sub-department, as well as workload dispatch in emergency.

As in the main department, a quality control workstation is used for the review and preparation of images. A demonstration room workstation, including a video unit, is used here also for case conferences. A film digitiser and a wax printer are used for importing and exporting images from and to radiologists without digital technology. As for referring departments, all referring examination rooms are equipped with viewing workstations, depending on their needs.

Referring Departments

All referring departments directly related to and relying on radiological examinations (Figure 5) are equipped with viewing workstations. These are either standard (reporting quality) workstations, as in the radiology department, equipped with 1, 2, or 4 high-resolution monitors, or PC-based viewing workstations with 1 or 2 standard PC monitors. The number and quality of

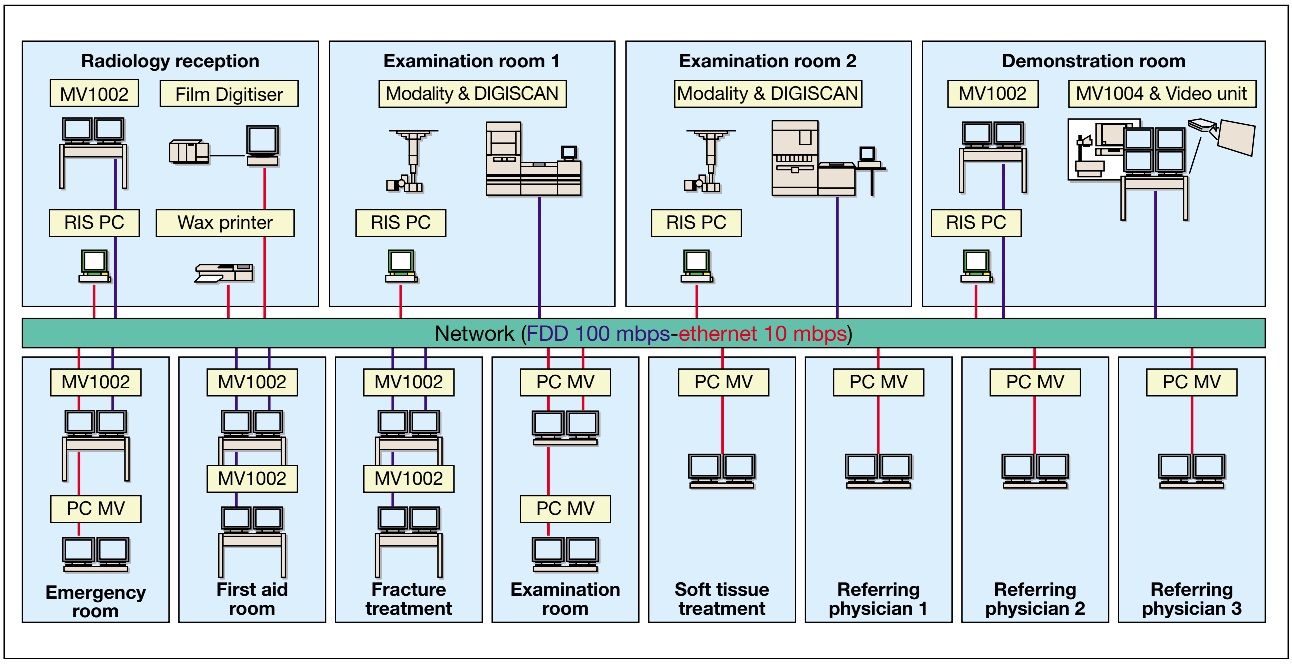


Figure 4. Digital network, modalities, and workstations in the trauma centre.

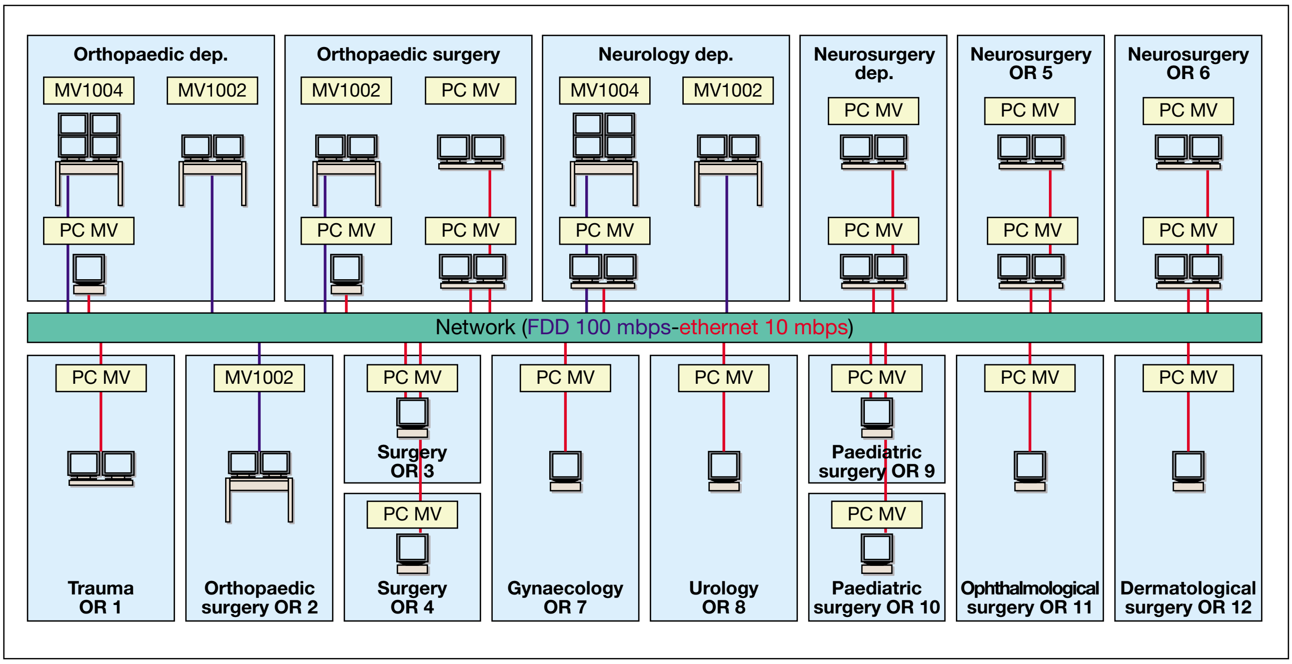


Figure 5. Digital network and viewing workstations in referring departments.

workstations, as well as the monitors installed, depends on the actual needs of the departments, based on many years of clinical practice with digital radiology.

GROWING WITH INCREASING NEEDS

The average data-volume per study is constantly increasing, as there is a clear tendency towards higher-resolution images, thinner slices in cross-section imaging in general, and additional sequences in MRI imaging. Images digitally archived over the last few years consume a storage capacity of over 6.5 million megabytes (MB).

The increasing number of patients per year, and increasing number of examinations per patient, also contribute towards a greatly increased number of new images each month (Table 3). This was foreseen when the network and central archive were set up. The network technology was already available at this time and no

Table 3. Number of examinations and patients during the last 4 years, indicating continuous growth.

Number of examinations (patients)/modality	1997	1998	1999	2000
CT	6,600 (6,273)	8,371 (7,147)	8,468 (7,685)	9,363 (8,422)
MRI	4,087 (3,621)	4,864 (4,235)	5,201 (4,526)	5,365 (4,570)
Trauma	53,447 (37,794)	53,807 (38,730)	58,442 (46,271)	59,812 (42,267)
Others	66,851 (59,090)	71,799 (59,087)	64,714 (56,131)	63,582 (53,731)
Total	130,985 (106,778)	138,841 (109,199)	136,825 (114,613)	138,122 (108,990)

alteration has been required. The eventual need for increasing archive capacity was also clearly foreseen, but the requisite technology was not available at the time of implementation of the system. From the outset it was clear that the system would need to grow with increasing clinical demands. For this reason, the complete system was designed in a modular concept, allowing exchange and replacement of outmoded components without any significant changes to the structure.

Unforeseeable future changes, such as new imaging techniques, should not pose a significant problem for a digital radiology system; this is an essential reason for implementing a flexible system that can accommodate future requirements. Rapid developments in IT made it possible for our hospital to switch from specially designed hardware to commercially available workstations in 1997. This was one of the major steps in improving cost-efficiency. During the first decade, archiving costs have dropped significantly, as the price of long-term digital archive media has fallen markedly.

RADIOLOGY INFORMATION SYSTEM

The development of a RIS that serves as the master of the imaging part of the digital radiology system was one of the major steps in the improvement of time-efficacy, because practical automation of workflow depends on the integration of sub-systems.

The newly integrated RIS represents a new generation of administration systems; it is a comprehensive, easy-to-use system, modelling optimal workflow within the radiology department together with the PACS. The client-server architecture with a Windows® user interface, together with the common database for the RIS and PACS, provide the following advantages:

- An integrated database, ie no interface between RIS and PACS. No special implementation work during software updates necessary.
- Guarantee of data consistency (eg when modifying patient data).
- Common data backup for all PACS and RIS components.
- Less work for system administrator due to the use of a common database.
- Control of the pre-fetch and auto-route mechanism via the PACS. The relevant images are automatically loaded from the archive and sent to the reporting workstation.

The functionality of the RIS reflects the entire administrative workflow within the radiology department (see below), including:

1. **Communication:** Examination requests are interfaced from the HIS. Verified reports are interfaced back to the HIS, including billing information.
2. **Scheduling:** Examination requests are planned for a certain date, time, and modality, considering availability of resources.
3. **Examination:** Documentation of the examination performed, and additional data such as contrast media used, exposure dose, complications, etc.
4. **Reporting:** Assists the reporting radiologist by providing information not readily available in the PACS (eg clinical data, examination request forms). Facilitation of report transcription and verification.
5. **Analysis:** Management of cases for scientific work, statistical analysis, and documentation (eg the information in Table 3).

Workflow — Example of an Examination

Before Examination

The examination request is booked electronically at the HIS terminal (Figure 6) in a referring department, and consists of the obligatory patient demographics, preferred date and time of the examination, and examination type. The examination request is then transferred automatically, via a proprietary interface, to

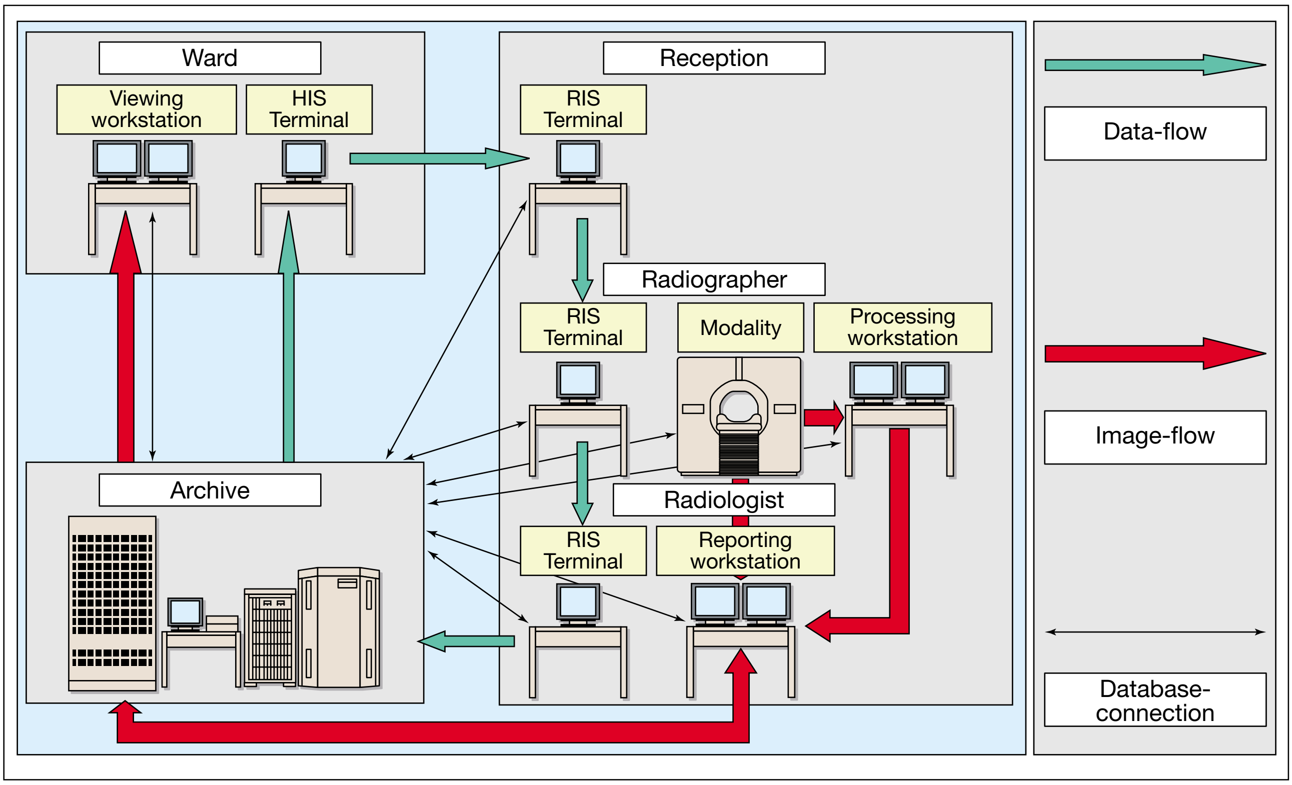


Figure 6. Diagrammatic representation of workflow and dataflow of an examination.

the common database for RIS and PACS (PDIR). Triggered by this input the PDIR allocates all relevant previous images, according to specified rules, and initiates pre-fetching and auto-routing. Thus, where possible, examination requests are booked 1 day before the examination, as this facilitates overnight pre-fetching and auto-routing.

At this point, radiographers or clerical staff schedule and specify the examination 'open' (Figure 7) at an RIS terminal and, depending on the scheduled modality, the examination request appears on the relevant RIS workflow list, with the examination status 'planned'. For conventional X-ray modalities, the same workflow list is also displayed on the CR reader's console. For modalities supporting 'DICOM Worklist', the worklist is displayed on the modality's console. The common database for RIS and PACS guarantees data consistency between these worklists.

During Examination

When the patient arrives for the scheduled examination, he/she is checked in at the reception and the examination room worklist is updated. The patient is then examined according to the information entered in the examination request. During and after examination, information such as number of CT slices, X-ray dose, staff involved, etc, is recorded in the RIS, and is available for statistical analysis and documentation. Additionally, while the patient is passing through the department, the staff involved may enter comments on the electronic request form, which may be helpful to the reporting radiologist. The examination form is then signed by the radiographer, and disappears from the 'planned' RIS worklist, now having the status 'done'.

After Examination

Images acquired from conventional X-ray modalities are routed to a designated quality control workstation,

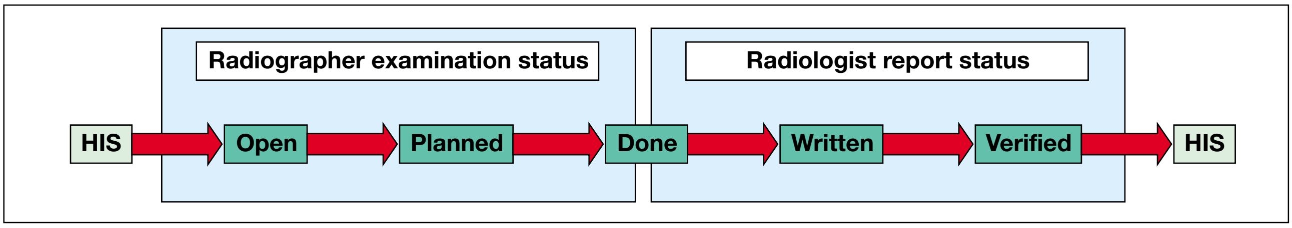


Figure 7. Diagrammatic representation of examination and report status in the Radiology Information System (RIS).

optimised by a radiographer, and then auto-routed to a specified reporting workstation. Images acquired from direct digital modalities (CT, MRI, ultrasound) are auto-routed directly to a reporting workstation. All relevant patient and examination information, as well as all previous images, are of course also accessible at this workstation. To the reporting radiologist, it is clear at a glance what work is required, since all 'done' examinations are displayed on his/her personal RIS worklist. The radiologist then reports the examination, the status of which status changes after typing and verification to 'written' and 'verified', respectively. Finally, the signed report, with all relevant information, is automatically sent back to the HIS via the same interface. The referring physician at the ward can now initiate treatment as he/she has obtained all relevant information at his/her HIS terminal, and all relevant images at his/her viewing workstation.

SYNERGISTIC EFFECTS OF DIGITAL RADIOLOGY

Benefits of Digital Radiology

Digital radiology allows the functional integration of physically separated systems, centralised archiving and image display, rapid access to images from multiple locations, and effective image communication. Since the beginning of this new digital era in radiology in 1992, some years have passed, and it is now possible to demonstrate and prove the benefits that evolve from the implementation of these digital technologies. Computerised diagnostic equipment provides new capabilities for radiologists. It provides improvement of the workflow within the department, the exchange of information between radiologists and referring physicians, and the exchange of information between radiologists specialised in specific diagnostic procedures. This exchange of information is possible locally within the department, between different departments, and even between widely separated buildings in different hospitals.

Eliminating film as the radiological medium, with all its well-known limitations, was only possible due to the development of diagnostic monitors with high contrast and brightness, and radiological consoles equipped with high-resolution formats. Digital radiography separates the acquisition medium and the viewing medium, and permits different image representations by insertion of computerised processes (pre-processing, post-processing) between the actual radiograph at the acquisition medium and the radiograph represented on a hard copy or a monitor. In addition, digital radiography provides direct advantages in the generation and production of plain X-rays, using photostimulable phosphor plates, which have a much wider latitude than conventional films — thus allowing more tolerance in the exposure parameters, resulting in a more consistent image quality without the need of avoidable re-examinations. Depending on the diagnostic question, it is also possible to reduce the exposure dose, particularly if dynamic investigations are performed, where spatial resolution is not so important and some image noise may be tolerated. (Where high spatial resolution is necessary, eg in searching for subtle signs of arthritis, dose reduction in digital radiology is less practicable.) Another substantial advantage is the ability to alter the window and level of an X-ray, so that both soft tissues and bone structures can be assessed on the same image, whereas in a film-based system 2 exposures would be necessary. The same is true for the elimination of re-takes due to lost films. Further improvement can be expected by the implementation of new flat panel detector technology based on amorphous semi-conductors.

Faster access to imaging data, and the elimination of the need to search for old films, have resulted in increased departmental efficiency. The quality of diagnosis depends not only on its accuracy but also on its time of delivery, so that the correct treatment can be initiated as early as possible. Digital radiology thus contributes to the quality of healthcare, in that a faster report cycle time means better treatment (Figure 8). Although precise data are difficult to obtain, digital radiology is clearly an essential factor in reducing the average length of stay in hospital. In comparison with other Austrian hospitals, the Danube Hospital has the lowest hospitalisation time of 7.1 days. The average cost of radiology services is also remarkably low compared with other Austrian hospitals. Moreover, the advantages of digital over conventional archiving produce savings

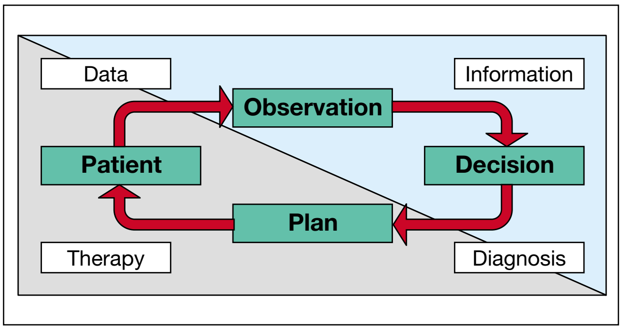


Figure 8. The diagnostic-therapeutic cycle.

Table 4. Advantages of a digital archive.

	Digital archive	Conventional archive
Space	10 m^2	900 m^2
Loss of films	-	5-20%
Image access	Fast/easy	Slow/difficult
Communication	Online	-
Costs	Low	High
Staff	Few	Many

in materials, hospital space, and personnel, which although not measurable are obvious (Table 4).

Finally, the fact that an increase in the number of patients and services in our department (Table 3) did not necessitate an increase in staff numbers, shows that the stepwise implementation of newer technology resulted in increased efficiency.

TELECONSULTATION IN RADIOLOGY

In essence, teleconsultation consists of obtaining expert advice from colleagues when the physician is confronted with especially difficult or rare cases. The term also denotes the transfer of information concerning a specific patient for the purpose of comparison, and for establishing the diagnosis or making decisions about therapy. The transfer of medical data and images to elucidate written medical reports is also within the realm of teleconsultation.

The World Medical Association recognises that, in addition to the positive consequences of teleconsultation, there are many ethical and legal issues arising from these new practices. Notably, by eliminating a common site and face-to-face consultation, teleconsultation disrupts some of the traditional principles governing the physician-patient relationship. Therefore, there are certain ethical guidelines and principles that must be followed by physicians involved in teleconsultation.

As the technical requirements for teleconsultation are particularly advanced, especially in the field of radiology, the Austrian Radiological Society established a working group to review the current requirements and legal and structural prerequisites for teleconsultation. Based on the results of this investigation and a legal expert report, 5 guiding principles were formulated in early 1998:

- Telecommunication and teleconsultation improve the quality of medical services.
- Teleconsultation is an additional service.
- Teleconsultation is no substitute for specialised medical care.
- The immediacy of medical action must be ensured.
- All hospitals must have a specialist (radiologist) on call.

Teleconsultation is only meaningful if it provides improved service for the patient. It is therefore important to formulate basic conditions for the use of this technology so that the user retains freedom of choice. Fulfilment of the physician's social and legal obligation to act immediately should not be jeopardised. Only if this requirement is fulfilled can 'networked medicine' develop to optimise medical diagnosis and therapy for the benefit of the patient.

INTEGRATING THE TRANS-DANUBE HEALTHCARE ENTERPRISE

The trans-Danube healthcare enterprise provides medical and social services ensuring comprehensive healthcare for all patients in eastern Vienna, and forms an addition to or an extension of the cooperation of the hospital network (KAV) with the home care network (MA47) in Vienna. The core of this healthcare enterprise, also known as the Regional Alliance/Donaustadt, is the Danube Hospital of the SMZO. The project-target of integrating this healthcare enterprise is to provide comprehensive healthcare through a close network comprising the Danube hospital, the health centre of the district, resident physicians, and all attached extramural services (Figure 9).

The project is divided into 4 sub-sections. While each of the sub-sections is independently functionally effective, their synergetic effectiveness is far greater, in terms of:

- optimisation of hospital admissions
- optimisation of hospital discharges
- coordination of the extramural services, and
- electronic networking of all institutions and services.

IMPORTANCE OF TECHNICAL SUPPORT

The technical support of a digital radiology system is divided into 2 primary areas: user support and system support. In our department, 2 designated helplines (1 for PACS and 1 for RIS) operate during normal office hours, and supply competent solutions to user and system problems. The 2 system administrators manning these helplines are certified in terms of the service contract with the vendor.

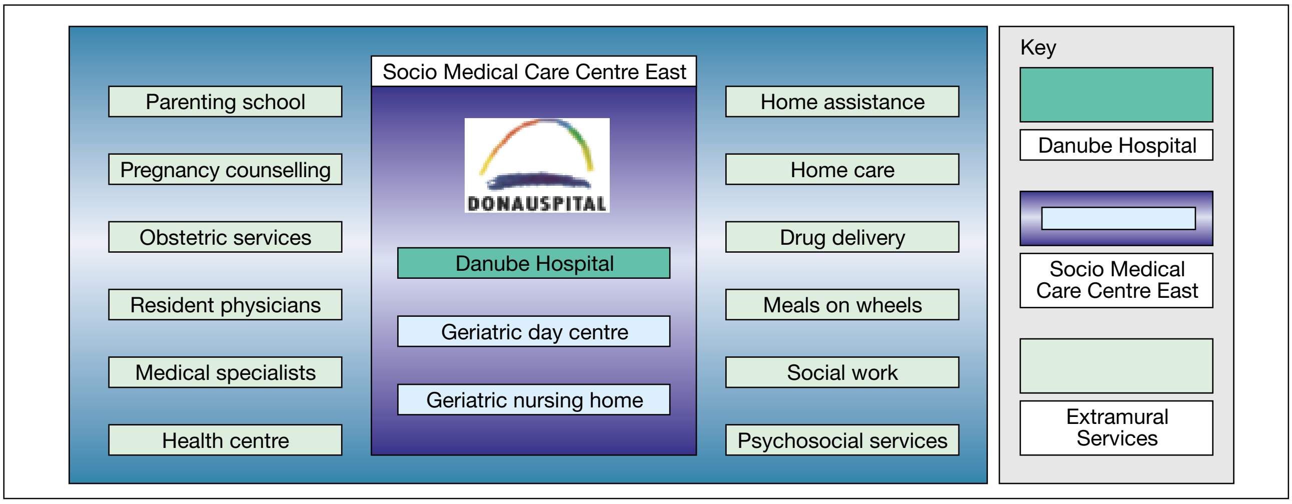
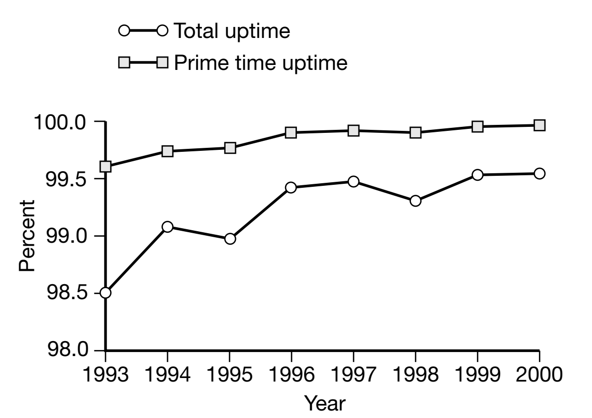


Figure 9. Structure and services of the trans-Danube healthcare enterprise.

Users must be trained to be competent in operation of all functions. After initial training in small groups, further refresher training is provided 'on request'. Routine system support and monitoring is needed to ensure effective operation. Therefore, the entire system is constantly monitored for minor malfunctions, which can be rectified before workflow is impaired. If immediate repair is not possible, the system administrators are immediately informed and a graded response sequence initiated, depending on the seriousness of the malfunction. Most system-dependent errors can be repaired within a short time by the administrators; if not, an expert team is always accessible on the vendor's helpline. The vendor's hotline, together with the hospital IT hotline, is available at all times.



	1993	1994	1995	1996	1997	1998	1999	2000
Total uptime	98.52%	99.09%	98.97%	99.43%	99.49%	99.32%	99.53%	99.54%
Prime time uptime	99.60%	99.74%	99.77%	99.91%	99.92%	99.91%	99.95%	99.97%

Definitions: Uptime: time with full archive availability and no major disruption of clinical workflow; Prime time: Mon-Fri 7:30 am-1:30 pm.

Figure 10. Increase in uptime and prime time uptime throughout years of clinical operation.

Because of high system stability and competent technical support, a workflow impairment of 20 minutes' duration during office hours, or 40 minutes during the night or at weekends, would be considered critical. In the trauma centre's radiology department, reflecting the higher priority of its work, these figures are 15 and 30 minutes, respectively. Finally, it is important to report that, in the past 5 years (Figure 10), system downtime during prime time was less than 0.05% (a part of which was planned and announced service downtime), during which the clinical operation of the department was never compromised. [*Note:* Downtime = planned or unplanned lack of archive availability or major disruption of clinical workflow.]

VENDOR SELECTION — UPGRADE FREQUENCY

Since any digital radiology system is clearly not a 'plug and play' system, the selection of a vendor must be made with due consideration of project responsibility, standardisation, compatibility, and ease of upgrading and updating, as well as service and maintenance.

Over the last few years, frequent system upgrades proved not only necessary, but also effective with regards to cost and operating efficiency. The choice of a major vendor was an advantage, in relation to both the development of new technology, and service and maintenance.

CONCLUSION

The principal advantage of digital radiology is reliable and fast access to all relevant medical information. This reduces the time to produce reports, and results in better diagnosis, since not only the accuracy, but also the timeliness of delivery of the diagnostic outcome is crucial to the success of the therapeutic encounter.

The last decade has proven that digital radiology is an excellent working clinical tool to improve healthcare delivery. Furthermore, it has the potential to become even more useful, as the focus shifts from simply saving film to increasing institutional productivity and efficiency.

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