THE INFORMATION EXPLOSION*

EDWARD J. HUTH, M.D.
Editor
Annals of Internal Medicine
American College of Physicians
Philadelphia, Pennsylvania

THE SIZE OF THE literature relevant to medical research and practice is widely seen as having grown enormously in our time. The Louis Harris poll[1] recently carried out for the New York Academy of Medicine seems to have confirmed these judgments in the medical community that we do face an "information explosion." The problem appears to be in part an oversupply of medical information in the form of journals and books. Further, the poll seems to have confirmed perceptions of growing difficulties for managers of published information, notably librarians, and growing difficulties for academic people in medicine in finding information for their needs. The findings in the poll seem to me to lead to five questions: Is it the growth in numbers in recent decades of journals that has produced the perceived difficulties in using medical literature? Is there more than the size of the medical literature that produces difficulties in information seeking and recovery? Who perceives such difficulties? How have we adapted to the apparent difficulties? What are possible new or additional solutions to our problems?

Before trying to answer these questions, I must point out that the medical community is not a homogeneous group of people with identical kinds of information needs with the same ease of access to the same kinds of sources, and, probably, the same perceptions of "problems." The best solutions for perceived problems are likely not to be the same for everybody in the medical community. Proposed solutions should take this inhomogeneity into account; there will probably not be one best solution for all groups in medicine. Solutions for investigators may be inappropriate for practicing physicians.

HOW HAS THE NUMBER OF MEDICAL-SCIENCE JOURNALS GROWN SINCE WORLD WAR II?

Ascertaining the number of scientific journals relevant to medicine that have been published in any year since 1950 is not easy. What journals are

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"relevant to medicine"? The substantive medical science and clinical journals are relatively easy to identify when we see them, but I have not been able to find any clear data for this class of serials. In counts of relevant journals should we include controlled-circulation journals? What about synoptic newsletters?

Some students[2] of scientific literature have estimated that the number of scientific journals has for many decades doubled every 10 to 15 years. I have not been able to find data for unequivocally substantive journals in the medical sciences and clinical medicine from which I could estimate their growth since 1950. So I have drawn on the National Library of Medicine's annual counts[3,4] of the serials it receives as the best index I can find of this growth. For technical reasons I have focused on the changes from 1960 to 1975. The classification "serials" includes more than journals but the changes in totals of received serials is probably a reasonable index to growth in numbers of journals. Data shown in Figure 1 with a trend line suggest that during the 15 years between 1960 and 1975 the total number of medical journals almost doubled. This rate of growth is very much like that identified for all scientific journals through a much longer period. This climb does indeed look like an "information explosion." Certainly the climb in the numbers of serials received by the National Library of Medicine in this period could have been due in part to increased resources available to the Library to collect serials. But these are the best numbers I could find for my purposes in this paper.

Growth in Numbers of People in the Medical Community

Note that in the same 15 years the numbers of people in the medical community (and I include dentists and nurses in the count) also rose steadily (Figure 1). The growth in the number of medicine-related serials published worldwide and collected by the Library might simply reflect the social and intellectual needs of a growing medical community. Indeed, if one divides the number of serials received by the Library by the total number of people in the American medical community,[5,6] the growth does not look so sharp (Figure 2). The ratio of serials to 1,000 physicians, dentists, and nurses for the years 1960, 1965, 1970, and 1975 rose only slightly during those years, from 15.5 to 17.3.

Are There Other Reasons Why We Perceive an "Explosion" in Information?

Some apparent threats in the world around us are not truly threats when we pause really to look at them. I am thinking here of the physician who through recent years has been receiving steadily growing piles of mail that include not

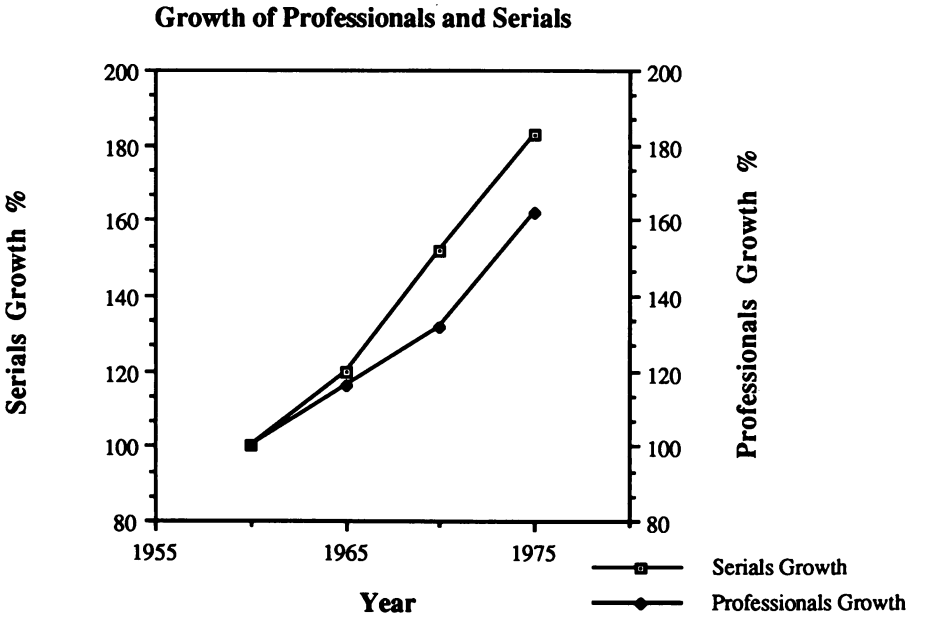

Fig. 1. Percentage growth in the number of serials received at the National Library of Medicine[3,4] from 1960 to 1975. Percentage growth in numbers of U.S. physicians, dentists, and nurses[5,6] in the same period. 1960 serves as the 100% reference point.

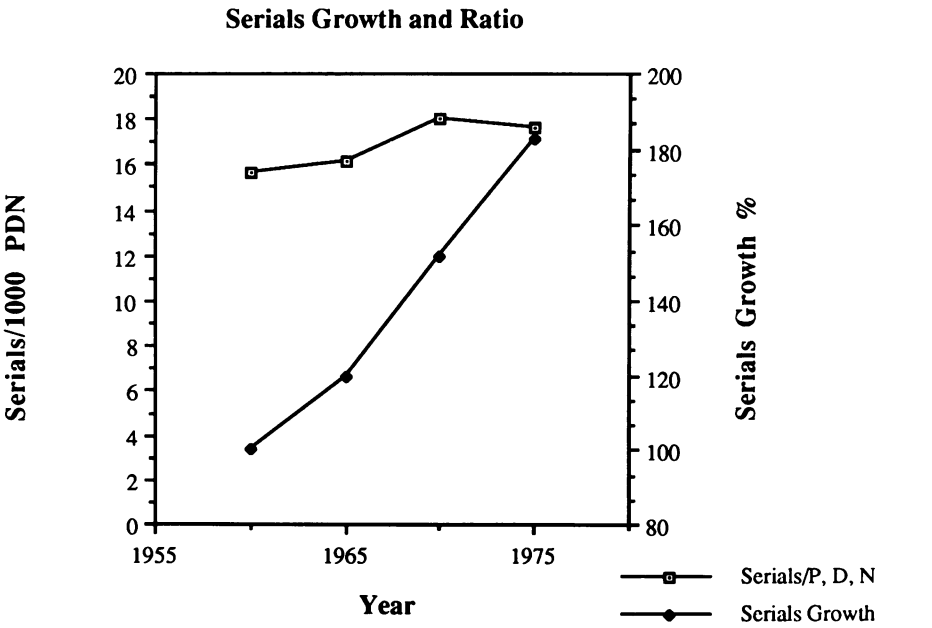

Fig. 2. The ratio of the number of serials received at the National Library of Medicine in the period 1960 to 1975 per 1,000 U.S. physicians, dentists, and nurses. The points and trend line for the numbers of serials are given for contrast with the ratio.

only advertising, solicitations, and mail-order catalogs but also still increasing numbers of "throw-away" journals. He may not really need to read them, but their shape and garb implies that they cannot be ignored. Their numbers alone intimidate.

The numbers of articles per issue of journals may similarly affect our perceptions. Many journals that once carried only 10 articles, on average, per issue now carry 20 to 30. Intelligent, selective readers of journals know that they need not read all that each issue carries but the numbers alone appear to present a problem.

The growth of technology has spawned a still growing number of journals representing new technical methods: imaging methods, cardiac pacing, dialysis, respiratory supports. These journals may serve more to carry advertising than to convey new information of value for concept or reference. But their existence itself implies that they carry needed information. They appear to represent in part the putative "information explosion."

Some of the sense of an "information explosion" may come simply from the growth of basic medical science and its generation of new concepts. These new concepts and the associated new facts have called for new terms. Thus, new science generates new vocabularies. When these new terms begin to appear in journals that have heretofore dealt only with familiar concepts we may feel that we are being presented with too much new information for us to process for its possible usefulness.

What is Today's Information "Landscape" for a Searcher?

I have been speculating on some reasons why our information explosion might not be in fact an explosion for individual needs. The number of journals being published has steadily climbed through the past three or four decades. But the number of journals published per thousand health-care professionals has not climbed sharply. We can assume, I think, that most researchers and clinicians should be able to scan four to six journals per month for their need to keep aware of new developments. If the information relevant to the needs of particular groups of investigators or clinicians is indeed concentrated within small clusters of journals, then we may not truly face an "information explosion." But perhaps the information needed by particular groups is not carried only within small clusters of journals. Is the problem not the numbers of journals per 1,000 health-care professionals but the greater scattering of needed information?

A physician or investigator of our time could keep as well informed from journals as his counterpart in 1950 if the most vitally needed information

could still be found regularly in a small number of readily accessed journals. Does the perceived problem arise in part from the scattering of needed information in a much larger range of journals and books? Such scattering would mean that more time and effort are needed to be comfortably sure that valuable information is not being overlooked or left unfound.

I have tested this hypothesis by looking at the sources of references in articles published in *The New England Journal of Medicine* in 1950 and 1985. Figure 3 shows the data from this ministudy. Clearly, the intellectual foundations of what was published in the *NEJM* in 1985 was much wider by far than in 1950. In 1950 20 journals were the sources for 53% of the cited papers; in 1985 20 journals provided only 38% of the references. I conclude, then, that our perception of an "information explosion" does not arise just from the simple fact of growth in the number of journals and books published. Our perceptions also arise from the scattering of needed information through many more sources now than some years back. I have already mentioned other signals in our environment that probably also affect our perceptions—growing piles of mail, greater numbers of articles per issue in journals, new vocabularies.

How Have We Adapted Through Recent Decades to the Spreading Out and Increasing Complexity of Medical Information?

Medical research and practice have not bogged down or come to a halt since 1950. Obviously we have adapted in some ways that have maintained our capacity to do our work.

First, we have continued to specialize. The human brain is an amazing instrument for storing useful information for rapid access. But it has a limited capacity. So we continue to work our brains to their limits, but we simply carry more information in our heads about smaller intellectual territories. The internist says to himself, for example, that he cannot remember all that is vital for expert practice in all of internal medicine so he decides to confine himself to being an expert on infectious diseases. (I am aware that the economic advantages of specialization in high-technology, high-fee practice have also encouraged specialization.) This ongoing trend might be slowed or even reversed if expert knowledge were rapidly and cheaply available to more practitioners through new kinds of information systems.

Second, we have had great growth through the past three decades in programs for continuing education. The seeker of needed information always goes to the source that is cheapest for the value received. This accounts in part

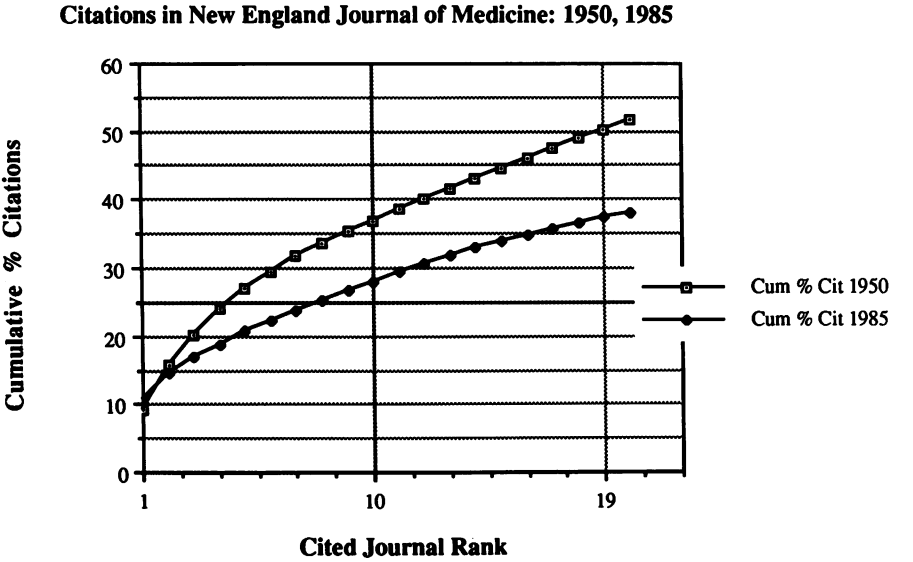

Fig. 3. The cumulative percentages of references in articles in *The New England Journal of Medicine* attributable to the 20 most cited journals: data for 1950 and 1985. In both years the most cited journal contributed about 10% of all references. In 1950 the 20 most cited journals contributed about 52% of all references; in 1985, only about 38%.

for the great growth since 1950 of programs in continuing medical education. These programs are very expensive compared to journals and books in terms of dollars per thousand words received. But these programs offer information distilled by experts from a wide range of primary sources. You pay for experts who will select, distill, and integrate information, and you expect that the experts will deliver only what you really need to know and no more. Whether you put to use what they tell you is another question. If the information you get will enhance your income you probably will use it.

Third, computer storage of huge amounts of information rapidly accessed has enabled us to move much more rapidly through a much larger intellectual landscape than we could 30 or 40 years ago with on-paper indexes such as the print versoin of *Index Medicus*. Simplified entry ("front-ends") into huge files like the National Library of Medicine's "Grateful Med" for MEDLINE are enabling many searchers to bypass search specialists in medical libraries and search MEDLINE at much lower costs in time and fees. The spreading use of MEDLINE files in the CD-ROM format will cut search costs even more.

What Are the Main Problems We Face?

I see three main groups of problems to be faced by producers of medical information (such as professional societies) and the brokers for that informa-

tion (such as the institutions that maintain information sources such as libraries).

First, the growth of medical literature is driven by many more needs than information needs of end-users. These include the social functions of journals for their originating groups and the availability of advertising from burgeoning technologies. The selecting, buying, and storing of the resulting additions to medical literature is increasingly not supported by the putative users of these new products because these additions to the literature do not always arise out of true end-user needs.

Second, the spreading out of useful information into more sources than scanners and searchers can readily access is creating needs for faster and easier access to what is sought in these sources.

Third, the expanding of information into dimensions greater than can be traversed rapidly and efficiently is raising needs for synoptic and critical digestion of needed information. Such digestion and synopsis is costly in intellectual effort that is not well rewarded academically or commercially.

WHAT MIGHT BE SOME NEW ADAPTATIONS AND NEW POTENTIAL SOLUTIONS?

New developments in information storing, seeking, retrieving, and use must not simply arise from technical innovations that happen to become available. For example, the CD-ROM medium and format can hold amazingly large amounts of text. But we should not rush into using CD-ROMs to carry huge amounts of medical text until we have answered the question of what information needs would be better served by CD-ROMs than by other kinds of storage and access. Plans for new developments that are likely truly to serve needs and get put to use must take into account that information seeking is governed, as are other human activities, by economic factors. I contend[7] that use or nonuse of a particular information source is controlled by the utility/cost equation.

$$\text{Value} = \frac{\text{Utility}}{\text{Cost}}$$

This notion is not original with me. I have not systematically searched for all possible antecedents of the idea, but it was nicely developed in Zipf's analysis of information seeking that was guided by his Principle of Least Effort[8]: "...a person in solving his immediate problems will view these against the background of his probable future problems, *as estimated by himself.* More-

over, he will strive to solve his problems in such a way as to minimize the total work that he must expend in solving both his immediate problems *and* his probable future problems. That in turn means that the person will strive to minimize the *probable average rate of his work-expenditure* (over time). And in so doing he will be minimizing his *effort*, by our definition of effort. Least effort, therefore, is a variant of least work.''

In my formulation *utility* is the extent to which information acquired satisfies the seeker's need for solution of a problem or an answer to a question; *cost* is an equivalent of work, an expenditure of a resource derived from previous work, or a resource that could be applied to work alternative to the information seeking.

The value of the numerator, *utility*, is determined by how closely the information obtained fits the seeker's need. A particular kind of information source may be highly valued because it reliably delivers exactly what is needed and no more and delivers highly reliable information.

The value of the denominator, *cost*, is determined not only by purchase or service cost but also by the perceived cost of the time needed for access or retrieval.

$$\text{Value} = \frac{\text{Utility}}{\text{Cp} + \text{Tr} + \text{Tu}}$$

(in which Cp=purchase cost, Tr=retrieval time [a cost], Tu=utilization time [also a cost])

If a lot of time of high value is needed for a search, that is a high cost. This factor accounts for how infrequently practicing physicians use medical libraries for help in solving new clinical problems. This kind of analysis also explains why certain kinds of information sources survive in market competition despite relatively high purchase costs (Table I). Journals survive in part because of their low price. Further, their utility probably lies not only in the extent to which they offer information for specific case problems, which is generally small. Much of their utility may lie in giving their recipients the comfort that comes from the feeling that they are doing what should be done to continue to be well-informed insiders in an esteemed professional community. Audio cassettes are very inefficient vehicles for rapidly needed information but they can be used in time that has no value for generating income, such as the time spent in driving to work. Postgraduate courses are costly in purchase price but offer, as I have already commented, distilled and expertly

TABLE I. APPROXIMATE COST (SALE PRICE) PER 1,000 WORDS FOR THREE TYPES OF INFORMATION SOURCES (1980 DATA)

New England Journal of Medicine	$0.01
Annals of Internal Medicine	$0.02
American Review of Respiratory Diseases	$0.05
Audio cassettes (Audio Digest)	$0.50
Postgraduate courses	$10.00

focused information; they also offer side utilities such as taking one's spouse or close friend to a resort for various kinds of recreation.

From this concept we can conclude that new methods for storing, seeking, and delivering information should be designed so as to deliver only the information needed and no more, information highly specific for the needs, and information that is valid. Further, the methods should be as cheap as possible to acquire and cheap in time to use (Table II). Do not forget, however, that kinds of information needs almost certainly differ among different kinds of seekers.

How Do the Information Needs of Investigators and Physicians Differ?

The medical community is not homogeneous. We have a wide range of kinds of work and, hence, we have a wide range of kinds of needs for information. Therefore, solutions for better access by investigators to information that they need might not help practicing physicians at all.

Science in medicine and the practice of medicine differ greatly. How they differ was described succinctly by Peter Mere Latham[9] well over a century ago: "Medicine is a strange mixture of speculation and action. We have to cultivate a science and to exercise an art. The calls of science are upon our leisure and our choice; the calls of practice are of daily emergence and necessity." Latham's point is well made, but it is not quite detailed enough for our considerations here. Let me sketch out how the information needs of investigators and physicians differ.

1) An investigator usually poses one question (or faces one problem) at a time and works on it for a long period. A physician constantly faces a quick succession of problems that call for rapid solutions.
2) The investigator's problem is usually narrow and readily defined. The problems dealt with by the physician tend to be highly various and fogged by many uncertainties.
3) An investigator's earnings are not tightly coupled to how he spends time from minute to minute and hour to hour. A physician's earnings are

TABLE II. THE IDEAL INFORMATION SOURCE

High in utility	*Low in cost*
Precisely responsive to specific needs	Low acquisition cost
Valid information	Low cost in time to find and consult

tightly coupled to every day's working hours and how they are spent. These differences lead to differences in kinds of information needs and searches.

1) The investigator tends to need an exhaustive search of information sources ("the literature") but at infrequent intervals. The time available for the search is relatively large and can be carried out at relatively low cost in "purchase" and in "time-cost".
2) The physician needs quick access to valid information of immediate and high utility. The time available for a search is small. The "time-cost" for a search is high. The physician has to work mainly with thoroughly digested concepts and with most of the needed data carried in his head; the brain has a very rapid access time. Additional facts needed for clinical decisions must be accessed very rapidly.

Both investigator and physician occasionally have needs like those of the other. The investigator may need quick access to a small and specific piece of technical information; the physician may be willing occasionally to embark on a broad search to deal with a rare problem. Further, both have ongoing needs for general awareness of new developments that may come eventually to have high utility.

These differences seem to me to determine how investigators and physicians use or do not use various kinds of information materials and sources.

Investigators tend to use reports of specific and individual research efforts—journal articles. They tend to carry out searches themselves or to assign them to close professional associates. They have time to assess and to digest individual papers. Synoptic information, such as that in review articles, is used mainly for orientation to a new problem.

Physicians lean heavily on rapid access to information. Discussion with colleagues is both cheap and efficient. They draw frequently on synoptic information in such sources as drug-information handbooks. Journals and libraries are inefficient (time-costly) sources, and journal articles call for too much effort in seeking, reading, and integrating for their frequent use for specific clinical problems.

WHAT CAN WE DO TO MAKE ACCESS TO NEEDED AND RELIABLE INFORMATION EASIER AND CHEAPER?

If my analysis is correct, then we must think about how to change both the numerator and denominator of the value equation as it applies to information sources. We must increase the utility of information carried in medical literature. We must reduce its costs, both purchase and access costs.

OUR NEED FOR BETTER INFORMATION ABOUT INFORMATION NEEDS

Efforts to improve the utility of information sources cannot avoid defining utility in terms of needs. New efforts toward raising the utility of ever growing amounts of increasingly scattered information should start with analysis of needs, known and unrealized. We should not simply hold to present shibboleths and unexamined assumptions.

My discussion so far implies that we know quite a bit about the characteristics of information needs of investigators and physicians and how they seek to fill those needs or fail to do so. The literature relevant to these questions is larger for the needs of investigators (scientists); I have not tried to compile an adequately representative bibliography for it, but one of the best surveys is that of Garvey,[10] based on his work with information development and flow in psychology and its literature.

We know far less about physicians' needs. A small number of studies have been carried out. Among the best of the recently reported studies are those by King[11] and by Covell and associates.[12] Covell's comes closest to the ideal kind of study, one in which the investigator would identify what concepts and discrete facts are needed by physicians as they go about their clinical work: the concepts and facts they pull from their brains, those that have to be searched for among colleagues or other sources, and those not even sought because no sources are known and no time can be spared for exploratory searching. We need more detailed and broader studies of physicians' information needs; a good start would be compilation of a thorough and adequately annotated bibliography and critical review of the relevant literature. I am not dismissing the need for a similar bibliography relevant to investigators' needs. I simply think that the problem of providing information sources for physicians is more difficult and needs the priority. After needs are accurately identified, we can begin to design systems to meet them.

WHAT ARE SOME SOLUTIONS FOR COST PROBLEMS?

The size and spread of literature relevant to the needs of investigators are raising the costs of acquiring and storing it. With the decline in the dollar the

acquisition costs are climbing sharply; with growing competition for capital funds, libraries are getting cramped. Therefore, libraries with large journal collections because they serve mainly investigators must begin to collaborate within economical networks in decisions on how to divide responsibilities for journal holdings. They must collaborate in finding new and faster ways, such as facsimile transmission, to move documents within the networks.

Substantial savings in storage costs could result from digital storage of marginally needed journals in the CD-ROM format. But such conversions are not initially cheap. Entrepreneuers might be willing, however, to invest in such conversions if an adequate market were assured. Therefore, a large consortium of medical libraries (perhaps under the auspices of the Medical Library Association and the National Library of Medicine) should begin to assess what journals should be thus converted and how far back. But such an assessment should not thoughtlessly proceed with present assumptions that were valid only as long as we did not have technical means for rapid teletransmission of documents. Careful new thought should be given to quality assessments by citation analysis and to the "half-lives" of journals' contents. Low value journals should not be held forever; journals of marginal value should be accessible only from a small number of repositories.

How Might We Improve the Speed of Searches?

The most efficient searches of a system such as MEDLINE are probably those done by librarians. More efficient searches might be done by less experienced searchers if better "front-end" or "gateway" programs were available to improve the selection of databases and the selection of entries within them. Such programs might demark topical territories within particular databases and tag entries for documents by type and functions represented. Such changes would be likely to improve searching speed and specificity only if they were responsive to searchers' particular needs. Therefore, libraries should begin to collect and analyze data representing the kinds of searchers and the generic characteristics of the searches they wish to carry out. Particular attention should be given to needs presently unmet.

Most journals are doing little today to improve how their papers are characterized in databases; most tagging is done by indexers. If the kind of information I suggest above that libraries should collect does become available, libraries (and notably the National Library of Medicine) should develop standard types of tags and formats and require journals thus to characterize the papers they publish. An important study by Perry Miller and colleagues[13] of semantic descriptors for functional, causal relationships expressed in ab-

stracts could lead to much more efficient retrieval of relevant papers through index-and-abstract databases. My journal has taken some steps in this direction with adoption last year of the structured abstract developed by Brian Haynes and his colleagues[14] for papers reporting prospective trials and assessments. The format of the structured abstract forces authors to be more specific and accurate in representing a paper's content and thus speeds the searcher's assessment of whether to spend more time with the paper. This concept has not yet been applied widely, but I have noticed that the British journal of gastroenterology, *Gut*, is beginning to use it, although without overt structure.[15] The *Annals of Internal Medicine* has just published a paper[16] that applies the same principle to abstracts of review articles, and we are already asking authors of reviews to prepare their abstracts with the new format. Wider application of this principle of better tagging of papers may need better classifications of types of documents; this is also a kind of study that librarians are well equipped to carry out.

How Might We Particularly Help Physicians?

I have discussed the special problems that limit the use of journals and books by physicians: the high cost in time for searching them for needed information and physicians' special need for synoptic and highly reliable information that can be rapidly accessed.

The high cost of search time might be lowered by educational programs to train lower-cost personnel in search methods. I am not thinking of librarians; I am thinking of office assistants who might be trained to search MEDLINE, for example, and to present physicians with printouts from which they could select the documents of greatest promise of usefulness. Retrieval and delivery of the selected documents would be requested of the librarian. Therefore, I suggest some pilot programs to test the possibility of training low-cost personnel in MEDLINE and other database searching. I am thinking specifically of physicians' office staff—secretaries, nurses, assistants—and not of librarians.

But even if physicians get their hands more easily and cheaply on relevant journal articles, will they use them? Physicians will not, in general, take time to assess critically numbers of journal articles in search of reliable conclusions; the time-cost is too high. They may use synoptic information they consider reliable and can be accessed rapidly. But developing highly useful synoptic information is costly in somebody's time. Therefore, good synoptic information will be developed by individuals only when it will have a profitable market, with profit in immediate pay or in professional reputation. More

of the development of synoptic information should be the responsibility of professional societies. But it may be easier to increase collaborative efforts in the building of synoptic information within individual institutions such as hospitals. For example, residents often have to find journal literature relevant to a grand-rounds presentation. If they have been properly trained in critical assessment of journal papers, their judgments and digests could be saved in a departmental microcomputer-maintained bibliographic database for use by others later. The same use could be made of article critiques developed for a journal club in a residency program. Therefore, I suggest that medical libraries consider developing programs to train clinical departments in how to build their own synoptic databases that will preserve for future consultation the intellectual work that has been done for particular case needs.

CLOSING REFLECTIONS

The present and future problems of buying, storing, accessing, and using information needed for research and clinical work will not be solved by individual institutions. Their resources are limited and competition for them is unremitting. And few people in individual institutions, other than librarians, have a grasp on the size of the problems, such as do, for example deans, see other problems as bigger. Therefore, librarians cannot be passive goodbodies waiting to serve; they must join in getting done what they know we need. Much is, in fact, being done by the community of American medical libraries. Some of the possibilities for new efforts I have suggested are well known in the library world, and we can be proud of how rapidly the National Library of Medicine is moving to solve today's and tomorrow's problems. But the greater the number of us working on these problems, the better.

I hope the menu laid out here has enough substance to make its components worth chewing on.

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