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Reality and perspectives in teleradiology: a personal view based on personal experiences

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1. Introduction

This paper is a subjective view based on 8 years of personal experience in teleradiology. We think the results are of interest to telemedicine in general.

Telemedicine is a broad field, which can be defined in different ways. A Japanese definition of 1996 described it as "… the use of any electrical signal to transmit medical information…" [1]. This is a very technical and simplistic view. The University of Athens in Greece published a more detailed definition: "… the transfer of electronic medical data (i.e. high resolution images, sounds, live video, and patient records) from one location to another." [2]. A broader definition, which takes the entire health care system into account, says: "… the use of telecommunications technology to deliver health care services and health professions education to sites that are distant to the host site or educator…" [3].

The driving factors in telemedicine were investigated in a study by Frost and Sullivan [4]. The following reasons were identified for developing and using telemedicine: first, there is pressure to reduce costs. Centralization, specialization and outsourcing need this technology. Furthermore, there is a need for greater efficiency in the health care system. Advances in technology help in implementing telemedicine systems today. The dissemination of international standardization is an important aspect in implementing systems that are interoperable. Examples of such standards are DICOM, MEDICOM and HL7. The shift from institution-based care to citizen- and homecare-centered provision is another important driver. Increased health-care demands can only be satisfied with telemedicine. Aging populations need tele-monitoring to cut costs and isolated patients need and demand full healthcare services. Physicians are motivated to implement telemedical applications since they recognize an income potential [4].

Telemedicine can help patients, physicians and other medical staff as well as medical institutions, insurance carriers, politicians and the medical devices market according to this study [4].

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Current European research activities in telemedicine can be identified when we look at the papers accepted at the MIE-2000 conference held in Hannover, Germany [5]. They deal with telemedicine platforms, physicians' attitudes to telemedicine, web-based intranets, teleconsultation, ophtalmology, telepathology, teleradiology, telemedicine for family practices, vital signs monitoring, real-time stereo imaging and teleteaching.

2. A classification of telemedicine

The authors would like to structure the broad field of telemedicine into the following areas.

2.1. Patient-independent telemedicine (1:n relations)

Here we mainly find medical information providers. Usually, one provider offers information to many consumers or customers. The Internet is used to present information (via WWW Servers, e-mail, ftp etc.).

- Literature databases.
- Medicine-related information.
- Knowledge bases.
- Guidelines.
- Computer-based training.
- Teleteaching.
- On-line journals.
- Electronic billing.
- Advertisement.
- etc.

2.2. Patient-related telemedicine (1:1 relations)

In this area we find 1:1 relations between actors in the medical field. Patient data are exchanged for example in.

- Cardiology.
- Homecare.
- Pathology.
- Surgery.
- Radiology.
- Emergency care.
- Dermatology.
- Psychiatry.
- Oncology.
- Ophthalmology.
- Nephrology.

Tele-cooperation can be realized by asynchronous (e.g. data transfer via e-mail, ftp, www) or synchronous (e.g. video conferencing, computer-supported cooperative work) means. Applications for synchronous tele-cooperation can again be achieved with.

- Video-conferencing systems: They are general-purpose, cheap but without domain-specific features.
- Application-sharing systems: Domain-specific applications are shared over the network. This can be very slow over the telephone (analogue and ISDN).
- Dedicated applications: Specific telemedicine applications with domain functionality. Systems have been built, e.g. for telepathology, telesurgery and teleradiology. These systems have in common their specific requirements that cannot be satisfied with general purpose applications, e.g.
    - Domain-specific functionalities.
    - Huge amounts of data.
    - Specific data formats.
    - Interfaces to medical equipment.
    - Speed versus network bandwidth.
    - Data security.
    - Integration into IT infrastructure and workflow.

3. Experiences in teleradiology

The authors have been actively working in this field since 1992. Teleradiology belongs to patient-related telemedicine according to the proposed classification. Different approaches such as video-conferencing, application sharing and dedicated applications can be found here and in other application areas as well. Based on our own experiences, we identified three generations of teleradiology:

- Image file transfers.
- Dedicated teleradiology systems.
- Integrated radiological workstations.

3.1. Image file transfer

The implementation of image file transfer applications in the early 90s was a primary phase in teleradiology in which the original image quality could be preserved. This was not the case with video-conferencing tools. The ACR/NEMA standard defined a vendor-independent file format and even a transfer protocol [6] but, in fact, the protocol was not used to transfer data between vendors. Even the image file format did not yet meet the required standardization due to vendor specific additions and interpretations.

Most of these applications are relatively cheap and simple. The disadvantages of such solutions are that they are not secure and very often unreliable. In particular, PC-based implementations under DOS were unstable since any user could change global operating system settings and additional hardware extension cards influenced the operation of the existing configuration. The connections with the digital modality were due to a lack of sufficient standards, i.e. vendor-modality and version-dependent ad-hoc solutions [7].

This kind of solution can still be found today. Modality vendors currently extend the local area network with ISDN lines to submit images to viewing stations or film printers at remote sites. The DICOM standard [8] is nowadays used but proprietary vendor-specific image transfer protocols are still in use. The remaining problems (even with DICOM) are data security and privacy, failure recovery, logging of transfers, flexibility (definition of additional communication partners) and user friendliness.

3.2. Dedicated teleradiology systems

Radiologists as well as software and hardware vendors in this field do not always share the same definition of teleradiology. Therefore, it is probably necessary to point out that we are using the definition of the American College of Radiology in the ‘ACR Standard for Teleradiology’ (Res. 21-1994) [9]. This resolution includes an initial definition of teleradiology (in addition to goals, personnel qualifications, equipment guidelines, licensing, credentials, liability, communication, quality control and quality improvement for teleradiology). Important requirements defined by the resolution specify that images be sent over a network to a different location and that users must be able to view the images simultaneously. Furthermore, DICOM must be used for the exchange and representation of images and image data must be stored in patient databases.

Systems, which are (partly) compliant with these requirements, have been developed since 1994. The main features of such systems are.

- Digital connections to many imaging modalities based on DICOM are possible.
- Teleconferencing over ISDN, LAN, WAN with synchronized data and functions.
- Integrated patient database.

Examples of such systems were developed in Germany with funding from German Telekom, (i.e. DeTeBerkom). They are the KAMEDIN [10] and MEDICUS-2 [11,12] projects.

3.2.1. Example: the MEDICUS-2 Project

The MEDICUS-2 Project was funded by German Telekom (DeTeBerkom) from 1994–1996. User requirements were investigated in a system analysis before the system was developed. Important aspects of this system were the involvement of experts in the fields of human–computer interaction and cognitive psychology [13] as well as the development of a security concept [14]. The system was installed at thirteen locations and evaluated in a field test.

3.2.2. Experiences with the MEDICUS network

The MEDICUS system was evaluated based on computer-generated log files and interactive computer-based forms from 6/96-2/97. The program was used more than 4600 times by 13 users and more than 46 000 images were processed in that network. The partners conducted 170 teleconferences, which typically lasted 5 min each. All teleconferences were shorter than 10 min. Mean conference preparation time was less than a half minute. Preparation time increased to about 2 min when an accompanying cover letter had to be written.

Reasons for data transfers were remote reporting (50%), image transfer (45%), therapy planning (2%) and miscellaneous reasons (1%).

The reasons for teleconferencing were collected in 434 electronic forms. The users answered: discussion between radiologist and clinician (54%), report delivery (20%), therapy planning (13%), interesting case (5%), second opinion (3%), scientific cooperation (3%) and miscellaneous (2%).

When we asked the same teleradiology users where their savings from teleradiology were incurred, they answered: fewer film prints (50%), travel by the radiologist (35%), examinations (3%), patient transport (1%) and miscellaneous (1%).

The statistics proved that this system was in use in the daily routine and that the advantages of using this system were obvious.

3.2.3. General experiences and obstacles solved during this project

The system developers experienced that simply using standards at I/O interfaces was not enough. Translation into and from a different internal data model caused numerous problems.

The establishment and implementation of the data security concept was absolutely mandatory and requested by end users. Implementation in MEDICUS proved that this was feasible in a user friendly way [14].

A critical realization was that development of a dedicated teleradiology system does not make sense! Users started to use the system for other purposes as well. In most cases the MEDICUS workstation was the first computer screen on which radiologists could diagnose filmless images. However, the system was not built for that and users requested a general purpose radiology system with integrated telefunctionality and interfaces to other IT Systems such as the Radiology Information System (RIS) and the Hospital Information System (HIS) [12,15].

Organizational complexity was another important experience: for each partner we had to speak with representatives of hospital management, the head of the radiology department, the responsible (tele-) radiologist, technicians (MTRAs), representatives of inhouse data processing, the firewall administrator, data security officials, the modality vendor's sales engineers, the modality vendor's service technicians as well as network specialists of the modality vendor! Thus, about 10–12 people were involved per connected institution and more than 250 people in the realized network of 13 installations. This means that project management is a very complex task and coordination between so many people requires a great deal of effort and time. This is usually underestimated in telemedicine projects.

The connection of a non-DICOM compliant modality (Philips CT) was successfully implemented at the Lutherkrankenhaus in Essen, Germany. The modality images were first grabbed via the AGFA printing equipment, then captured at the printing gateway and converted into a digital image at the first teleradiology workstation. The demographic data was read from the screen-captured bitmap with an OCR (optical character recognition) program. Bitmap and demographic data were then merged into a valid DICOM image, which could be transferred to a Siemens MagicView workstation in another hospital (Krupp–Krankenhaus, Essen, Germany) using the DICOM protocol [16]. This solution was technically delicate because no less than eight companies were involved. It was also a management challenge because too many people were involved and responsibilities were not always clearly defined. We, as the driving force to get the link between the hospitals running, acted as coordinators between the different companies. No main contractor was responsible for the success of the entire project. Several financial problems occurred since the responsibility for unforeseen investments and inputs was unclear.

An intrinsic problem in daily routine is to find out where technical malfunctions are caused and whose responsibility it is to solve the problem, i.e. to pay for repairs. It is quite complicated to run such a system without maintenance contracts for all (!) components. For future projects we strongly recommend a main contractor or application service provider and maintenance contracts for all involved components.

The project was quite successful from the scientific and medical viewpoint. The system was used during daily routine. Clinical acceptance was very good since the system accelerated and improved the information flow. Interdisciplinary cooperation was enhanced. The radiologists profited from improved clinical information and could deliver faster and better diagnoses and suggestions for further diagnostic or therapeutic procedures in the teleconference. Financial advantages were measurable with lower film printing costs (e.g. about ten Euros per patient), reduced travel by the radiologists, less patient transport and reduced hospital stays [15].

3.2.4. The end of a funded project

The critical point in a funded project is the end of funding. What happens then? Who will look after software maintenance and malfunctions during daily routine? Who will continue to develop the software? Software without maintenance and permanent development is dead and should no longer be used.

3.2.5. Technology transfer

Technology transfer could be an answer to the questions raised in the last section. Nevertheless, converting project results or scientific results in general remains a critical question. Our own experience in this field is "Those who know it have to do it!" This means that not only the technology has to be transferred but also the vision, knowledge and experience. This insight was confirmed in a roundtable discussion of business angels and venture capitalists at the CARS conference at Stanford University in August 2000. As a consequence this means that people have to be transferred as well.

The Medical and Biological Informatics division at the German Cancer Research Center established a technology transfer center (Steinbeis–Transferzentrum Medizinische Informatik) where scientific results are converted into products. This company was established in 1995 for the MEDICUS project. The motivation was to have a clear separation between research and development-which is an important issue for a research institute.

The basic concept is to conduct research at the cancer center and to use the scientific results at the transfer center to implement software products for the market.

This vehicle has been used to build and market CHILI, the commercial successor of the funded MEDICUS project.

3.3. A radiological workstation with built-in teleradiology

CHILI is a completely new design and implementation [18] but uses the experience of the former project. The main features of this system are.

- It is a general purpose radiology workstation, which is integrated into the IT infrastructure of the radiology department and the hospital. It is used as a PACS workstation for reporting and other purposes [19,20].
- Telefunctionality is integrated: this means teleradiological functionality is available everywhere.
- Cross-vendor communication: many different protocols and image file formats are available to receive images and transmit them to other locations (DICOM, CHILI, ftp, scp, rcp, nfs, e-mail, CD-ROM, http etc).
- Standards are used in the internal architecture: the DICOM data model is used as a basis for the integrated patient database.
- It is integrated into the radiology workflow.
- It has a strong security concept, based on European and German requirements.
- Extensibility (PlugIn): additional software modules can be plugged into the running system without any changes [17].

A more detailed description of the system can be found in the literature [18] and on the Web [21]. The purpose of mentioning this system here is to learn from our experiences with this system.

4. Evaluation

4.1. Analysis of CHILI statistical data

We evaluated the CHILI network to find out what the system is used for, how often and when [22]. This analysis is based on statistical information automatically produced by the system. The evaluation covers the period from March 1998 to March 2000.

About 20 systems were installed at the beginning of the evaluation period. More than 50 systems were installed in March 2000 (see Fig. 1). All partners imported about 6 50 000 images altogether (Fig. 2). The aver-

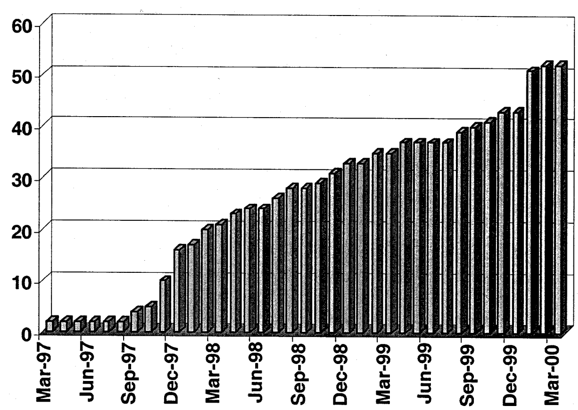

Fig. 1. Number of installations

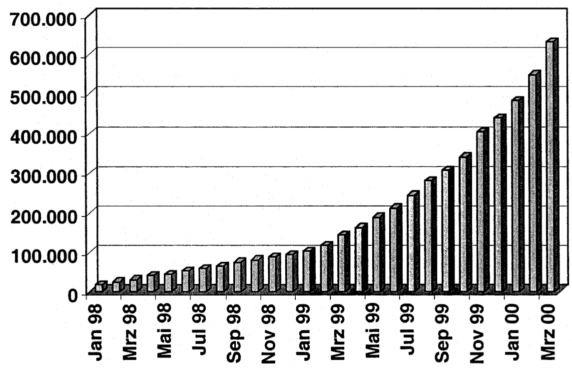

Fig. 2. Cumulative number of images

age number of imported images per partner varied in the range of 800 to 1600 images per month.

The number of system invocations was also logged. The profile for April 2000 shows that the system was mainly used on regular working days. Weekends are easily recognized (1st of April 2000 was a Saturday) in Figs. 3 and 4. Usually, Thursdays are busier than other days. The end of April shows very low system usage, which was caused by the Easter holidays. The system is also used on weekends and holidays but much less.

An analysis of the mean number of transmitted images shows that each partner trans-

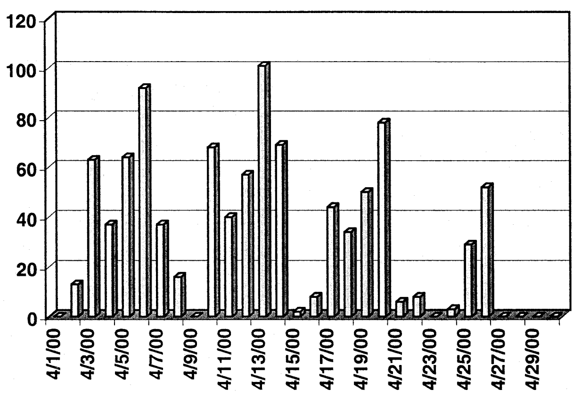

Fig. 3. Number of system invocations per day in the entire network (April 2000; April 1 was a Saturday; Easter holidays at the end of the month)

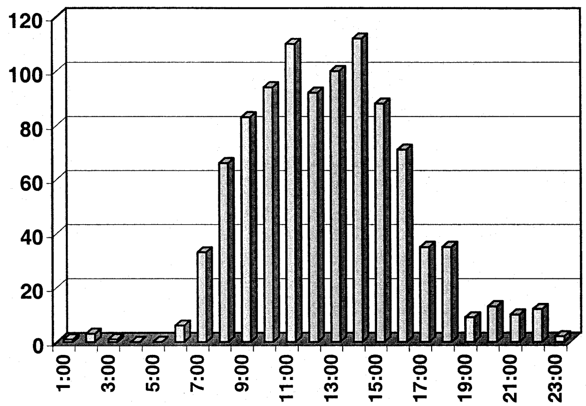

Fig. 4. System invocations: Profile over the day

mitted 400–1000 images per month (of 800–1600 imported images). This means that about 50% of the imported images are not transferred to the workstation for telemedical purposes.

Users of the CHILI system can utilise a broad spectrum of different image transfer protocols. The statistics prove that the most important protocols are the DICOM (49%) and CHILI protocols (51%). The latter has the advantage of higher transfer speed (up to factor 3) and security [14]. The DICOM protocol can be used between vendors.

Another transmission option is the choice between 'explicit transfer' and 'autorouting' (without user interaction). Autorouting can be configured where all images, which can be recognized by a specific field in the DICOM header, must be sent to another site. The statistical data show that slightly more images (50.3%) are automatically transferred. The use of this method increased over time. This means that teleradiology is integrated into the workflow of the communication partners and not just used from case to case.

The analysis of teleconferencing statistics is very interesting. More than 50% of the teleconferences are held between 14 and 15:00 h. The other conferences are distributed over 24 h but most of them are held during regular working hours. This finding proves that teleconferencing is used during fixed appointments in the daily routine. Spontaneous conferences are held but less often.

The system is used in the following application scenarios:

- Discussion between radiologists.
- Remote reporting.
- Emergencies during the night and on weekends.
- External archiving.
- Vacation replacement.
- Discussion between radiologists and clinicians/referring providers.
- Digital image delivery (instead of film).
- Clinical demonstration and discussion.
- Communication between the Centre of Excellence and referring providers
  - Data transfer for radiation therapy planning.
  - Gamma knife center.
  - Heart center/cardiology.
- Scientific projects.
- Image transfer to researchers.

Development of Plug-Ins for innovative image analysis tools (e.g. image segmentation, 3-D renderings, surgery planning, radiation therapy planning).

- In the PACS environment it was used for:
  - Diagnostic image workstation
  - Integration of archiving, reporting, image transmission, internal and external teleconferencing

4.2. Conclusions

The statistical data prove that the CHILI system is not merely an emergency system in the current teleradiology network. It is used during the daily routine as a general purpose radiology workstation with built-in teleradiological functionality.

We can learn from the different technical configurations and application scenarios that all installations are different and, thus, are able to realize that a system with high flexibility, scalability and extensibility is needed.

Our experience is that user needs are changing over time and that user requirements vary in different environments. Thus, a system will never be complete. The software development approach has to take that into account. The design process of such a system has to be open for external input and never ends. We had very good experiences using the software spiral model developed by Boehm [23].

The software architecture must be modular, open, flexible and based on standards. A component-based architecture must be preferred over monolithic system approaches.

Our own development in the past 10 years was an evolution from simple file transfer to a general purpose workstation with vendor-independent communication, multi-protocol data exchange, integrated data security, integration with PACS and extensibility. This process was mainly influenced by end user needs.

5. Security and privacy in telemedicine

There is no doubt that telemedicine needs security! But the problem of many system developers is that they do not know how to create a security concept. Yet, the procedure is available in European and national manuals such as in the European IT security manuals: ITSEC and ITSEM [24,25] and the German IT security manual published by the Federal Bureau of IT Security (BSI, Bonn) [26,27].

We used the proposed approach to integrate security and privacy requirements into one consistent concept [14]. The main steps in such a process are.

- Determination of the appropriate level of security.

- Threat analysis.
- Risk analysis.
- Development of the security concept.

The resulting security concept includes four checklists for.

- Organizational measures.
- Technical measures.
- User education.
- Software measures.

The input for the concept was in our case one person-year without implementation. The problem, which occurs after successful implementation, is that it is no longer compatible with other systems (when applying the security measures). Thus, we need international standardization to create interoperable and secure systems. There are many ongoing activities with respect to data security in Europe, mainly in the CEN/TC 251 Working Group III (Healthcare Security, Safety and Quality).

A valuable outcome of these activities is the 'Security categorization and associated basic protection profiles' (ENV 12924: Health Informatics). The application of this standard could make risk analysis much easier in the future. Unfortunately, the security infrastructure is not covered and the implementation costs (even the baseline requirements) may be high according to the objections of German radiologists (DRG) and modality vendors in Germany (ZVEI). Nevertheless, security standardization is important and necessary.

There is also ongoing work in the DICOM committee (WG 14) to add security to the standard (Suppl. 31, Suppl. 41 Security Enhancements). This covers secure transport connections and digital signatures. The introduction of digital signatures in DICOM seems to be a suitable way of increasing the security of medical data if an appropriate public key infrastructure (PKI) in hospitals can be ensured [28]. But the security enhancements will not help as long as an international PKI is not available.

The discussion regarding security in healthcare in the United States became more relevant with the Health Insurance Portability and Accountability Act of 1996 (HIPAA). These regulations were developed to ensure the integrity and confidentiality of healthcare information that is electronically stored and communicated [29].

6. Perspectives

6.1. The IHE initiative

Integrating the Healthcare Enterprise (IHE) is a US initiative of the Healthcare Information and Management Systems Society (HIMSS) and the Radiological Society of North America (RSNA). The goals of IHE are the integration of health care information resources, promotion of existing standards (e.g. HL/7, DICOM, CORBA, XML) and implementation profiles for the transactions used to communicate images and patient data within the organization between the Hospital Information System (HIS), Radiology Information System (RIS) and the picture archiving and communication system (PACS) [30].

IHE demonstrations of interoperability were presented at conferences of the Radiological Society of North America (RSNA 1999, RSNA 2000) and the Healthcare Information and Management Systems Society (HIMSS 2001). Demonstrations of vertical integration in the radiology department were demonstrated in the first year (before RSNA 2000). Horizontal integration with information systems outside the radiology department is the task of the second year. IHE will also have an impact on telemedicine as the promotion of standards and their usage are a prerequisite for telemedicine.

The European IHE Initiative (IHE-E) was founded in July 1999 by several professional organizations (COCIR, EAR, ECR, DRG, SFR) and vendors in the field (GE, Philips, Siemens, Toshiba). A first workshop took place at the MIE-2000 conference in Hannover, Germany.

6.2. Critical obstacles to fully integrated telemedicine

Fully integrated telemedicine needs standardization by EPR, EHR, HIS, RIS, PACS etc. The standardization issue is more important in telemedicine since information must be exchanged not only inside one operation but also between institutions and even countries. There are still problems to be solved in:

- security and confidentiality,
- legality of electronic signatures,
- health care professional cards,
- security infrastructure,
- security standards (e.g. in DICOM),
- costs and reimbursement,
- medico-legal aspects (i.e. liability).

But existing standards must also be applied. Existing laws, regulations and even possible solutions are ignored by many existing solutions in telemedicine today.

7. Conclusion

Telemedicine is not merely a question of technology. As we learned in our projects, it needs much management and personnel. There still is a long way to go but the authors are optimistic that in the end we will have secure, integrated systems with built-in 'telefunctionality'.

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