A Multimedia Database System for Thermal Ablation Therapy of Brain Tumors

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A prototype multimedia medical database is described for supporting thermal ablation therapy of brain tumors. Its design is motivated by the major need to manage and access multimedia information on the progress and reaction of tumors to various therapy protocols. The database links images to patient data in a way that permits the user to view and query medical information using alphanumeric, temporal, and feature-based predicates. Visualization programs permit the user to view or annotate the query results in various ways. These results support the wide variety of data types and presentation methods required by neuroradiologists to manage thermal ablation therapy data. The database satisfactorily meets the requirements defined by thermal ablation therapy. A similar approach is being undertaken for supporting different therapies of other types of tumors, thus showing the generality of our approach.

KEY WORDS: medical databases, multimedia databases, thermal ablation therapy.

MAGNETIC RESONANCE (MR)-guided thermal ablative therapy of brain tumors is a new technique that combines the diagnostic power and soft tissue contrast resolution of magnetic resonance imaging (MRI) with aggressive interventional methods to produce a new treatment model that has the potential to become a major defining therapy of the 21st century. Alternative therapies for brain tumors include conventional craniotomy and radiation therapy, both of which have disadvantages in terms of cost and invasiveness when compared with this newer technique.

To fully evaluate the potential of the new therapy and appropriately apply it to patients, it is essential to have access to the prior patient treatment data in a convenient format. The database system described in this article maintains the patient records, models, and images that are relevant to the thermal ablation therapy application domain. It represents a typical application of current work in medical informatics, and is based on the knowledge-based multimedia medical distributed database (KMeD).[1] Using the modeling constructs provided by KMeD, our system can store patient records and images, associate them with each other, and perform queries on these data based on features such as tumor volume or histology.

We describe thermal ablation therapy in greater detail, and typical queries that this application would like to answer. Then we describe the database's logical model and outline the user interface and illustrate the interaction with a walkthrough of a sample query. We describe and illustrate the display and visualization of query results, and we conclude with an overview of further research that is either ongoing or will be undertaken in the future.

DESCRIPTION OF THE APPLICATION

Thermal ablation therapy is the use of focal heating for the treatment of tumors. Techniques for thermal ablation of brain tumors were pioneered in the 1960s and have been further refined since then.[2-10] The procedure is particularly important in the treatment of brain tumors, where invasive surgery is either impossible or poses the risk of severe brain damage. Using specially designed interventional MR instruments, a radiofrequency electrode is directed into the tumor with MR guidance. Instead of the usual surgical craniotomy exposure, a 2-mm twist drill hole is used for access in the skull of the patient, who remains awake during the procedure.

Local anesthesia is used for skin, scalp, periosteum, and dura—the brain itself does not have pain receptors. With the assistance of MR visualization, the tumor is destroyed as the local temperature of the tissue is heated above 60°C, which is necessary to denature proteins and cause coagulation necrosis. Patient demographics, treatment information, and imaging-derived information about the lesion before, during, and after treatment are stored in the database for manipulation and retrieval.

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SAMPLE QUERIES

The development of the database described in this article was driven by the information system requirements demanded to properly support research into and treatment of brain tumors. Implementation work has resulted in our ability to answer the following types of queries:

- What is the volume of the enhancing portion of the treated area?
- Which patients have tumors that grew by more than 70% after tumor ablation treatment?
- Retrieve other tumor cases whose histology classification, patient age, and location in the brain are similar to the one currently displayed.
- Graph the growth of this patient's tumor over time.

Future work on the thermal ablation database will be driven by the need to correlate simulation data, images, and actual measurements. While fulfilling some of these requirements requires new technologies that our group is still in the process of investigating (similar shape matching, for example), other functionalities are hindered only by the current unavailability of data, such as those generated by simulation and mathematical models of the therapy. The sample queries presented are currently expressed in terms of an implementation of the PICQUERY+ tabular language.[11]

METHODS

Our methods consist of two standard phases in database design: the definition of an overall data model and the specification of the ways in which a user may interact with this model.

Logical Data Model

The logical data model of the thermal ablation database uses KMeD's framework of objects, image stacks, and type abstraction hierarchies to represent the data generated by the application domain.[1,12]

Patients and Procedures

The standard representation of a patient is shown in Figure 1. This representation stores an individual patient as an entity participating in the relationship *undergoes* in conjunction with a procedure entity. This relationship is 1-to-n; thus, a patient undergoes one or more procedures. A one-to-one relationship going in the other direction also shows that any given procedure is performed on one and only one patient.

The database keeps track of two types of procedures: examinations and treatments. Examinations typically generate a set of MRI scans of the patient's brain and tumor, including a measurement of the tumor's volume at the time. Treatments generate further information, relating to the actual ablation procedure: the number of doses applied, whether a biopsy was performed, etc. Procedures (both examinations and treatments) study one or more neoplasm entities.

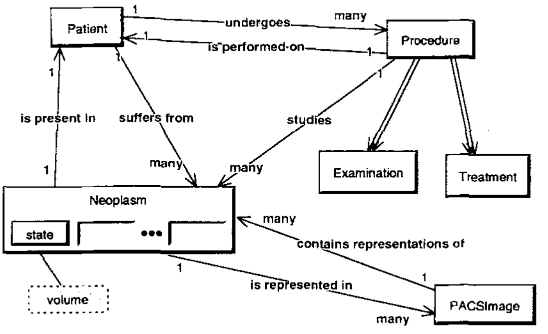

Fig 1. Logical model for the thermal ablation database.

Neoplasms

The modeling of brain tumor, or neoplasm, entities is needed to fulfill a number of requirements, the most significant of which are the ability to track a tumor's condition over time and the ability to capture the spatial features of a tumor. Our neoplasm modeling also aims to fulfill other, more advanced requirements: in particular, the constructs described in this section are also capable of supporting tumor simulation models and multimedia visualizations of these models or their real-world counterparts.

As can be seen in Fig 1, the neoplasm entity is expressed in a different notation that represents a neoplasm as a stream entity. Stream entities are based on models and file formats defined in the area of multimedia and digital video.[13-16] Our work extends this construct to a more general set of applications.

Stream modeling. A stream entity represents a real-world object that changes over time. Stream entities can be viewed as a series of snapshots or states of the object being modeled, each series or state representing the object at a particular time.

Because one of the key requirements for the database was to track changes in a brain tumor's volume over time, the neoplasm entity is modeled as a kind of stream entity, in which each snapshot within the stream represents the condition (ie, volume, position, appearance) of the neoplasm during a particular time.

Images

Data modeling of images has long been a focus of past and current research.[12,17] For the thermal ablation database, we extend the image stack construct introduced by Chock et al[17] and further developed by others.[1,11,12,18]

The image stack construct is an aggregation of related images along a third dimension. The image stack data model maps very well to the volumetric nature of MR data and is therefore used to represent MR scans. These scans are instances of an image class called PACSImage, shorthand for picture archiving and communications system image.[19]

The link between PACSImages and neoplasms is a pair of relationships: neoplasms are represented in PACSImages, and conversely, PACSImages contain representations of neoplasms. These relationships permit the user to easily express queries of the forms "show me the image(s) where this neoplasm appears" and "show me the neoplasm(s) represented in this image."

Query Interface

Figure 2 shows the thermal ablation therapy database interface. This diagram corresponds to the logical model shown in Fig 1, and should, ideally, match it exactly. Also included in Fig 2 are windows showing the inheritance hierarchy of the neoplasm entity and a detailed display of its attributes.

The primary difference between the implemented interface and the logical, paper diagram is the representation of a neoplasm. A supplementary entity called the neoplasmstate is used to capture the features of the neoplasm over time, and we say that a neoplasm is manifested as a neoplasmstate.

When an entity box is clicked (such as the TAPatient box), the corresponding operation is performed on that entity:

- Inheritance hierarchy: This operation displays the classification hierarchy to which the clicked entity belongs. The inheritance hierarchy that is displayed for neoplasms is included in Fig 2.
- Detailed definition: A window displaying the internal structure of each entity is presented (ie, the window for the neoplasm entity in Fig 2).
- Plain English description: These free text descriptions of an entity are stored in and retrieved from the global directory, along with the entities themselves.
- Filtering table: The data filtering PICQUERY+ table operation[11] presents a table on the clicked entity for filtering out the desired database objects. Query examples are:
  1. Which tumors in the database classified as "adenocarcinoma" grew by more than 70% after thermal ablation treatment?
  2. Select neoplasms located in the frontal region of the brain.
- Browse: To access the database without issuing any queries or constraints, the user can choose the browse operation. This action brings up the actual data for the clicked entity. Selections can then be made from this list for individual viewing by the user.

When an object from the database is displayed onscreen, the user may follow links from that object to other entities in the database, if a relationship exists between them. In Fig 3, a display window for a neoplasm is shown. At the bottom of this window is a list of image files, representing the MR scans in which the neoplasm can be found. By choosing the desired image, then clicking on *View Image*, the user follows that link to bring up that image.

The neoplasm entity also links to the various states in which it was measured. By choosing an item in the middle list, then clicking on *View State*, the user can examine the neoplasm as it was on the given date, with time-dependent data such as volume, percent change, etc.

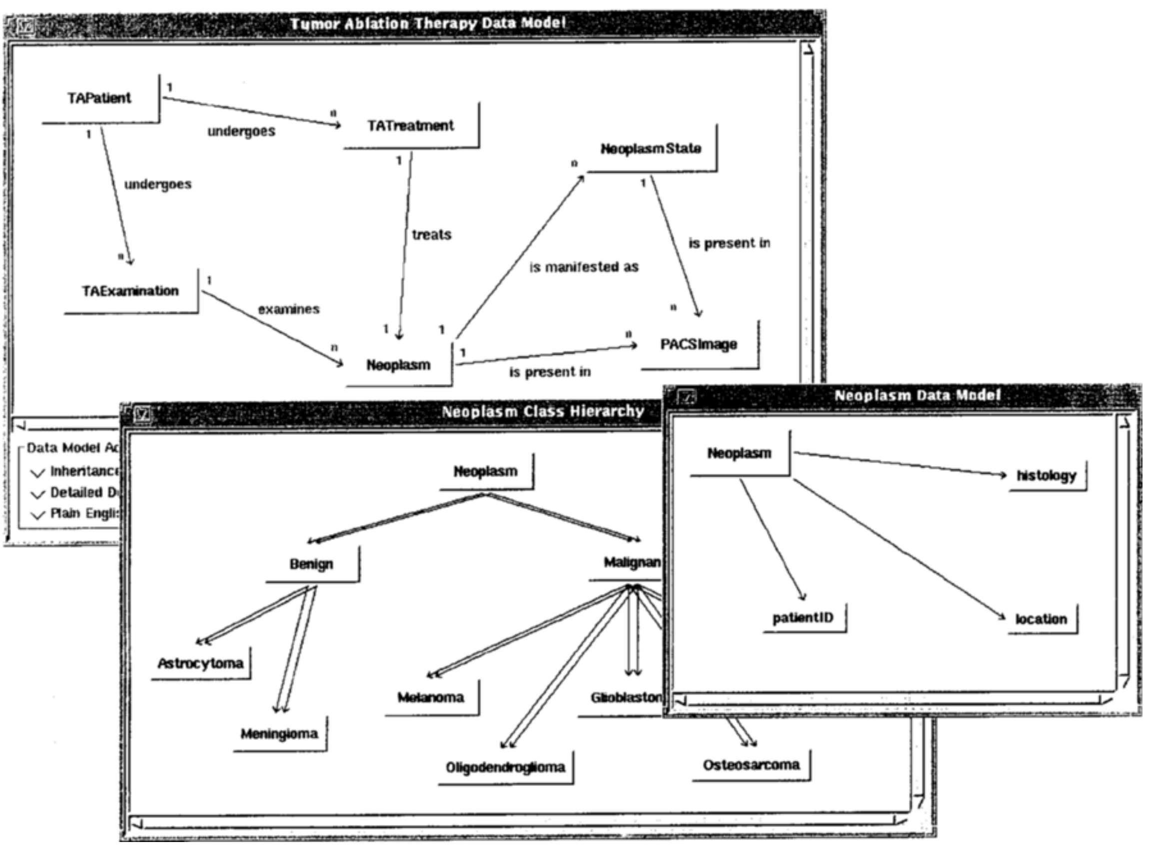

Fig 2. The thermal ablation therapy database interface.

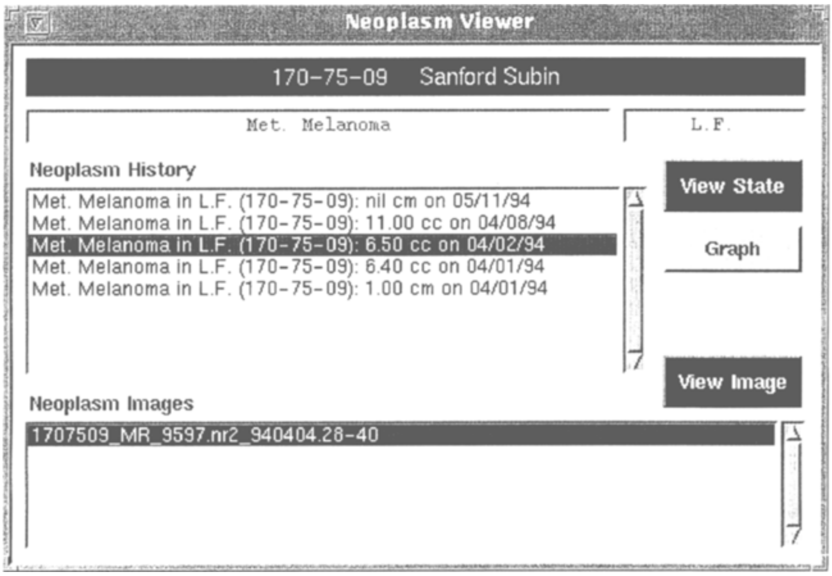

Fig 3. Display window for viewing Neoplasm entities, showing the list of hypertext-style links to associated images in the database.

RESULTS

The end result of the data modeling and querying presented in the previous section, whether with the sample query shown previously or with any other query, is the display and visualization of the query's output. Previous sections have already illustrated some of the data display capabilities of KMeD and the thermal ablation database.

Figure 3 illustrates KMeD's approach to displaying retrieved data: each KMeD entity is given one or more custom display windows tailored to the attributes and relationships of that entity. If more than one display type is available for an entity, a menu automatically opens up, listing the available display approaches. The window shown in Fig 3 is the layout that was designed for neoplasm entities. Other types of entities, such as patients, examinations, treatments, etc., also may be given such layouts. If the user does not provide a custom window design, KMeD generates one on-the-fly, though the on-the-fly layout tends not to be very useful except for basic examination of the entity's attributes.

This modular approach is particularly useful for multimedia data; in this case, we are dealing with MR images. Because images may be visualized in many different ways, and such visualization methods vary depending on the application domain, it is beneficial to have the capability to plug and unplug new visualization modules as application needs evolve.

Succeeding sections describe the results that can be retrieved using KMeD and the thermal ablation database. Depending on needs or resources, virtually any visualization module may be connected to KMeD, as long as image data can be sent to the visualization module.

Tabular and Graphical Output

One of the most important factors in thermal ablation therapy is the change in size that the tumor undergoes through time. This change in size is best visualized by a graph viewer, shown in Fig 4. The graph viewer retrieves all of the states associated with a neoplasm entity, sorts them by date, then plots their volumes in a window. The graph view provides the user with an immediate feel for the relative success of the thermal ablation therapy.

Single-Image Visualization

Most of the image visualization modules in KMeD are capable of viewing a single image or slice from the MR scan. A particularly useful tool is the display module from the ImageMagick package, which is available in the public domain. The display module permits the user to view one MR slice at a time, with a "hot magnification" feature that provides a real-time 2× view, which follows the movement of the mouse over the normal-sized image.

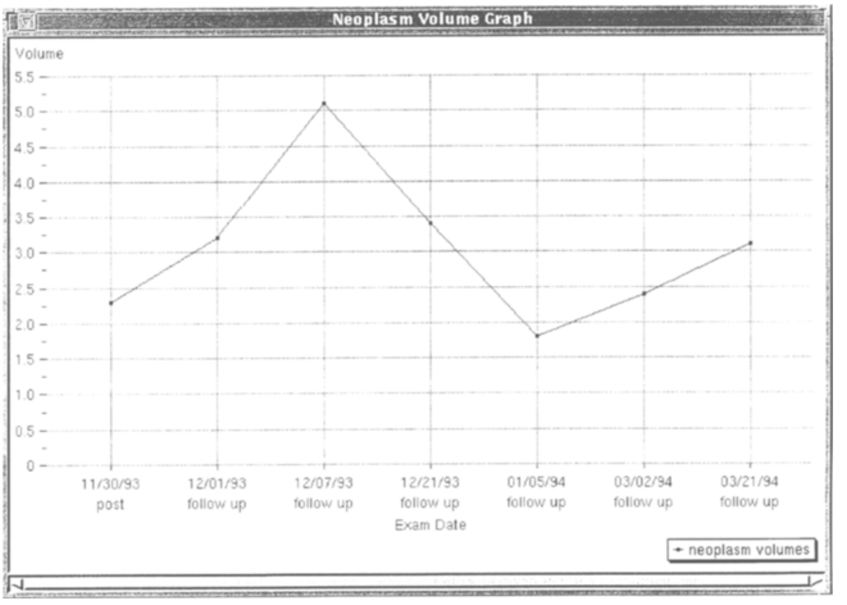

Fig 4. Graph window used for visualizing the volume change in a tumor over time.

Cine-Style Visualization

Another mode of visualization for image data that consists of multiple slices is *cine mode*, or the ability to "step" through each slice of an image stack either one by one or in an animation sequence. We have a number of modules that support cine mode, including ImageMagick's animate program and software that was developed by our group using the IDL[20] system and VisualWorks 1.0.[21]

3D Visualization

MR data are volumetric data and so can be meaningfully viewed in three dimensions. We adapted IDL's slicer program so that it could

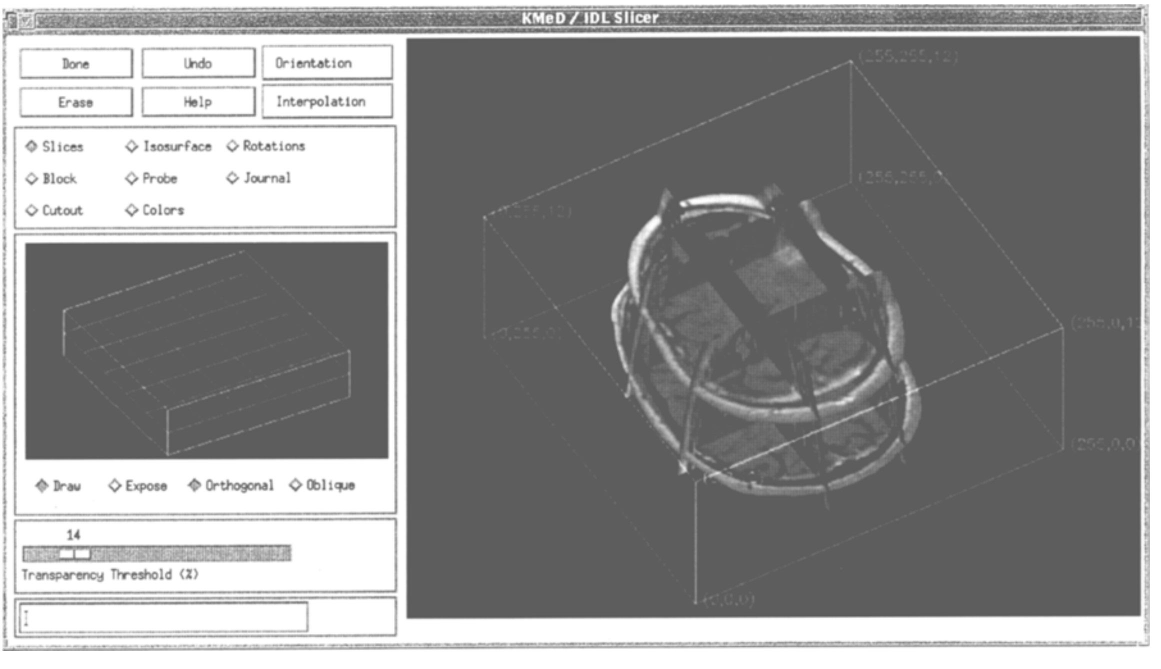

Fig 5. 3D slice-by-slice view of an MR scan using a slicer program implemented in IDL.

communicate with KMeD; with the slicer, an MR scan may be viewed along any 3D axis, rendered as an isosurface, or cut into 3D blocks. Rotations and 2D plane slices on any angle are also permitted. Figure 5 illustrates the KMeD slicer window.

CONCLUSIONS

MR-guided thermal ablative therapy of brain tumors is a revolutionary investigational technique that has potential advantages over other treatments. A conveniently accessible database is essential to properly evaluate the strengths and weaknesses of the new technique.

The database described in this document is built as a high-level application running on top of KMeD, a multimedia database system which has been in development since 1991. Significant features of the database include the ability to query the tumor data through meaningful features such as tumor volume, the ability to track the development of a tumor over time, and the ability to retrieve and visualize MR images of a patient with a given tumor.

The thermal ablation database presented here, including its data model, query interface, and visualization facilities, represents what has been implemented as a real system. Ongoing and future work includes full implementation of the stream model, development of more sophisticated visualization and annotation techniques, and addition of simulation modeling and validation of the overall information structure.

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