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Integrated Multimedia Timeline of Medical Images and Data for Thoracic Oncology Patients

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Integrated Multimedia Timeline of Medical Images and Data for Thoracic Oncology Patients[1]

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A prototype multimedia medical database has been developed to provide image and textual data for thoracic oncology patients undergoing treatment of advanced malignancies. The database integrates image data from the hospital picture archiving and communication system with textual reports from the radiology information system, alphanumeric data contained in the hospital information system, and other electronic medical data. The database presents information in a timeline format and also contains visualization programs that permit the user to view and annotate radiographic measurements in tabular or graphic form. The database provides an efficient and intuitive display of the changing status of oncology patients. The ability to integrate, manage, and access relevant multimedia information may substantially enhance communication among distributed multidisciplinary health care providers and may ensure greater consistency and completeness of patient-related data.

■ INTRODUCTION

The care of patients with cancer represents a substantial departure from traditional ambulatory medical practice. These patients are committed to complex, lengthy multimodality treatments that have potentially significant morbidity rates. Large amounts of clinical and imaging data may be generated for extremely ill patients, and trends may become difficult to identify. Several oncology groups have realized the need for computer-based decision-support systems that can organize patient-specific information according to a care continuum rather than as a series of event-specific data (1-3). Most of these systems have been designed to integrate alphanumeric data exclusive of radiologic data. Although medical images are inherently visual, their content is communicated primarily as free text. It is often intuitively easier to grasp changes in tumor burden by directly reviewing pertinent image data (4,5). Moreover, in contemporary medi-

Abbreviations: KMeD = Knowledge-based Multimedia Medical Distributed Database, PACS = picture archiving and communication system

Index terms: Computers, multimedia • Radiology reporting systems • Radiology and radiologists, design of radiological facilities

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cal oncology practices where large numbers of patients are enrolled in clinical trials that require meticulous data management and scrutiny, a visual record that abstracts pertinent information would serve critical auditing needs. The unique character of image data poses a challenge to traditional medical information science: how best to integrate and display image data with other electronic medical data to convey information efficiently and intuitively.

We have designed a prototype database management system in which medical images and alphanumeric clinical data relevant to thoracic oncology are presented by using a graphically oriented visual timeline. The system was implemented by using technologies under development by the Knowledge-based Multimedia Medical Distributed Database (KMeD) system research team at our institution (6-8). These technologies include comprehensive object-oriented data models, process models, database integration strategies, multimedia query processing, and the integration of database and data visualization methods. The user interaction paradigm for the timeline was determined by performing a comprehensive data and process modeling exercise that described the tasks performed by both radiologic and medical personnel while caring for thoracic oncology patients. Those specific tasks that would be most significantly affected by the clinical implementation of the timeline were identified and analyzed.

The Oncology Imaging Timeline functions as a common documentation medium for medical oncologists, other oncologic care providers, and thoracic radiologists. Support programs collect, abstract, and insert into the timeline electronic patient information from our radiology information system, hospital information system, and picture archiving and communications system (PACS). The resulting multimedia timeline expresses the temporal continuum of medical care for thoracic oncology patients. By presenting the data in timeline format, the database gives the passage of time a visual dimension. The reader observes both the actual image data, with related computations, as well as graphic icons that relate to other types of clinical data. The icons provide hypertext-style links to more comprehensive report information (eg, laboratory, admission, discharge, pathology, history, physical examination, consultation).

An additional result of the timeline was improvement in the consistency of data entry and image-related computations. Radiologic assessment of the size and number of tumor lesions is often the primary or sole means of determining tumor response in oncology patients. The measure of tumor response is defined according to criteria established by the World Health Organization (9). This measurement is based on changes in specific indicator lesions such as the primary tumor and other metastases. These changes are measured by using cross-sectional or projectional image data. For example, the area of a particular lesion on a computed tomographic (CT) scan is the product of its maximum diameter multiplied by the largest diameter perpendicular to its maximum diameter determined at the widest axial level of the lesion. The accuracy of these measurements is limited by technical factors (eg, volume averaging effects, differences in axial plane of section between different CT examinations) and observer variability. Observer variability in the calculation of tumor area can result from differences in the axial planes selected for measuring diameters or, with irregularly shaped masses, from differences in exactly how diameters are selected. These inconsistencies may cause misrepresentation of radiographic trends in tumor burden. Variability is greatest when the lesions are small; slight technical or computational differences result in a larger percentage of variability in the total volume computed for these lesions (10). CT studies of lung cancer staging have shown moderate interobserver variability in the measurement of mediastinal lymph nodes; this variability has been greatest for small lesions and specific lymph node chains (11). The Oncology Imaging Timeline partially addresses problems relating to observer variability by providing a mechanism for permanently indexing and annotating the images from which lesion diameters are determined. In addition, intelligent image-navigation software incorporated into the PACS workstation provides an efficient platform for sorting high volumes of examination and image data—such as those typically obtained for oncology patients undergoing treatment. This system is especially useful for tracking the tumor burden of patients who undergo frequent imaging examinations.

In this article, we describe the Thoracic Oncology Imaging Timeline and its main components. Process models from which the timeline functionality were based are illustrated by the hypothetical examples of the principal users of the timeline, the radiologists and medical oncologists. The logical data model and the stream model are also described. Finally, details of the hardware and software requirements for clinical implementation of the timeline are reviewed.

Figure 1. The main screen of the Oncology Imaging Timeline is shown.

■ COMPONENTS OF THE TIMELINE DISPLAY

The interface developed for the Thoracic Oncology Imaging Timeline is a custom layer built on top of the KMeD database server designed specifically for our thoracic oncology application. In a filmless environment in which primary radiologic diagnoses are made with use of soft-copy displays, the timeline would be incorporated directly into the radiology workstation. It is possible to build custom interfaces for other applications in the same manner; alternatively, the generic KMeD interface can be used. This generic interface allows greater flexibility in querying and retrieval of data at the expense of user interface complexity (12). There are four primary parts of the main display (Fig 1): (*a*) the main patient list; (*b*) a detailed abstract of the patient oncologic and imaging history; (*c*) the imaging timeline; and (*d*) the document timeline, which contains alphanumeric data from the electronic medical record. The user interface includes a mouse and keyboard.

• Patient Information

The main patient list includes all patients from the Lung Cancer Clinic whose data are entered into the timeline. After a specific patient has been selected, various aspects of the patient's oncologic and imaging history are displayed. The following information is provided: patient name, sex, age, and date of birth; hospital number; lung neoplasm by histologic type and grade; clinicopathologic TNM stage; treatment plan into which the patient has been entered; treatment cycle and day; imaging examination list; and tabular description of the indicator lesions.

Selection of an imaging examination will initiate the display of indicator lesions specific to that examination. These lesions are tabulated on the "imaging findings" menu with a description (eg, primary lesion, lymph node metastasis), location, and pertinent measurements (Fig 1). If the user specifies a lesion, details about

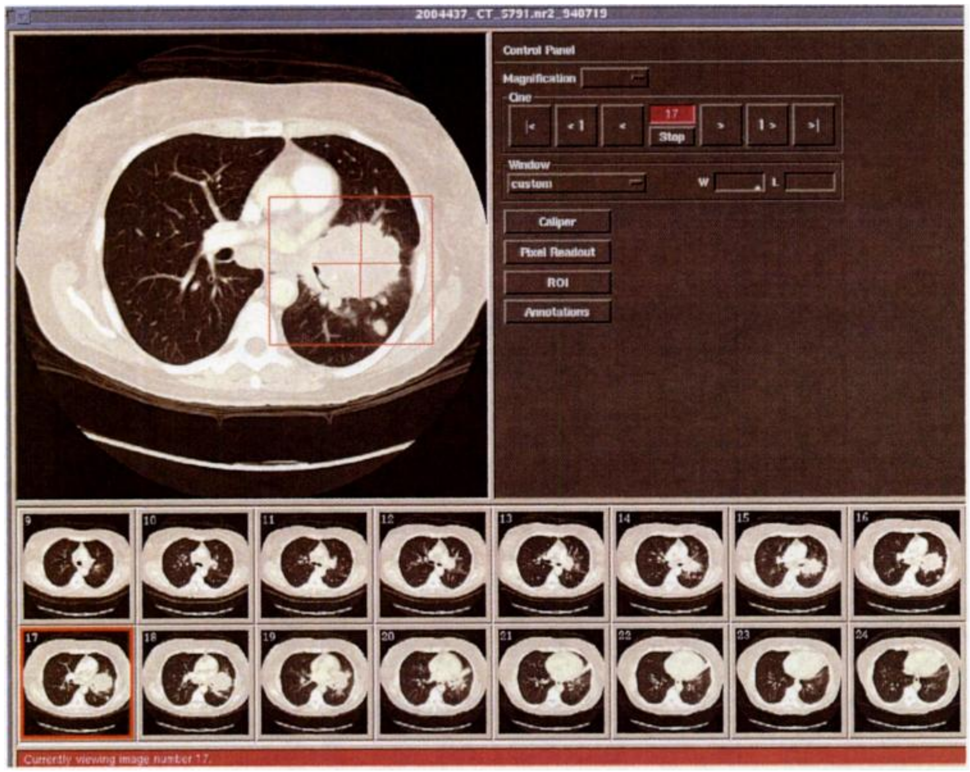

Figure 2. Screen shows the result of invoking the examination visualization tool on the first image seen on the main screen. The tool is invoked by requesting that a timeline image be "opened in full" from the main timeline display. The visualization tool provides the following features: (*a*) a primary view or a single enlarged image on which cine viewing or basic image analysis may be performed; (*b*) a tile format from which the entire data set from a multi-image examination can be reviewed in lower resolution; and (*c*) the control panel, which allows the user access to the cine function, window-setting adjustments, and basic image analysis tools such as measuring calipers and attenuation data.

that lesion appear on the right-hand side; the image number in the study from which the lesion was extracted, the window level settings, and graphs or tables of the lesion's measurements over time are shown.

• Imaging Timeline

The most prominent portion of the timeline interface is the imaging timeline itself. Each row of the imaging timeline represents the temporal history of one indicator lesion. The individual frames are aligned so that the user can also read the display vertically as an imaging abstract of the patient's tumor burden at the time of one imaging examination. The imaging timeline display also determines the way in which time is scaled in the document timeline, so that documents are temporally aligned with the imaging data.

For each indicator lesion, a region of interest is defined around the lesion at the time of formal radiologic interpretation. When invoked, the imaging timeline uses this region of interest to center the individual time frames around the indicator lesions. The region of interest, as seen in Figure 1, appears as a red rectangle; the diameters drawn electronically by the radiologist to determine cross-sectional areas are permanently stored and linked with the derived size calculations.

On the imaging timeline display, scroll bars enable the user to view all time frames for the selected lesion (horizontal scroll) or all indicator lesions for a given time (vertical scroll). With the mouse, the user can magnify portions of the image, permanently annotate the image, or invoke the examination visualization tool to review the complete image data set from which a selected image frame originates (Fig 2).

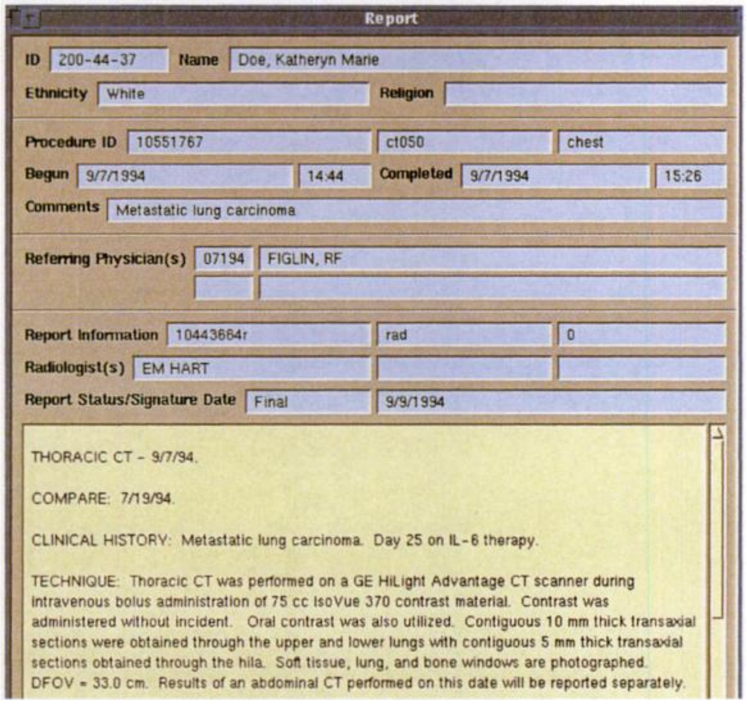

Figure 3. Screen for a textual radiology report is shown. The report is invoked by clicking on the radiology report icon in the main timeline display. From this display, the textual report generated at the time of formal interpretation can be accessed, as can a variety of imaging data that are automatically entered by the technologist at the time of image acquisition. Scroll bars allow the entire report to be reviewed if it extends beyond the viewable space.

The examination visualization tool includes three features. The first is a primary image view, which provides an enlarged display of a single image at full resolution, as well as the marked region(s) of interest and all annotations. From the primary view, the user can make annotations or perform additional operations such as anatomic or attenuation measurements as necessary. Because the visualization tool is built within an object-oriented environment, it is easy to incorporate additional functions as dictated by practice needs. The second feature is the comprehensive tile view, which displays the entire examination as a set of thumbnail icons at 128 × 128-pixel resolution. The image displayed in the primary image view is highlighted with a colored border. Any tile image may be selected and displayed in the primary view at full resolution. Because most cross-sectional CT chest studies consist of 40 or more images, the user can page up or down in tile view as necessary by using the control panel. The third feature, the control panel, includes a number of image-navigation tools, including a magnification menu, cine mode controls to allow for rapid movement of images in the primary image view, preset and manual window width and level settings, primary view buttons that allow the user to jump to the first and last images in the examination, annotation features, and basic image analysis tools.

• Document Timeline

Below the imaging timeline is the document timeline, which parallels the time scale established by the imaging timeline. Within the document timeline, icons representing specific kinds of reports or events are presented according to when the event occurred. The icons include miniaturized CT scans for textual radiology reports, red blood cells for pathology reports, test tubes for clinical laboratory reports, and notebooks for other medical documents. When more than one report or event occurs on the same date, the icons are "stacked" together (Fig 1, lower left corner).

Event or report icons function as hypertext-style links to the reports themselves. By clicking on the icon, the user invokes a full display of the corresponding report or event (Fig 3). Medical reports generally consist of two main sections: (*a*) a set of fields, such as the date of the report, historic comparison reports, reporting physician, referring physician, and other ad-

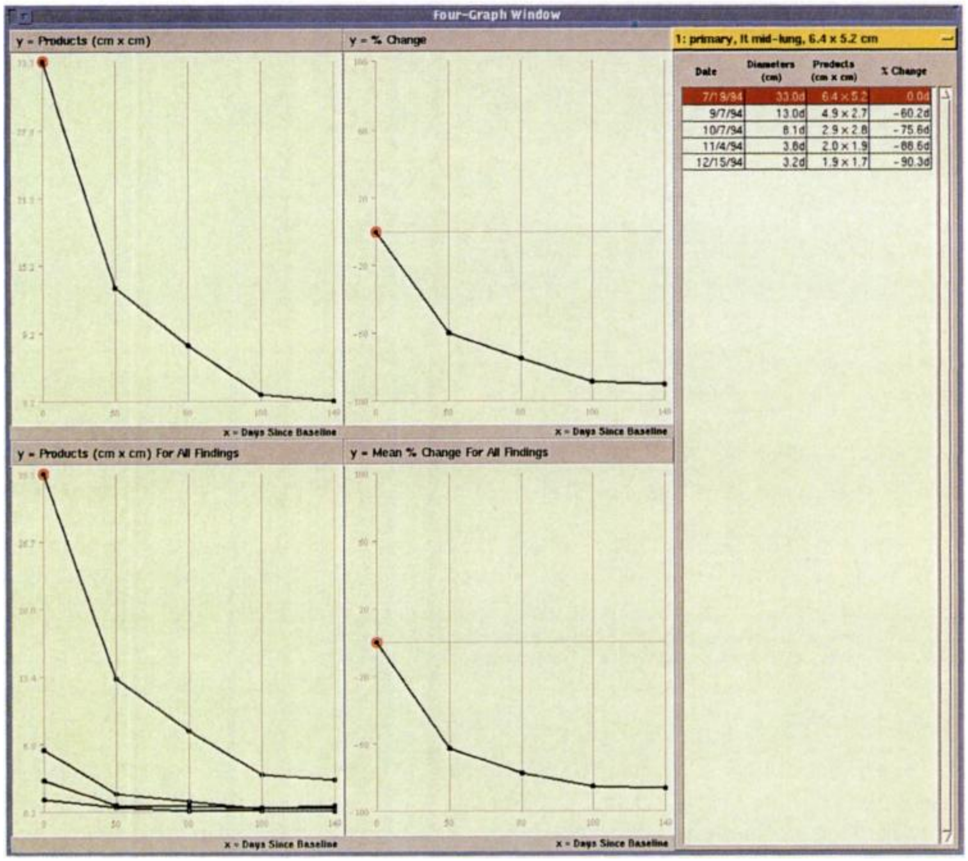

Figure 4. Graphic and tabular views are shown. The full graphic and tabular views are invoked by clicking on the "full view" button of the timeline display. These graphs and tables summarize the changes in size of each indicator lesion over time with respect to the baseline data.

ministrative information and (*b*) the full text section, which is the formal free-text description of the report. Selecting the icon for clinical laboratory reports will invoke a tabular display of the available kinds of laboratory data. From this menu, the desired data, such as white blood cell counts, can be selected. Available data are displayed in tabular fashion according to date, and time is bracketed such that the particular date represented by the icon appears in the middle of the table and is indicated in color. This permits the user to have access to all the patient's electronic medical information without each clinical laboratory report being represented by an individual icon on the document timeline. To prevent the document timeline from becoming excessively cluttered with icons, only specific dates (such as a particular day within the treatment cycle) or critical laboratory values are represented by a clinical laboratory icon; the values to be included on the document timeline can be selected in a treatment- or patient-specific manner.

• Graphs and Tables

The main timeline display includes miniature graphs for the selected indicator lesion. On these graphs, all calculated measurements such as lesion area (the product of the perpendicular diameters) and the percentage change in these products from baseline are charted over time. These calculations are performed by the radiologist at the time of formal interpretation by using basic image analysis tools. The measurements are mapped to square millimeters or centimeters by using calibration information provided within the PACS image study headers.

Radio buttons are available to the right of the minigraph views for selecting graphic or tabular views of the measurement data. Radio buttons located to the right of the minigraph views toggle between the graphical or tabular displays of the measurement data. If a more comprehensive data display is required, the user can click on the "full view" button in the upper right-hand corner of the lesion detail display to invoke a full graph and table window (Fig 4).

The full graph window contains enlarged versions of the minigraphs in the main timeline

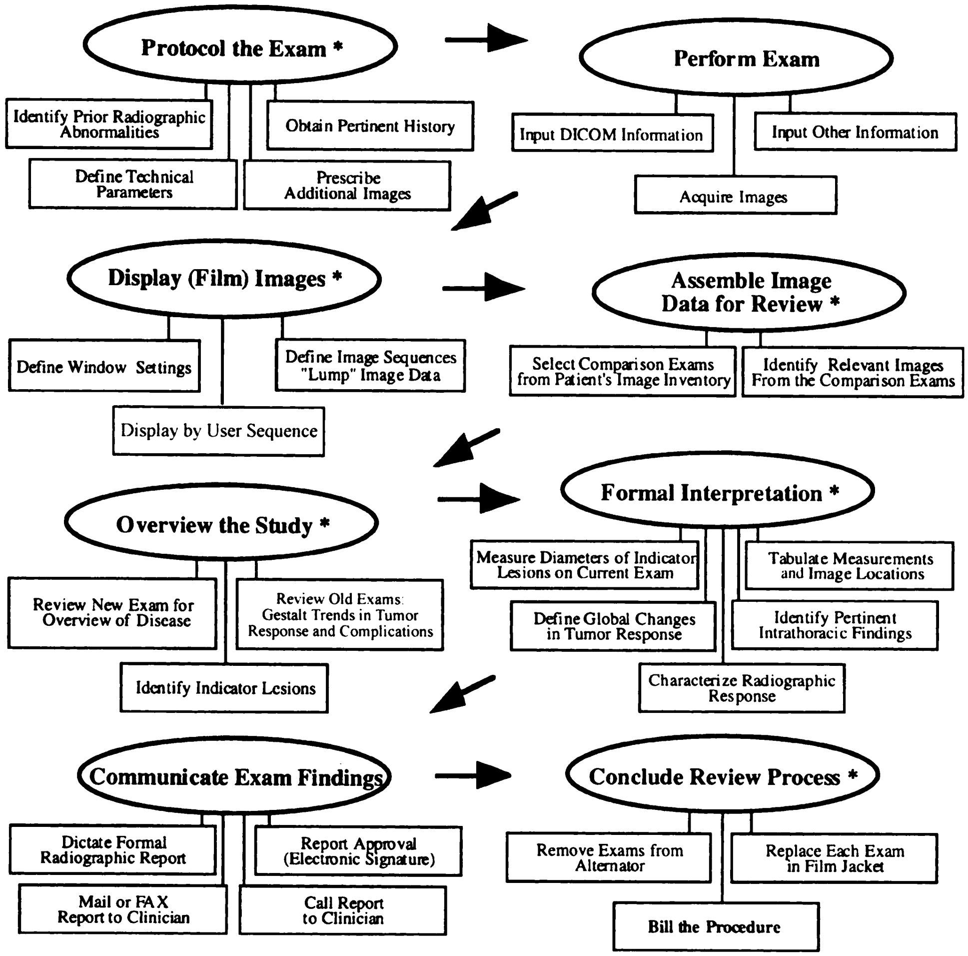

Figure 5. Process model for the radiologist describes the processes and activities involved in the care of thoracic oncology patients. The timeline will affect several aspects of each user's activities; asterisks indicate the processes that will be most directly affected.

display. In addition, it integrates a measurement table and two summary graphs. The individual measurement graph, the size change graph, and the measurement table all pertain to the indicator lesion selected when the full view button was clicked. Once the full graph window has been invoked, a different lesion and its corresponding graphic data can be selected from a menu in the upper right-hand corner of the full graph window. In addition, two summary graphs are shown at the bottom of the full graph window. These summary graphs consist of a combined display of size measurements for all indicator lesions and the mean percentage change in total measurable disease relative to baseline measurements. These data can be directly extracted for auditing purposes when patients are entered into formal treatment protocols.

■ PROCESS MODELS

The graphical user interface and the functionality of the workstation are based on process models that describe the activities of the various users who provide care for patients with lung cancer (Figs 5, 6). Although the clinical implementation of the Thoracic Oncology Imaging Timeline will influence virtually all aspects of the radiologic and medical oncologic processes, the practical functionality of the timeline is best understood by means of descriptions of the principal users: (*a*) the thoracic radiologist who formally interprets the images and evaluates the patient's radiographic response to treatment and (*b*) the medical oncologist who is responsible for the overall care of the patient.

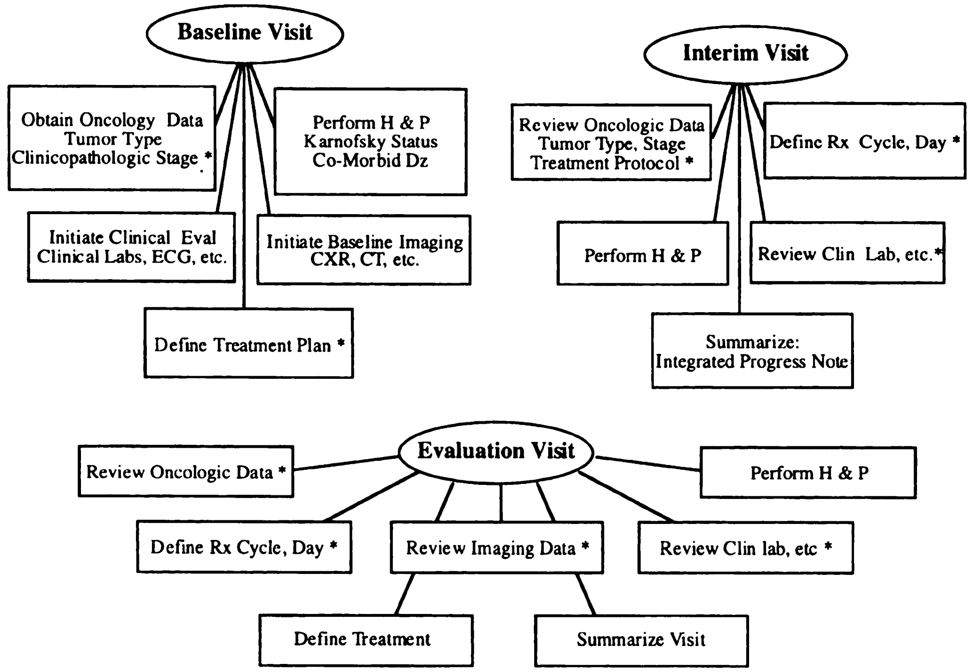

Figure 6. Process model for the medical oncologist describes the processes and activities involved in the care of thoracic oncology patients. The timeline will affect several aspects of each user's activities; asterisks indicate the processes that will be most directly affected. *Clin* = clinical, *CXR* = chest radiography, *Dz* = disease, *ECG* = electrocardiography, *Eval* = evaluation, *H & P* = history and physical, *Rx* = treatment.

• Thoracic Radiologist

The thoracic radiologist receives a request for a follow-up examination of a patient with advanced lung cancer who is enrolled in one of the treatment protocols of the National Cancer Institute. The radiologist can sign onto the workstation and select the patient's name from the Lung Cancer Clinic directory listing. The system responds by displaying the patient's cancer diagnosis, initial clinicopathologic stage, and treatment protocol and by tabulating descriptions of all prior imaging examinations. By selecting the most recent examination, the radiologist can immediately review the technical parameters used to acquire that study. These parameters will be repeated in the current study to facilitate comparison with prior examinations. If intravenous contrast material will be administered, current laboratory indexes of the patient's renal function can be accessed by selecting the clinical laboratory icon from the document timeline. The radiologist can communicate the necessary technical parameters to the technologist by telephone.

To become familiar with the patient's imaging history, the radiologist reviews the thumbnail icons for the baseline and prior CT examinations that are incorporated into the imaging timeline. These icons are miniaturized displays of the indicator lesions used to determine tumor response after each cycle of therapy. The icons provide the radiologist with an immediate visual abstract of the patient's history of tumor response to treatment. The radiologist can also invoke the graphic display to review the percentage change in size of indicator lesions from all previous examinations.

After it is completed, the examination is stored on the PACS archive and can be retrieved at the radiologist's workstation along with the previous examinations. Ideally, the radiologist's workstation will toggle between a primary diagnostic review mode and the timeline mode or will include separate hardware platforms on which the image-viewing monitors and the timeline are situated. The radiologist can select the examination to be interpreted from the list of unread examinations; image display and navigation schemes are customized for the particular radiologist's viewing preferences. In cine fashion, the radiologist quickly overviews the current and baseline studies to obtain a visual gestalt of gross changes over time. The radiologist can then select the images from the new examination that illustrate the indicator lesions. After the lesions are measured, images can be annotated and automatically stored on the timeline so that all measurements are permanently recorded and indexed for that image. All measurements are referenced according to the indicator lesion and image number for the permanent records. This process is repeated for each indicator lesion; the information is automatically correlated with the prior measurements for each indicator lesion, and the percentage changes from baseline values are calculated and incorporated into both the graphic and tabular displays.

Any other pertinent intrathoracic findings or changes in tumor burden can also be incorporated into the timeline. There may be a new finding, such as a lytic lesion of the right clavicle with an associated incomplete fracture. The radiologist can review all prior CT scans to confirm that this is a new abnormality. The soft-tissue component of the lesion can be measured, and the relevant images from both the current and prior examinations can be incorporated into the timeline for future reference.

The radiologist then completes the textual report associated with the current examination; he or she makes all relevant comparisons and provides a descriptive and numeric summary of tumor response. Tumor response is automatically calculated, based on measurements of the indicator lesions previously entered into the database, although the radiologist may override this calculation if necessary. The textual report (whether in written or audio version) is linked with the appropriate study and is associated with a radiology report icon on the document timeline, where it can be accessed for review. After the radiology report is signed electronically, the consultation is automatically forwarded by facsimile or mail to the clinician. When the "image folder" of the current patient is closed, billing information is forwarded to the billing offices for processing.

• Medical Oncologist

The medical oncologist at the Lung Cancer Clinic reviews the names of all patients with appointments in the thoracic oncology clinic that day. Some patients are there for a baseline visit; the remaining patients are returning for either interim visits, during which treatment complications or toxicity are assessed, or evaluation visits, during which tumor response and treatment modifications will be determined.

Baseline Visit.—During a baseline visit, a new patient is seen. The patient may have, for example, a diagnosis of stage IV non-small cell lung cancer with metastatic spread to the liver. In this example, the patient's diagnosis was established after a recent hospitalization for acute pneumonia, at which time the patient underwent radiologic imaging and staging with percutaneous needle aspirations of the lung and liver. The radiologic, pathologic, pulmonary function, and clinical laboratory data from this hospitalization are already available for review on the document timeline at the workstation.

After reviewing the medical background, the medical oncologist refers to the timeline for a summary of currently available treatment protocols. This material is updated continuously (either manually by data coordinators or through compact disk, read-only memory systems connected to the workstation) and includes eligibility criteria, specific components and timing of the treatment protocol, potential complications of treatment, and necessary baseline and follow-up clinical data. After selecting a potential treatment plan, the oncologist visits the patient to obtain a complete history and to perform a physical examination; the oncologist then determines the patient's Karnofsky status and discusses treatment options. After the patient's written informed consent to undergo treatment has been obtained, the oncologist can order the clinical laboratory tests and baseline imaging studies necessary for the treatment protocol. The dictated report from this baseline visit will automatically be incorporated into the document timeline.

Evaluation Visit.—The next example is of a patient with a diagnosis of advanced lung cancer who is receiving ongoing treatment. The medical oncologist reviews all pertinent timeline data, which include the original tumor stage and histologic findings as well as the present treatment cycle and day. Knowing that leukopenia and thrombocytopenia are common side effects at this time after therapy, the oncologist reviews the most recent peripheral blood cell counts from the document timeline and finds that the patient has moderate pancytopenia. Review of past chemotherapy treatment reveals that during the last treatment, the doses of some of the chemotherapeutic agents were reduced because of significant leukopenia.

Results of CT examinations performed after this most recent treatment cycle can be reviewed on the imaging timeline. The icons that correspond to the indicator lesions being monitored as well as the graphic displays of their percentage change in size from baseline measurements can be viewed. In this example, there is a new image "snapshot" depicting a pericardial effusion. The textual report associated with the recent CT examination has been incorporated into the document timeline, which allows the oncologist to review the summary statement from that report for clarification. After performing a focused history and physical examination, the oncologist will prescribe a fourth cycle of treatment at adjusted doses. All clinical information, diagnostic plans such as additional tests, and conclusions of this visit will be incorporated into the document timeline as part of the evaluation visit.

■ LOGICAL DATA MODEL

A logical data model was developed that describes the relationships, for an individual patient, between various health care activities and biologic processes. This model describes the kind of data to be tracked, as well as the relationships between different types of data. The logical data model of the database for the Thoracic Oncology Imaging Timeline (Fig 7) uses an expanded version of the combined object and entity relationship model described in the KMeD system (13). New constructs are capable of expressing objects that exist as a series of multiple states through time. These constructs have also been successfully applied to other clinical endeavors (6).

• Patients, Procedures, and Processes

The data model stores an individual "patient" as an entity that undergoes one or more "health care activities." The database has a bidirectional, one-to-one correspondence such that any given health care activity is performed for only one patient. The database tracks several different types of health care activities, including radiologic procedures, pathologic procedures, laboratory procedures, and other diagnostic procedures (pulmonary function tests, history and physical examination, and others). Each of these procedures results in a "report" that states "findings." "Diagnostic conclusions" are the aggregation of all findings.

Diseases that can be measured or evaluated, such as the "primary lesion" or "adenopathy," are "radiology findings." Collectively, these findings determine "total radiographic tumor extent." These radiologic findings are visually represented on the timeline by time-stamped frames that capture temporal changes in the patient and in the tumor extent. Finally, "total radiographic tumor extent" has a relationship to the "biologic function," which in this medical data model is "lung neoplasm."

• Radiologic Reports, Images, and Findings

"Radiology procedures" result in "radiology reports" that state one or more "radiology findings." The radiology report is the textual description of the "radiology findings" extracted from the "radiology image(s)." Natural language-processing algorithms and expanded medical metathesauruses that include descriptive radiologic terms have been developed that allow these reports to be analyzed automatically to extract concepts and findings (14).

This system will support all forms of digital image data, including projectional images, CT scans, magnetic resonance images, digital angiograms, positron emission tomograms, and others. Calculations of tumor volume derived from imaging examinations are linked with the appropriate examination. A "radiology procedure" contains a "radiology image stack," which is a stack of one or many "radiology images" from which "radiology findings" are extracted.

As can be seen in Figure 2, "radiology findings" are visually represented by a frame within the timeline. For any given finding such as a primary lesion, frames acquired at different points in time are linked to form an image stream that temporally sequences frames for review as a single entity. Alphanumeric data are managed similarly as a document entity. However, in the case of textual data, the frames correspond to similar kinds of time-ordered data from pathologic, laboratory, or "other diagnostic reports."

■ STREAM AND TIMELINE MODELING

Inherent to the Oncology Imaging Timeline is the ability to capture temporal evolutionary changes through the use of the stream entity, which allows a sequence of real-world objects to be related over time. The timeline includes

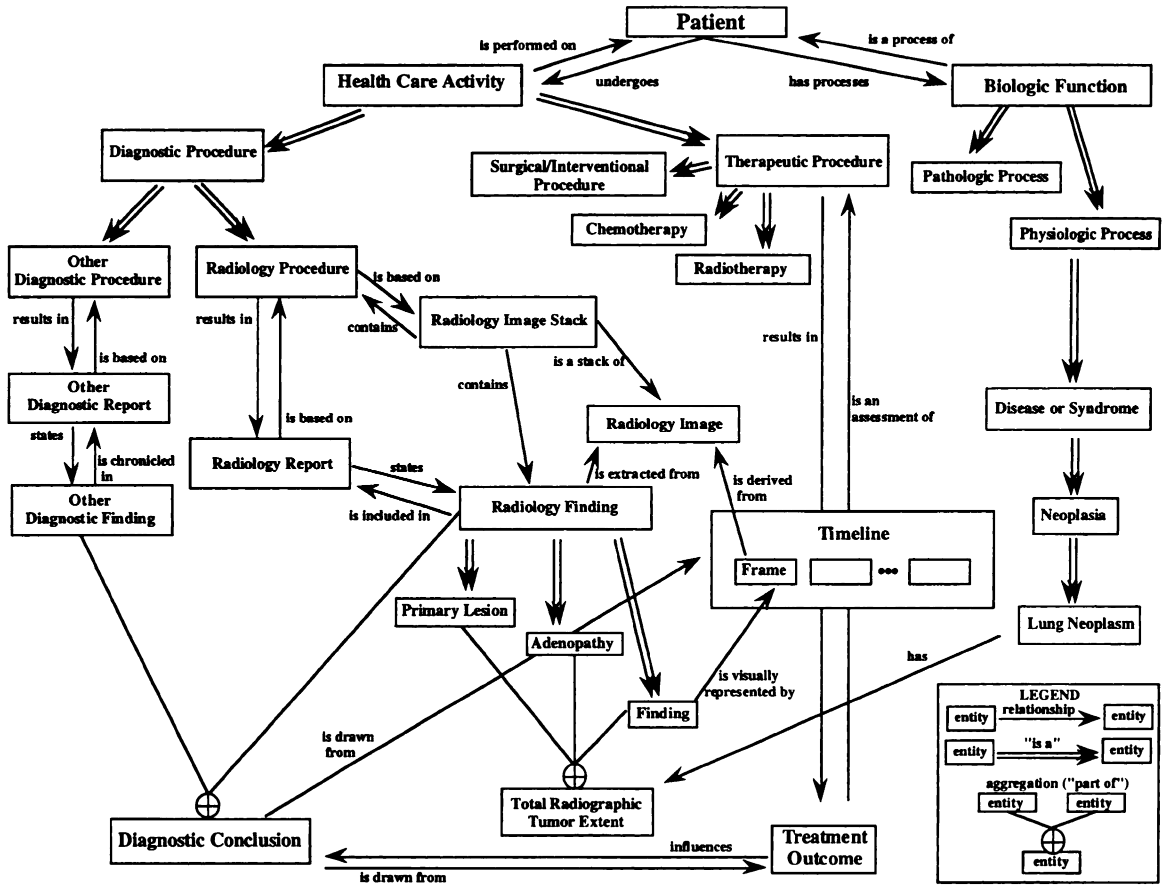

Figure 7. Data model describes the kinds of data to be tracked for each patient as well as the relationships between different types of data.

both image and document streams. Image streams allow images to be viewed as a series of snapshots that capture the states of a radiographic abnormality, with each snapshot or state representing the finding at a particular time. Document streams chronicle sequences of events or milestones such as changes in white blood cell count during the course of chemotherapy. Each component of the stream therefore corresponds to some finding, event, or object that possesses a definite time stamp.

Because one of the central purposes of the database is to provide an immediate, intuitive measure of tumor response to treatment, individual radiographic findings such as primary lung lesions are visually stored as snapshots or "frames," and frames of the same lesion are extracted from sequential examinations. The frames are annotated to reflect the locations and corresponding measurements of the lesions, such as diameters or areas. With volumetric image data, the volume of the lesion can be calculated, and all images on which tumor measurements were made can be accessed from a single image frame, which usually corresponds to the image obtained at the point of the greatest cross-sectional diameter of the lesion.

Alphanumeric data from the electronic medical record are similarly time stamped and are visually represented by icons that denote clinical laboratory, pathologic, or other medical documents. The icons localize and date the acquisition or completion of the respective procedure. In instances in which a procedure is frequently performed, the frames localize particular milestones. For example, although complete blood counts are routinely performed at weekly intervals in some clinical protocols, a single icon localizes laboratory information obtained at a specific time, such as day 10 after the beginning of chemotherapy, or localizes abnormal test results of clinical importance. Clutter of the timeline display by excessive numbers of icons is thus prevented.

The individual image streams that illustrate all indicator lesions or other significant radiographic findings are combined with the document stream to form an integrated imaging timeline that represents a comprehensive visual history of the patient's medical course. The formal data modeling supporting this aggregation of stream entities automatically provides temporal synchronization and alignment, so that images and documents are displayed in the correct temporal order when viewed as a whole. This integrated construct is an image- and alphanumeric-inclusive abstract that can be used to access the comprehensive history of the patient. This history is normally stored separately in the PACS and the radiology and hospital information systems.

■ HARDWARE AND SOFTWARE IMPLEMENTATION

Application of the Oncology Imaging Timeline depends on the technology and infrastructure made available by the PACS and our KMeD research group (6,8,12,13). The PACS infrastructure is necessary to acquire, store, and communicate imaging studies to the radiologist's and oncologist's workstations. KMeD technology provides transparent access to the database management systems of the radiology and hospital information systems and a means to develop object-oriented data models for the comprehensive characterization of all data relevant to the oncology timeline.

The system is driven by a Sun Sparc 20SX computer (Sun Microsystems, Mountain View, Calif) with 128 Mbyte of memory and a 6-Gbyte redundant array of independent disks (RAID). The user interface for the timeline was written by using the VisualWorks object-oriented development system (ParcPlace Systems, Sunnyvale, Calif). The patient text and the contour information are uploaded from hospital and radiology information systems into an object-oriented database management system (Gemstone; Servio, Alameda, Calif). The radiology workstation software for defining contours and viewing complete patient studies was written in C programming language with calls to the X11 libraries and using the Xview library calls that run under the OpenLook 3.0 tool kit (Sun Microsystems, Mountain View, Calif).

■ CONCLUSIONS

The purpose of any medical information system is to support and enhance the care of patients. The system must capture, index, and display information from different sources so that the providers of care can understand the relationship between symptoms, treatments, and consequences. The Oncology Imaging Timeline is the product of a multidisciplinary effort in thoracic oncology to promote more efficient communication of medical data for patients with complicated thoracic oncologic diseases. By working together, we have designed an integrated database that addresses the limitations of the highly distributed environment of contemporary subspecialty practice as well as the current heterogeneity of medical databases.

The timeline is an image- and alphanumeric-inclusive abstract of the patient's electronic medical record that logically groups medical data according to time. The benefits of intelligent image navigation provided by PACS infrastructures are incorporated into an electronic architecture that seamlessly integrates information from radiology and hospital information systems. The addition of data to the timeline initially will be primarily manual and therefore time intensive. However, the introduction of automated mechanisms for retrieving alphanumeric data from radiology and hospital information systems will make the task considerably easier.

Through detailed process models of the activities involved in the treatment of these patients by both the radiologist and the medical oncologist, those areas in which this system can improve the quality and efficiency of dialogue between the subspecialists have been identified and developed. The system is also highly effective as a means of improving the consistency and completeness of medical information. As advanced concept-based (rather than simple keyword) querying capabilities become available, this database will be an extremely valuable tool for addressing clinical outcome questions and other research needs. Future efforts will be directed to the practical implementation of this system, the objective documentation of its ability to enhance the communication of information between members of the integrated health care team, and the improvement of the functionality of the timeline through clinical experience.

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