Knowledge retrieval as one type of knowledge-based decision support in medicine: results of an evaluation study

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Abstract

We report on a prospective, prolective observational study, supplying information on how physicians and other health care professionals retrieve medical knowledge on-line within the Heidelberg University Hospital information system. Within this hospital information system, on-line access to medical knowledge has been realised by installing a medical knowledge server in the range of about 24 GB and by providing access to it by health care professional workstations in wards, physicians' rooms, etc. During the study, we observed about 96 accesses per working day. The main group of health care professionals retrieving medical knowledge were physicians and medical students. Primary reasons for its utilisation were identified as support for the users' scientific work (50%), own clinical cases (19%), general medical problems (14%) and current clinical problems (13%). Health care professionals had accesses to medical knowledge bases such as MEDLINE (79%), drug bases ('Rote Liste', 6%), and to electronic text books and knowledge base systems as well. Sixty-five percent of accesses to medical knowledge were judged to be successful. In our opinion, medical knowledge retrieval can serve as a first step towards knowledge processing in medicine. We point out the consequences for the management of hospital information systems in order to provide the prerequisites for such a type of knowledge retrieval.

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'*Medicine is characterised by an increasingly growing complexity and knowledge base regarding both diagnostic and therapeutic action*' ([1], p. 90).

1. Introduction

1.1. Knowledge-based decision support in medicine: A major task for medical informatics

Supporting health care professionals, i.e. mainly physicians and nurses, in their tasks for patient care by providing knowledge for decisions on diagnosis and therapy is one of the major concerns of medical informatics. Knowledge is primarily needed on diseases but also, for instance, on side effects and interactions of medications.

For the health care professional, besides information logistics [2], adequate *knowledge logistics* is needed. Current knowledge shall be provided

— in time and
— in the right place
— to authorised persons
— in an appropriate form.

For this purpose, medical knowledge must be captured, processed, and documented systematically in order to ensure that correct and up-to-date knowledge can be supplied.

1.2. Knowledge-based decision support in medicine: still fiction or already reality?

For the past four decades various approaches have existed for computer-based decision support in medicine [3] and on the methodology of designing knowledge-based systems in medicine. However, many systems realised so far did not exceed the stage of prototype and have not been used regularly in clinical routine. But there are exceptions of systems which have been applied in special areas of a hospital or of systems working with limited medical knowledge combined with few patient data from special areas of a hospital such as clinical laboratories [4]. Reflections on the reasons for the slow dissemination of medical decision support systems [5] and demands like 'the physician must be able to apply such systems in a clinical environment' or 'it should be intended to integrate medical knowledge-based

systems into hospital information systems' [6] may underline the scepticism, whether systems for knowledge-based decision support in diagnosis and therapy have already gained significant practical relevance. In addition, research programs such as the MEDWIS program of the German Ministry of Education and Research on medical knowledge bases and parts of the telematics program of the European Union may indicate that there is still a considerable need for research and development on methods and tools for the knowledge-based decision support of diagnosis and therapy.

Therefore, a certain amount of scepticism seems to be justified when ascertaining whether knowledge-based decision support in medicine, in its fifth decade, is still fiction for most of the health care professionals and for major areas in health care, or whether it has already become reality with a significant, demonstrable benefit to many health care professionals and areas, especially with respect to patient care.

1.3. Intention of this paper

Within this paper, we confine ourselves to approaches on the knowledge-based decision support for diagnosis and therapy within hospitals, that should be used by many health care professionals in major areas of a hospital.

We report on a prospective, prolective observational study, supplying information on how physicians and other health care professionals retrieve medical knowledge on-line within the Heidelberg University Hospital information system [7]. Within this hospital information system, on-line access to medical knowledge has been realised by installing a medical knowledge server and by providing access to it by health care professional workstations.

The main questions of interest of the inquiry were:
Q1. How are accesses to medical knowledge characterised as far as health care professionals making use of it are concerned (reasons for use, kind of use, medical knowledge base used as well as local distribution and distribution in time)?
Q2. How do health care professionals judge the quality of their medical retrieval and how large is the share of useful knowledge intended for patient care?

Q3. What influence does medical knowledge retrieval have on patient care, especially on the latter's quality (described by citing concrete cases)?

The evaluation study was carried out in October and November 1994. Results are presented in Section 4 and summarised in Section 5.1.

Based on the results of the study and on our general experience in managing hospital information systems, we then suggest in Section 5.2 an answer to the question:

Q4. How is it possible today to provide knowledge-based decision support in hospital information systems, up to a certain level, quite easily

— to *most of the physicians* and to other health care professionals for routine use in patient care, — to *major areas* of a hospital such as wards and outpatient units

by medical knowledge retrieval, and which methodical, technical and organisational aspects should be considered as far as hospital information systems are concerned?

Finally, and with respect to more general reflections by Peter Reichertz [8], we, as a quintessence, suggest in Section 5.3 an answer to the question:

Q5. Does knowledge-based decision support in medicine still have to be fiction or can it already be regarded as reality with significant, demonstrable benefit with respect to patient care to many professionals and areas of a hospital?

Parts of this paper are based on Refs. 9 and 10. The complete results of the inquiry can be found in Ref. 11.

1.4. Remarks on terminology

We denote as *hospital information system* [12] the partial system of a hospital, which is dealing with the complete information processing and information storing of the hospital and not only its computer-supported part. We will use the *three level graph-based model*, or briefly *3LGM*, as terminology to describe hospital information systems ([2], see also Section 2.5.4 and Fig. 1). 3LGM distinguishes between

— a *procedure level*, at which the functionality of a hospital information system can be described. Nodes in a procedure level graph represent 'information procedures' carrying out certain informa-

tion processing activities. Edges correspond to an information interchange among them and 'procedure accesses' refer to those procedures being used directly by users.

— a *logical tool level*, at which the first step of describing the tools required by information procedures is done. A logical tool level graph consists of nodes which represent (e.g. computer-based) 'application systems'. Edges correspond to their communication interfaces and 'functions' serve as their entry-points for users.

— a *physical tool level*, at which as a second step the physical tools of information processing are described. A physical tool level graph consists of nodes, which represent 'physical subsystems' (e.g. computers). Edges correspond to their data transmission interfaces. There are also entry-points which are now called 'terminals'.

2. Medical knowledge processing in hospital information systems

2.1. Levels of medical knowledge processing in hospital information systems

Knowledge-based decision support for diagnosis and therapy in hospital information systems can be achieved at various levels. With regard to decision support for major areas of a hospital and for most of its health care professionals we can observe e.g.:

(A) decision support based

(A.1) on extensive medical knowledge combined with (in principle all documented) patient data, or

(A.2) on limited medical knowledge combined with few patient data, where knowledge and data are specific to a special area of a hospital, where health care professionals receive suggestions or warnings by computer-based application systems. We can also observe

(B) decision support based on medical knowledge, where health care professionals retrieve medical knowledge from computer-based application systems.

As to (A.1): If the computer-supported part of a hospital information system consists mainly of one 'large' application system covering most of the functionality needed to support or to realise the information procedures for the different per-

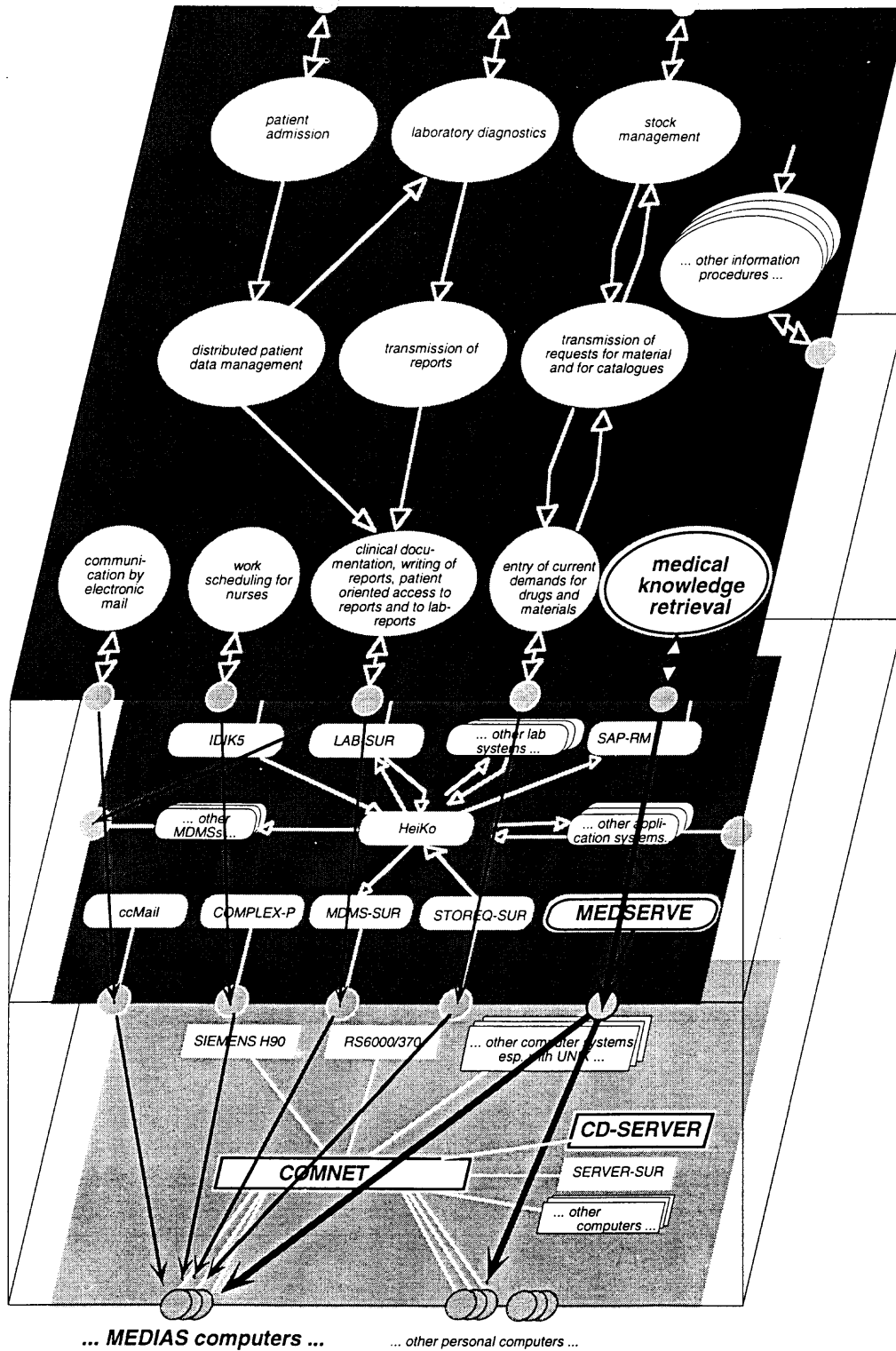... MEDIAS computers ...   ... other personal computers ...

Fig. 1. Three level graph-based model (3LGM) of the Heidelberg University Hospital information system, at the time of the evaluation study. This 3LGM is focusing on medical knowledge retrieval using MEDSERVE as medical knowledge server and MEDIAS as health care professional workstation. It is simplified to some extent. At the (upper) procedure level: white nodes in the procedure level graph represent information procedures, small grey nodes procedure accesses, edges represent information interchange. At the (middle) logical tool level: white nodes in the logical tool level graph represent application systems, small grey nodes functions, edges represent communication interfaces. At the (lower) physical tool level: white nodes in the physical tool level graph represent physical subsystems, small grey nodes terminals, edges represent data transmission interfaces. The edges between the levels give examples of how procedure accesses correspond to application system functions and how these correspond to computers as terminals. Corresponding mappings could be drawn between information procedures, application systems and physical subsystems.

sons and areas of a hospital, then conditions are good for decision support which is based on medical knowledge *and* on patient data. This decision support can consider specific aspects of a certain patient and can range from general watchdog functions to specific support, e.g. in medication. An outstanding example in this context is the HELP system [13]. To achieve this state of decision support, access to patient data containing a detailed documentation of the treatment as well as implementing specific functionality for decision support within this application system must be possible. Today we are, however, often confronted with heterogeneous hospital information systems including a variety of (frequently commercially procured) application systems, where this type of decision support is normally hard to achieve.

As to (A.2): A 'reduced' approach is to provide decision support by using data and knowledge from special areas of a hospital such as clinical laboratories as mentioned in Section 1.2. Here, specific medical knowledge from this area (e.g. on lipometabolic disturbances) and the (few) patient data available in this area (e.g. laboratory data of a patient) are combined for decision support. These systems can be implemented more easily in heterogeneous hospital information systems. Such a type of decision support, however, is only successful if the patient data available together with the specific medical knowledge allow useful decision support.

A necessary requirement for acceptance of application systems to support decisions according to level (A) in a hospital is usually that they consider the multiple usability of patient data [14–18].

As to (B): Another 'reduced' approach is to provide access to medical knowledge without combining it directly with patient data. Usually medical knowledge servers inside a hospital and/or outside it are needed for this purpose. These application systems to support decisions according to level B obviously *cannot* consider the data documented for a certain patient. However, they are relatively easy to design and to implement, e.g. also within heterogeneous hospital information systems. This approach will now be discussed in more detail.

2.2. Medical knowledge servers

Let us define as *medical knowledge server* an application system
— which, on the one hand, contains knowledge bases or knowledge base systems with medical knowledge and, on the other, provides access to this knowledge, and
— where the knowledge bases and major parts of the software are realised on one computer.

Medical knowledge means primarily knowledge on diseases but also, for instance, on side effects and interactions of medications. Medical knowledge can range from electronic medical textbooks, literature bases (e.g. MEDLINE) or DNA and protein databases to specific knowledge base systems. Such knowledge servers often contain large medical knowledge bases which are stored, for example, on CD-ROMs.

2.3. Medical knowledge retrieval

Retrieving medical knowledge by accessing on-line literature bases such as MEDLINE is widely done on 'isolated' single-user personal computers provided with CD-ROM device. Such installations, however, are primarily used for research purposes. In addition, they usually offer access to only one or few literature bases for economic reasons.

For several years, there have been networks of personal computers in libraries (often located in one room) which are connected to a local knowledge server ('computer reading room'). The knowledge, usually literature bases, is stored, for example, on CD-ROM towers. Using this knowledge for patient care is, however, almost impossible because for patient care medical knowledge has to be available 24 h/day at the health care professional's desktop [10,19].

2.4. Medical knowledge retrieval with health care professional workstations

How can knowledge retrieval be applied to patient care? A quite simple way is to use health care professional workstations [20,21] connected to the computer network of a hospital, and to

provide by means of these workstations access to one or several medical knowledge servers. For this purpose, at least one medical knowledge server has to be installed on a computer, which has to be connected to the network of a hospital. Hence, every health care professional workstation is principally capable of being used for medical knowledge retrieval.

In Germany, approaches of this sort have existed for several years in a number of hospitals, for instance at the University Hospitals of Gießen [22], Munich [23], Tübingen [24], and Heidelberg [10].

In the United States, access to medical knowledge has been promoted by the NLM program on 'integrated academic information management systems' (IAIMS, [25]). On the basis of this program, several hospitals use application system functions related to the above-mentioned approaches [26,27]. Experience is summarised in Ref. 28. Effects on medical knowledge retrieval with respect to literature and patient care costs are presented in Ref. 29, and organisational consequences with respect to library institutions in Ref. 30.

2.5. Medical knowledge retrieval within the Heidelberg University Hospital information system

2.5.1. The Heidelberg University Hospital

The Heidelberg University Hospital comprises 62 medical departments with 117 wards and 1749 beds, 70 outpatient units, 31 operating theatres for in-patients and additional ones for outpatients. About 6 000 persons are employed in the fields of research, education and patient care (1994). Number of inpatient stays comes to about 50 000 per year, number of outpatients to about 200 000 [7].

2.5.2. The health care professional workstation MEDIAS

Based on the needs of health care professionals at the University of Heidelberg, the health care professional workstation 'MEDIAS' (Medizini-

sches Arbeitsplatzsystem, [10]) has been developed.

At the time of the evaluation study, MEDIAS supported information procedures as follows:

— clinical documentation, especially writing of medical and operation reports, patient-oriented access to these reports and to those of laboratory, radiology and other functional units, — receipt and printing of (electronic) reports from functional units, — entry of current demands for drugs and materials, — work scheduling for nurses (in test phase), working hours recording and statistical analysis, — communication by electronic mail, — medical knowledge retrieval.

With the exception of the first three information procedures, which are realised by self-developed application systems, all other information procedures are based on commercially procured application software products. In addition, general text processing and computing facilities are offered.

MEDIAS installations are mainly located in wards, in offices (for medical report writing), and in operating theatres (for operation documentation) but also in, for example, physicians' rooms, offices of head nurses and libraries.

Being based on personal computers under MS-DOS and MS-WINDOWS, these computers need to be connected to the computer network of the Heidelberg University Hospital. Apart from TCP/IP services, the NOVELL protocol is used for access to corresponding servers at the physical tool level. Application systems, which are to provide the above mentioned information procedures for a MEDIAS computer, have a HL7-like communication interface to the communication system at the logical tool level of the Heidelberg University Hospital information system (e.g. to receive patient data and reports).

After having started with the first implementation in 1989 we had, at the time of the evaluation study, 182 computers running as MEDIAS computers.

2.5.3. The medical knowledge server MEDSERVE

Within the Heidelberg University Hospital information system, we realised knowledge-based decision support for diagnosis and therapy

through retrieval of medical knowledge by installing a medical knowledge server and by providing access to this knowledge from each MEDIAS computer connected to the network of the Heidelberg University Hospital.

A computer-based application system denoted as 'MEDSERVE' ('*Med*izinischer Wissens*serve*r: Zugriff auf Literatur- und Wissensbanken') has been realised as a medical knowledge server. MEDSERVE is based on a commercially procured application software product. It allows medical knowledge retrieval from each MEDIAS computer, but also from other computers connected to the computer network of the Heidelberg University Hospital.

At the time of the evaluation study, *medical knowledge* was available in the form of

— literature bases (MEDLINE, EMBASE, TOXLINE, CANCER-CD from Silver Platter), — a drug base ('Rote Liste' from Editio Cantor), including knowledge on side effects and interactions of medications as well as

— full text databases and specific knowledge base systems (CONSULT, Oxford Textbook of Medicine, DIAGNOSIS, M.I.S., PHYSICIAN DATA QUERY (cancer therapy) from various publishers).

In addition, *general knowledge* was offered in the form of

— 'dictionaries' (rail connections, postal codes, German-English dictionary, shelf list of journals in German libraries from various publishers).

The computer, on which MEDSERVE has been realised, consisted of a file server (personal computer with 486 processor using NOVELL) and 2 CD-ROM towers with 42 CD-ROM drives.

We started in 1992 when the first part of the network could be used and we enlarged the access to MEDSERVE steadily with the extension of the network and with the increase of MEDIAS installations. Apart from the above-mentioned 182 MEDIAS installations, a variety of additional computers could access MEDSERVE within the network of the Heidelberg University Hospital at the time of the evaluation study.

With MEDSERVE we provide access to medical knowledge 24 h/day in wards, physicians' rooms, etc. in the range of about 24 GB. Conventional storage of this knowledge in the form of books would require a six-shelf book stack of about 45 m length in each place.

2.5.4. Medical knowledge retrieval at Heidelberg University Hospital presented as 3LGM

Fig. 1 shows the three level graph-based model (3LGM) of the Heidelberg University Hospital information system at the time of the evaluation study, with focus on medical knowledge retrieval.

At the logical tool level, IDIK5 is the patient management system, LAB-SUR a lab software installation in the surgical clinic, SAP-RM the stock management system, MDMS an application software for medical document management and MDMS-SUR one of its installations in the department of surgery, HeiKo the Heidelberg communication system, STOREQ-SUR an application system for material requests in the department of surgery, COMPLEX-P a work scheduler and ccMail the e-mail system used at the Heidelberg University Hospital. MEDSERVE is the medical knowledge server. At the physical tool level, the SIEMENS computer is the central mainframe, the RS6000/370 computer runs the LAB-SUR application system, other UNIX computers are mainly used in other laboratories, SERVER-SUR is for the MDMS-SUR application system, CD-SERVER is the file server for MEDSERVE, and COMNET is the communication network with all its active and passive components.

The actual integration of medical knowledge retrieval into the Heidelberg University Hospital information system takes place at the physical tool level of its 3LGM. Looking from bottom to top there are MEDIAS computers offering the functions of MEDSERVE and functions of other application systems. For being able to do so, all MEDIAS computers are connected to the communication network, which for its part is connected with the MEDSERVE's file server. For every function of an application system at the logical tool level at least one corresponding procedure access exists at the procedure level. It can thus be derived what procedures are available on a certain MEDIAS computer.

3. An evaluation study on medical knowledge retrieval at the Heidelberg University Hospital

3.1. Questions of interest

As mentioned in Section 1.3 the questions of main interest within the inquiry were:

Q1. How are accesses to medical knowledge characterised as far as health care professionals making use of it are concerned (reasons for use, kind of use, medical knowledge base used as well as local distribution and distribution in time)?

Q2. How do health care professionals judge the quality of their medical retrieval and how large is the share of useful knowledge intended for patient care?

Q3. What influence does medical knowledge retrieval have on patient care, especially on the latter's quality (described by citing concrete cases)?

Our detailed questions were as follows:

— As to item Q1:

Q1.1. How often does access to medical knowledge take place per day/week?

Q1.2. How are accesses distributed per day/week?

Q1.3. What groups of health care professionals are involved and how often?

Q1.4. What reason is indicated for its use and how often?

Q1.5. What medical knowledge bases or knowledge base systems are used and how often?

Q1.6. Which departments make use of medical knowledge retrieval and how often?

Q1.7. How is the duration of its use distributed?

— As to item Q2:

Q2.1. How do health care professionals judge their medical knowledge retrieval?

Q2.2. How large is the share of useful knowledge intended for patient care?

— As to item Q3:

Q3.1. What is medical knowledge retrieval like in concrete clinical cases?

Q3.2. What influence has medical knowledge retrieval, in the described cases, on the quality of patient care?

3.2. Study design

3.2.1. Introduction

The study was conducted as a prospective, prolective observational study divided into three parts. The three parts should supply answers to the three questions of main interest.

In parts 1 and 2 of the study an investigation was made into the characterisation of access and usage and the judgement of the benefit gained from medical knowledge retrieval. The method applied was that of a structured inquiry with response options, carried out among users *prior to* (part 1) and *after* (part 2) each access, accompanied by automated, structured recording (part 1). By *access* is understood, for example, the calling of MEDLINE (and working with it). Parts 1 and 2 of the study were scheduled to extend over a 3-week period which began on October 1st, 1994 and ended on October 21st, 1994. Recorded were the entirety of accesses to medical knowledge (but not those to general knowledge, see Section 2.5.3) made within the Heidelberg University Hospital in the course of this period of time. Accesses of a duration shorter than 30 s (equalling faulty selection by user) were not taken into account.

In part 3 of the study, two physicians (HKS and RW from the authors) and their accesses were observed casuistically because of their concrete clinical cases. Here, too, the method applied was that of a structured inquiry among the physicians concerned. Part 3 of the study began on November 14th, 1994 and ended, after a 2 week's inquiry, on November 27th, 1994.

3.2.2. Study, part 1: Characterisation of access and usage

Prior to each medical knowledge retrieval, a screen appeared on the monitor. The user was informed about the study and the following items were asked (A2, A3) or recorded automatically (A1, A4–A6):

A1. Beginning of use (Q1.1, Q1.2), A2. Group of health care professionals (Q1.3), A3. Primary reason for use (Q1.4), A4. Medical knowledge base or knowledge base system (Q1.5), A5. Department (Q1.6), A6. Duration of use (Q1.7).

The 'Beginning of use' included indication of date, weekday and time when use started. As far as 'Group of health care professionals' was concerned, a distinction has been made between:
B1. Physicians (head physician (Chefarzt), senior physician (Oberarzt), assistant physician, physician doing practical training (Arzt im Praktikum)) (with the exception of B4), B2. Nursing staff, B3. Medical laboratory staff, B4. Staff/medical informatics (including archives, documentation), B5. Staff in the fields of research and teaching (with the exception of B1 and B4), B6. Medical students, B7. Other students (i.e. except medical students), B8. Other users.

Primary reason for use could be:
C1. Own clinical case, C2. Current clinical problem, C3. General medical problem (continuing education), C4. Scientific work, study, C5. Other reason.

We defined, with a view to the evaluations made in the following, the primary reason for an access also as *clinical* if C1, C2 or C3 is indicated, and as *non-clinical* if C4 of C5 is indicated. The duration of an access is the time spent in the medical knowledge base or in the knowledge base system.

3.2.3. Study, part 2: Judgement of successful use

After each access to medical knowledge a screen was displayed on the monitor with the request to indicate:
D1. Judgement of medical knowledge retrieval (Q2.1, Q2.2), D2. General remarks.

For 'Judgement of medical knowledge retrieval' the health care professional could comment on the question 'Has its use been successful' by choosing from the following answers:
E1. Yes, all my questions were answered, E2. Yes, but not completely, E3. In part, E4. No, but it was not without benefit, E5. No, it was completely superfluous, E6. Other answer.

Usage was defined as *patient- oriented* (Q2.2) when for A2: 'Primary reason for use' C1 or C2 was indicated. Usage was defined as *successful* when for D1: 'Judgement of medical knowledge retrieval' E1 or E2 was indicated. Remarks (D2) could be made by the user in free text.

3.2.4. Study, part 3: Examples of concrete cases

For every access referring to a current clinical case, the following data were recorded on a conventional case report form by the two selected physicians:
F1. Name of physician, F2. Date, F3. Patient's name (abbreviated), F4. Description of problem, F5. Medical knowledge base(s) or knowledge base system(s), F6. Result of use, F7. Remarks.

4. Results

4.1. Introduction

As far a parts 1 and 2 of the study were concerned, 1461 accesses from a total of 1887 were included into the evaluation. As already mentioned before, we did not include accesses of a duration shorter than 30 s, nor did we consider accesses to general knowledge (see Section 2.5.3). Also excluded were accesses which appeared clearly erroneous (e.g. faulty selection of knowledge base). After completion of the two parts of the study we realised the need to add subsequently to attribute A2 the group of 'Library staff' (Q1.3).

In Part 3 of the study, seven retrievals referring to nine concrete clinical cases were carried out by the two selected physicians.

We now present the most important results of the study. Further details are given in Ref. 11.

4.2. Study, part 1: Characterisation of access and usage

The frequencies of accesses per day and week (Q1.1) and their distributions (Q1.2) are shown in Table 1, Fig. 2 and Fig. 3. The average number of accesses on a working day came to 95.9, the average number of accesses on Saturdays, Sundays and public holidays amounted to 17.0. The groups of health care professionals who made use of medical knowledge retrieval (Q1.3) are shown in Fig. 4. The primary reasons for use (Q1.4) are indicated in Fig. 5 and, in addition, listed according to groups of health care professionals in Table 2. The knowledge bases accessed (Q1.5), also listed according to primary reason for use, are indicated in Table 3.

Table 1

Frequencies of accesses per day and week to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study ($n = 1461$)

Week	Day							
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Σ
Oct 1–7	22	13	16	103	82	83	72	391
Oct 8–13	14	17	87	93	80	82	65	438
Oct 14–21	18	19	113	134	159	111	78	632
Σ	54	49	216	330	321	276	215	1461

The distribution as to departments (Q1.6) and duration of use (Q1.7), listed according to primary reason for use, is shown in tables 4 and 5.

4.3. Study, part 2: Judgement of successful use

The judgement of the benefit of medical knowledge retrieval (Q2.1), listed according to reason for use, is given in Table 6. It shows that 466 retrievals from a total of 1461, i.e. 32%, were carried out under patient-oriented aspects. In the case of 281 accesses, retrieval was successful. Thus, the share of a successful, patient-oriented usage came to 77% (Q2.2).

4.4. Study, part 3: Examples of concrete cases

In order to describe medical knowledge retrieval for concrete clinical cases (Q3.1) and its effect on the quality of patient care (Q3.2), all accesses documented in part 3 of the study are listed in Table 7.

4.5. Other results: Criticism and proposals for improvement

There were 76 comments included which contained useful criticism. The data available as free text could be assigned to five topics. Criticism with regard to contents did rank first and was put forward in 20 cases. They referred to insufficient topicality as far as inclusion of journals into MEDLINE is concerned, as well as to an Anglo-American concentration. In the second place, put forward in 18 cases, was criticism with regard to user prompting and difficulties in operating

MEDSERVE, long response times, as well as problems in the hardware and configuration areas of MEDIAS installations. Fourteen comments expressed the consent to the concept or documented the 'overall success' of many a retrieval. Seven comments included general, negative remarks with no further details indicated; another seven comments expressed disapproval of the study and of the additional work load involved for the user.

5. Discussion

5.1. Comment on the results of the evaluation study (questions Q1–Q3)

The results may indicate that medical knowledge retrieval with health care professional workstations is widely used, especially by physicians. It seems to be of importance for us that knowledge retrieval from the health care professional's desktop as presented here is already being used to a considerable extent to support patient care. Therefore, in our opinion, medical knowledge retrieval as presented here can support medical research and patient care.

Obviously, the casuistic descriptions obtained from part 3 of the study do not provide a representative survey of cases. They may, however, give some insight into concrete cases and on the variability of different physicians. The distribution of physicians in Fig. 4 seems somewhat biased to us. The relatively high number of 98 sessions of head physicians may be due to input errors by the users, as this entry was the first one in the questionnaire under the attribute group of health care
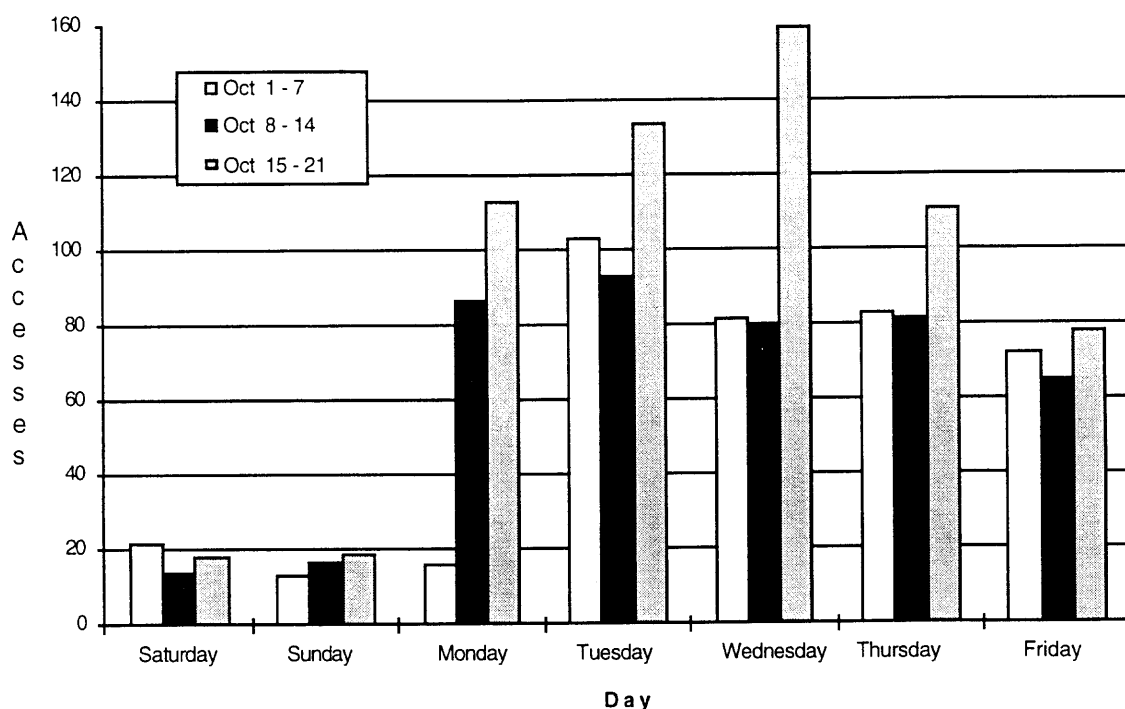
Fig. 2. Frequency of accesses per week to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study ($n = 1461$).

professionals. As far as departments are concerned (Table 4) it must be pointed out that reasons for differences in frequencies were also due to the different degree of networking available in the individual departments. Obviously, other covariates such as the size of the departments, especially the number of beds, could have been taken into account.

5.2. Consequences for the management of hospital information systems (Question Q4)

Question Q4 was:

Q4. How is it possible today to provide knowledge-based decision support in hospital information systems, up to a certain level, quite easily

— to *most of the physicians* and to other health professionals for routine use in patient care,

— to *major areas* of a hospital such as wards and outpatient units

by medical knowledge retrieval, and which methodical, technical and organisational aspects should be considered as far as hospital information systems are concerned?

In our opinion, medical knowledge retrieval with health care professional workstations can provide quite easily knowledge-based decision support in hospitals for *most of the physicians* and other health care professionals and in *major areas* for patient care. Obviously, with respect to the levels of knowledge processing in hospital information systems discussed in Section 2.1, it may be regarded as a first step.

The main requirements for the management of a hospital information system in order to offer this type of knowledge retrieval are:

— to provide a hospital-wide computer network,
— to install a medical knowledge server and connect it to this network,
— to install health care professional workstations hospital-wide, especially in physicians' rooms, wards, outpatient departments, but also in, for example, functional units, offices and libraries; to connect these workstations to the computer network of the hospital; to take care that a wide range of functionality on these health care professional workstations, e.g. as described in Section 2.5.2, is available; to take care also that a function 'medical knowledge retrieval' can easily be activated on such a workstation.
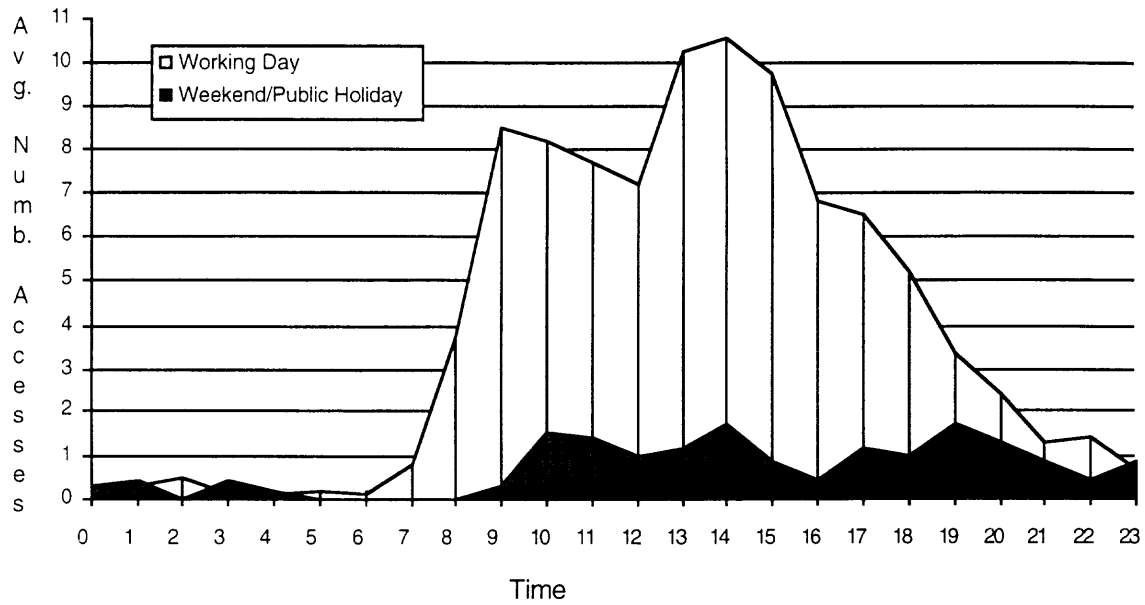
Fig. 3. Average frequency of accesses per day to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study (n = 1461).

Apart from these main requirements it is recommended to regularly inquire about the needs of the health care professionals concerning retrieval of medical knowledge. Don't forget to offer additional general knowledge, e.g. on rail connections or telephone directories. In addition, access to other medical knowledge servers and to other data — and knowledge bases outside the hospital should be offered, e.g. via gopher or world wide web.

5.3. Fiction or reality? In other words: Is knowledge retrieval really a type of knowledge-based decision support? (Question Q5)

Question Q5 was:
Q5. Does knowledge-based decision support in medicine still have to be fiction or can it already be regarded as reality with significant, demonstrable benefit with respect to patient care to many professionals and areas of a hospital?
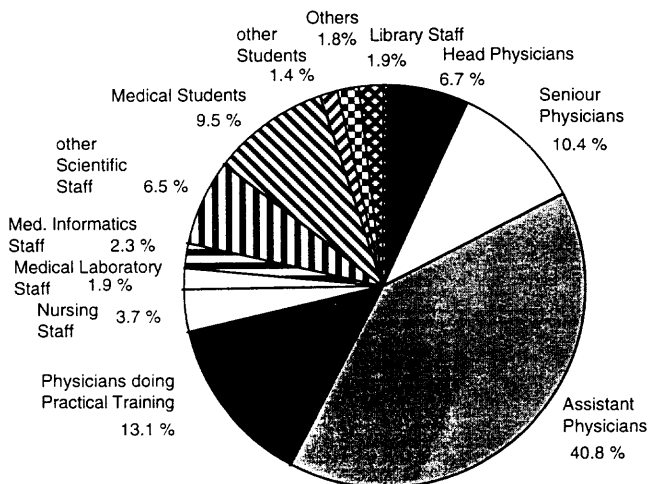
Fig. 4. Relative frequencies of accesses by groups of health care professionals who made use of the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study (n = 1461).
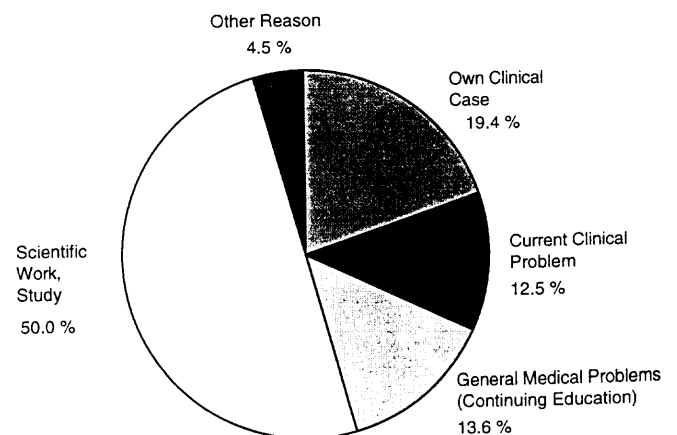

Fig. 5. Relative frequencies of accesses related to primary reason for use of the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study (n = 1461).

Table 2
Frequency of accesses, related to primary reason for use of the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study, listed according to groups of health care professionals (n = 1461)

Group of health care professionals	Primary reason for use (percentage refers to group of health care professionals)										
	Own clinical case		Current clinical problem		Gen. med. problem (Cnt.Educ.)		Scientific work, Study		Other reason		Σ
Head physicians	66	67.3%	8	8.2%	11	11.2%	10	10.2%	3	3.1%	98	100%
Senior physicians	18	11.8%	31	20.4%	8	5.3%	91	59.9%	4	2.6%	152	100%
Assistant physicians	112	18.8%	76	12.8%	95	15.9%	295	49.5%	18	3.0%	596	100%
Phys. doing pract. tr.	35	18.2%	13	6.8%	26	13.5%	116	60.4%	2	1.0%	192	100%
Nursing staff	8	14.8%	21	38.9%	22	40.7%	0	0%	3	5.6%	54	100%
Med. lab. staff	6	22.2%	0	0%	7	25.9%	9	33.3%	5	18.5%	27	100%
Med. informatics staff	2	5.9%	3	8.8%	7	20.6%	11	32.4%	11	32.4%	34	100%
Other scientific staff	4	4.2%	5	5.3%	9	9.5%	74	77.9%	3	3.2%	95	100%
Medical students	24	17.3%	15	10.8%	8	5.8%	89	64.0%	3	2.2%	139	100%
Other students	4	19.0%	2	9.5%	1	4.8%	13	61.9%	1	4.8%	21	100%
Library staff	0	0%	8	29.6%	2	7.4%	10	37.0%	7	25.9%	27	100%
Others	4	15.4%	1	3.8%	3	11.5%	12	46.2%	6	23.1%	26	100%
Σ	283	19.4%	183	12.5%	199	13.6%	730	50.0%	66	4.5%	1461	100%

Obviously, there are doubts and there is even disagreement, whether medical knowledge retrieval can be denoted as knowledge-based decision support in medicine. Shouldn't we argue that knowledge-based decision support in medicine does start when application systems give decision support by combining medical knowledge and patient data? Shouldn't we argue that within medical knowledge bases medical knowledge has to be represented formally, which, for example, is not the case in MEDLINE?

We regard these arguments as important. However, we should learn from approaches and systems that are accepted in clinical routine. We should take such approaches and improve them, e.g. as far as aspects like the formal representation of knowledge is concerned. The approach described here is accepted by our health care professionals. It already now supports decisions on the basis of medical knowledge and is of benefit for patient care and for medical research.

Table 3
Frequency of accesses, related to the medical knowledge bases or knowledge base systems used, to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study, listed according to primary reason for use (n = 1461)

Medical knowledge base (system)	Primary reason for use (percentage refers to med. knowledge base)					
	Clinical		Non-clinical		Σ	
MEDLINE	459	69.0%	692	86.9%	1151	78.8%
Drug base rote liste	77	11.6%	14	1.8%	91	6.2%
Journals in libraries	34	5.1%	46	5.8%	80	5.5%
TOXLINE	17	2.6%	11	1.4%	28	1.9%
Oxford textb. med.	16	2.4%	2	0.3%	18	1.2%
M.I.S.	16	2.4%	0	0%	16	1.1%
CONSULT	10	1.5%	4	0.5%	14	1.0%
Other	36	5.4%	27	3.4%	63	4.3%
Σ	665	100.0%	796	100.0%	1461	100.0%

5.4. Prospects

In Heidelberg we will further extend the possibilities of medical knowledge retrieval, especially with respect to electronic medical textbooks and dictionaries, and by providing access to data and knowledge servers outside the Heidelberg University Hospital, e.g. through gopher or through

Table 4
Frequency of accesses, related to departments, to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study, listed according to primary reason for use ($n = 1461$)

Group of health care professionals	Primary reason for use (percentage refers to group of health care professionals)										
	Own clinical case		Current clinical problem		Gen. med. problem (Cnt.Educ.)		Scientific work, Study		Other reason		Σ	
Internal medicine	47	15.3%	34	11.0%	38	12.3%	184	59.7%	5	1.6%	308	100%
Surgery	60	20.8%	50	17.4%	43	14.9%	130	45.1%	5	1.7%	288	100%
Pediatry	51	34.9%	9	6.2%	32	21.9%	49	33.6%	5	3.4%	146	100%
Pathology	28	20.4%	5	3.6%	6	4.4%	87	63.5%	11	8.0%	137	100%
Neurology	27	26.7%	18	17.8%	8	7.9%	46	45.5%	2	2.0%	101	100%
Neurosurgery	22	28.6%	25	32.5%	7	9.1%	22	28.6%	1	1.3%	77	100%
Dental medicine	4	5.6%	9	12.7%	14	19.7%	42	59.2%	2	2.8%	71	100%
Phorensic medicine	3	4.3%	4	5.7%	36	51.4%	26	37.1%	1	1.4%	70	100%
Dermatology	20	43.5%	12	26.1%	0	0%	12	26.1%	2	4.3%	46	100%
Ophtalmology	2	4.3%	1	2.2%	2	4.3%	31	67.4%	10	21.7%	46	100%
Gynecology	9	20.5%	3	6.8%	4	9.1%	24	54.5%	4	9.1%	44	100%
Hygiene	1	2.4%	2	4.9%	3	7.3%	27	65.9%	8	19.5%	41	100%
Labour and social med.	6	24.0%	2	8.0%	1	4.0%	15	60.0%	1	4.0%	25	100%
Otolaryngology	1	6.3%	2	12.5%	0	0%	10	62.5%	3	18.8%	16	100%
Psychiatry	0	0%	6	50.0%	3	25.0%	3	25.0%	0	0%	12	100%
Other	2	6.1%	1	3.0%	2	6.1%	22	66.7%	6	18.2%	33	100%
Σ	283	19.4%	183	12.5%	199	13.6%	730	50.0%	66	4.5%	1461	100%

world wide web. This world wide access, however, has to consider the specific data protection restrictions, a hospital has to take care for, because of the patient data stored. We will also try to provide a joint medical knowledge server service together with the university library and to store knowledge, which is frequently accessed, not on CD-ROM as it is done now, but on large disk space.

The success of medical knowledge retrieval as one type of knowledge-based decision support in medicine should also have consequences for research:

— Research work on methods and systems for knowledge-based decision support of diagnosis and therapy should be based primarily on methods and systems which have proven their value in practice. Approaches which do occur 'endemically' in the scientific literature but have not proven their value in medical practice even after a prolonged period of time should normally not be investigated (and funded) further.

Table 5
Frequency of accesses, related to duration of use, to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system during the evaluation study, listed according to primary reason for use ($n = 1461$)

Duration of use	Primary reason for use (percentage refers to duration of use)					
	Clinical		Non-clinical		Σ	
< 5 min.	331	49.8%	296	37.2%	627	42.9%
≥ 5 min., < 10 min.	136	20.5%	162	20.4%	298	20.4%
≥ 10 min., < 15 min.	62	9.3%	84	10.6%	146	10.0%
≥ 15 min., < 20 min.	23	3.5%	58	7.3%	81	5.5%
≥ 20 min., < 25 min.	25	3.8%	41	5.2%	66	4.5%
≥ 25 min., < 30 min.	20	3.0%	28	3.5%	48	3.3%
≥ 30 min., < 35 min.	9	1.4%	19	2.4%	28	1.9%
≥ 35 min., < 40 min.	11	1.7%	18	2.3%	29	2.0%
≥ 40 min., < 45 min.	4	0.6%	14	1.8%	18	1.2%
≥ 45 min., < 50 min.	8	1.2%	16	2.0%	24	1.6%
≥ 50 min., < 55 min.	0	0%	4	0.5%	4	0.3%
≥ 55 min., < 60 min.	3	0.5%	5	0.6%	8	0.5%
≥ 60 min.	33	5.0%	51	6.4%	84	5.7%
Σ	665	100.0%	796	100.0%	1461	100.0%

Table 6
Frequency of accesses to the medical knowledge server MEDSERVE of the Heidelberg University Hospital information system, related to judgement of medical knowledge retrieval, listed according to primary reason for use ($n = 1461$)

Primary reason for use	Has use been successful? (percentage refers to primary reason for use)													
	Yes, all questions answered		Yes, but not completely		In part		No, but not without benefit		No, completely superflous		Other comment		Σ	
Own clinical case	130	45.9%	42	14.8%	34	12.0%	21	7.4%	48	17.0%	8	2.8%	283	100%
Current clinical problem	80	43.7%	29	15.9%	27	14.8%	11	6.0%	31	16.9%	5	2.7%	183	100%
Gen. med. probl. (ct. ed.)	74	37.2%	33	16.6%	47	23.6%	15	7.5%	22	11.1%	8	4.0%	199	100%
Scientific work, study	369	50.6%	157	21.5%	110	15.1%	39	5.3%	41	5.6%	14	1.9%	730	100%
Other reason	31	47.0%	11	16.7%	8	12.1%	1	1.5%	10	15.2%	5	7.6%	66	100%
Σ	684	46.8%	272	18.6%	226	15.5%	87	6.0%	152	10.4%	40	2.7%	1461	100%

Table 7
Medical knowledge retrieval by two selected physicians on their concrete clinical cases during the evaluation study

Date	Physician	Patient	Problem	Medical knowledge base	Result	Remarks
Nov.14th	HKS	P1, P2, P3	Massive ileus without mechanical obstruction. Ogilvie's syndrome? Question about diagnosis and therapy.	MEDLINE 86–94	Several papers with sufficient information in their abstracts	Information for members of the Department of Surgery: Diagnostics and therapy of the Ogilvie's syndrome.
Nov.14th	HKS	P4	Inquiry from the Institute for Human Genetics: 3-year-old child, mentally retarded, with 5q interstitial deletion. Question: phenotype of familiar adenomatous polyposis?	MEDLINE 86–94	Two papers answering the question: mild phenotype to normal phenotype	Complete deletion of one APC allele as germ line mutation does not cause other phenotype compared with mutation in Exon 15.
Nov.16th	RW	P5	Massive hyponatriaemia. Question about differential diagnosis and therapy.	CONSULT	Hints on differential diagnosis and hints on therapy. In particular: very slow increase of serum Na$^+$.	
Nov.19th	RW	P6	Formulation of a drug	'Rote Liste'	Answer to question: Dytide H by the intestinal route only in the form of tablets?	
Nov.20th	HKS	P7	Differential diagnosis: cholecystitis, sigmoid diverticulitis. Question: does a correlation exist between cholecystitis and sigmoid diverticulitis?	MEDLINE 87–94: MEDLINE 82–86: MEDLINE 66–81:	Negative Negative One paper on the subject concerned with description of one case.	No literature on the subject concerned found in MEDLINE 87–94 and 82–86: description of one case found in MEDLINE 66–81.
Nov.23rd	RW	P8	Ingredients of the medication; patient will be transferred to France.	'Rote Liste'	All ingredients determined.	
Nov.26th	RW	P9	Domestic medication: Azi- or Acifugan.	'Rote Liste'	Equal to Allopurinol.	

— Programs for funding methods and systems for knowledge-based decision support of diagnosis and therapy can now put more emphasis on transformation into practice and assessment of benefit than they could do in the past.

— Checking the quality of the knowledge made available will become increasingly important in the future. Here, too, research should be promoted, e.g. by quality assurance programs.

'Many things have to be done and can be done, let us not just sit back and let them happen by themselves; let us not only react to events which induce a change, let us actively prepare for a meaningful evolution' ([1], p. 100).

Acknowledgements

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