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Multimodal medical imaging repository and information system in epilepsy surgery

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Abstract: Surgery is an option for patients with drug-resistant epilepsy, but it requires a comprehensive assessment. Electroencephalography (EEG), magnetic resonance imaging (MRI), and functional MRI (fMRI) are used to localize the epileptogenic zone, which directly affects the surgery outcome. Accessing EEG, MRI, and fMRI results and patient information simultaneously using traditional methods might result in misinformation and increase the workload of clinicians. In this study, we developed a modern web-based repository system for the preoperative evaluation of epilepsy disorder, including multimodal medical images and patient information. Our dedicated system is enriched with clinical metadata that are not currently available and is managed with an online application. It overcomes the identified problem and minimizes possible medical errors. In conclusion, this system has the potential to accelerate surgical procedures, get reliable results, and improve the seizure outcome. It is an extensive solution for epilepsy hospitals and clinical research centers. It may serve as a standard template for archiving multiple imaging techniques.

Key words: Health information management, electronic health records, epilepsy surgery, multimodal medical imaging, information system

1. Introduction

Epilepsy surgery is a treatment option for achieving seizure freedom or decreasing seizure frequency [1,2] in selected patients [3–5] with drug-resistant focal epilepsy [6]. To literalize and localize the epileptogenic zone, candidates for epilepsy surgery require an extensive presurgical workup, including a neurological examination, video-electroencephalography (EEG), high-resolution magnetic resonance imaging (MRI), functional magnetic resonance imaging (fMRI), a neuropsychological assessment, positron emission tomography (PET), and single-photon emission-computed tomography [7–10]. Separate systems are available for reviewing these presurgical assessments, while a comprehensive health information management system is lacking.

Databases containing brain images that increase understanding of normal and abnormal brain structures and functions have attracted research attention, and a need for integrating different types of medical imaging has been identified [11,12]. The International Consortium for Brain Mapping is a database including MRI, fMRI, PET, and MEG modalities (https://ida.loni.usc.edu/login.jsp?project=ICBM) [13]. Other databases, which integrate fMRI and PET data, are the European Computerized Human Brain Database and BrainMapDBJ

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[14–16]. The databases mentioned above are for the concept of the human brain atlas, and not used practically in clinics. However, using such databases is required for evaluating presurgical investigations of candidates for surgery.

The EPILEPSIAE project funded by the European Union is another extensive repository for epilepsy disorder [17]. It maintains long-term EEG recordings of 300 epilepsy patients from three epilepsy centers in Europe [18]. Unfortunately, EPILEPSIAE is not capable of storing multimodal images such as MRI, fMRI, and PET.

The goals of this study were (i) to develop a system that includes multimodal medical images, (ii) simultaneously maintains patient information, and (iii) allows independent access to the data, (iv) enabling a systematic approach to epilepsy surgery.

2. Materials and methods

The system was designed for clinical and research centers to obtain extensive presurgical evaluations of epilepsy disorder, including MRI, fMRI, ictal EEG, and interictal EEG, as well as additional clinical history and patient information. Here we provide a structured data handling mechanism for preoperative investigations of epilepsy surgery.

2.1. Technologies used

Our system is a web-based system and so the hypertext transfer protocol was adopted for communicating with clients. It was developed using C# programming language in the ASP.NET framework, and uses the SQL-Server database management system to organize patient data and their records. Instead of writing SQL queries to access and search the data, language-integrated query classes are preferred. A visible form of MRI data is obtained from raw data with viewer software and saved as pictures in the system. Raw fMRI data are processed using statistical parametric mapping (SPM) and FMRIB software library, and produced results are saved in the system in order to view them online. To view EEG data online, channels values are saved as JavaScript object notation (JSON) and plotted with JavaScript.

2.2. The content of multimodality

Multimodality imaging has improved data interpretation by combining existing brain imaging techniques. It is now possible to delineate structural and functional information of the part of the brain that causes seizures in patients with epilepsy disorder by combining EEG, MRI, and fMRI findings [11,19,20]. They can help to better localize the focus [21–24]. Hence, we decided to integrate EEG recordings, MRI, and fMRI in the proposed system as multimodal imaging parameters.

2.3. Database schema

The entity–relation (ER) model is a commonly accepted model for the conceptual design of a database [25]. The main procedure in ER is to convert entities and relationships into relational tables. Data types and complex queries are managed efficiently using a relational database [26]. Thus, we used the ER model to design flexible multimodality database, which allows us to add more multimodal image techniques without designing it from scratch. The general structure of the database schema for our system is presented in Figure 1.

The schema in Figure 1 is a general structure of database; not all tables are included (such as administration of the system). Tables are rectangular and relational tables are diamond-shaped. Cloud shapes demonstrate

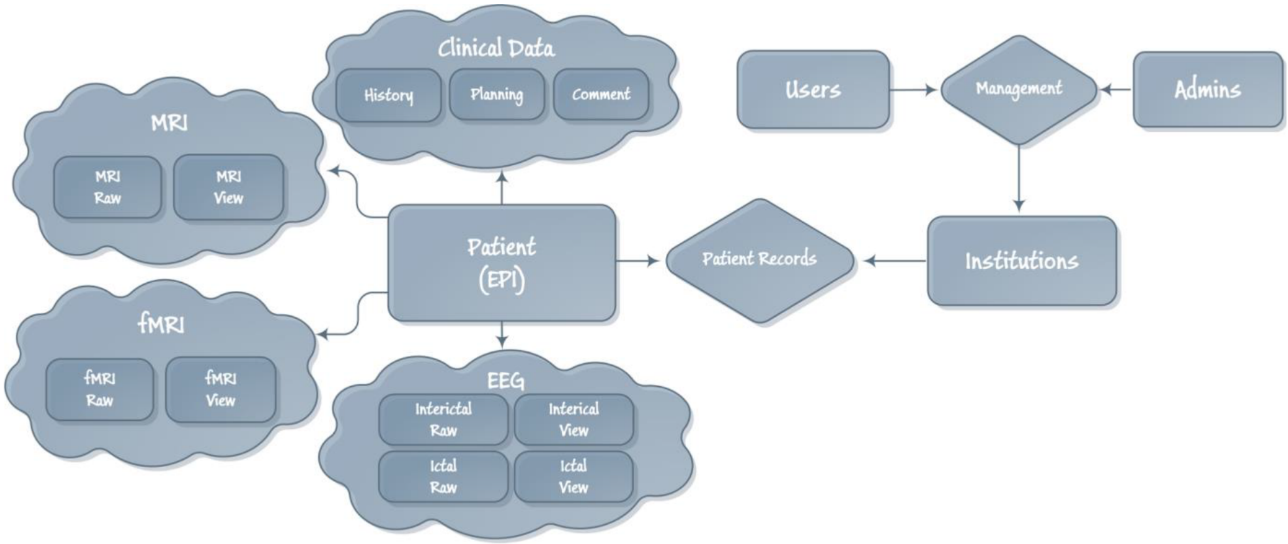

Figure 1. Relational design of the database. The database is structured in two hierarchical levels: management and patient tables. Users are organized by the admins via the management table and access to patient data is handled by the patient records table. Thanks to this mechanism, only authorized users can access patient data.

group of thematically related tables. More than one institution may exist. Patients are registered to institutions and managed via the "Patient Record" relational table. Institutions organize their users with the help of the "Management" table so their users can only reach the patients that admin has registered to them. All users and institution admin must have an account for authentication.

Authentication is required since the system is closed to public access. Admins can manage users' rights individually. For instance, they can designate a user fully authorized to download and manipulate the data, whereas they can also authorize a user to only view the data. Tables for the system management are summarized in Table 1.

Table 1. This group of tables is for the management of system. It contains information about user and administrator definitions. Admins can manage Users account by defining their rights and assigning them to institutions.

Table	Relation	Description
Admin	Management (1:n)	Holds information about administrators of the system. ID, password, first name, surname, email, date of birth, and phone number are important attributes of the table. Admins can create users and manage their rights individually.
User	Management (1:n)	This table includes the information of users such as ID, first name, surname, password, email address, phone number, date of birth, and specific rights for downloading each multimodal data.

The first hierarchical level of the database was management tables. Patient information and related data tables are handled in the second level. This part contains electronic patient information (EPI) records with clinical history and medical imaging data, including both raw and viewer format of EEG, MRI, and fMRI. Raw and viewer files are kept in separate tables, and they are relationally connected to the patient table (1-to-many relation). The tables we created for patients and their data are explained in detail in Table 2.

Table 2. The types of data that tables hold and their relations. This group of tables contains information about the patients, the institutions where they are registered, and the assessments they had before surgery. It also contains information about the surgery outcome.

Table	Relation	Description
Patient (EPI)	Patient records (1:n)	It includes basic patient information, such as first name, surname, sex, accommodation knowledge, phone number, and email address. Based on feedback from clinicians, sections were added to include the patient's education level and occupational knowledge. The EPI also contains the phone number of patients' relatives to facilitate urgent connections between the patient and health care centers.
History	Patient (1:1)	Aggregates the clinical history in detail. The important attributes are seizure onset (the patient's age when the first seizure occurred), seizure frequency (how often the patient has seizures), seizure type (complex partial, simple partial, and generalized tonic-clonic seizure), aura, seizure semiology, date of surgery (if applicable), operation result, operation area, pathology result, reports (reports of MRI, fMRI, EEG, and neuropsychological tests), seizure outcome, medications before surgery, medications after surgery.
Planning	Patient (1:1)	Holds the details of the preoperative planning before the surgery, including the operation side and region, electrode types, planning mapping, and intracranial application mapping.
IctalEEG_raw InterictalEEG_raw	Patient (n:1)	The tables keep the data path of original recordings of EEG. The recordings may have different file formats; all types of raw files are accepted. The upload date is a common attribute for data tables.
IctalEEG_vwr InterictalEEG_vwr	Patient (n:1)	Records of EEG data in JSON format for plotting. We have limited the duration of EEG (5 min) due to file size concern.
MRI_raw	Patient (n:1)	MRI files in DICOM standards are saved to the table.
MRI_vwr	Patient (n:1)	To view MRI images over the system, we uploaded sample MRI images. The image file format should be .jpg, .jpeg, .png, or .bmp.
fMRI_raw	Patient (n:1)	Original recordings of fMRI files.
fMRI_vwr	Patient (n:1)	Viewer files of fMRI. We performed a simple task in FMRIB software library to show activated brain regions and uploaded the resulting image files.
Comment	Patient (1:1)	Provides a free textual description for supplementary interpretations.
Institution	Patient records (1:n), Patient (1:n)	Patients are registered to institutions such as epilepsy hospitals and research centers. The table holds information about the institution.

2.4. Constraints in multimodal imaging

Original MRI recordings should be in DICOM standard, appropriate to epilepsy protocol, and they should be high-resolution images (at least 1.5 Tesla units).

EEG recordings should contain at least 19 electrodes, and a sampling rate of 128 Hz. To view EEG data online graphically, the system only accepts the ASCII file format, which includes a structured header consisting of patient name, date of recording, start second, end second, sampling rate, and electrode names. JavaScript must be enabled to monitor EEG recordings saved in the system. These constraints are intended to attain a certain quality for each patient.

3. Results

Our application integrates multimodal medical data for the purpose of epilepsy-based presurgical evaluations. The interface is organized to provide simple and user-friendly access so that clients can browse through the available datasets easily. In hospitals or clinics, medical records such as MRI, PET, and EEG are separated into specialized departments (radiology, nuclear medicine, neurology, etc.). Most of the time, operations are also scheduled for years ahead of time and patients have to wait for a long time. These two factors make data access a difficult task for both clinicians and patients. Our system achieves ease of access and prevents medical records from being lost because all data are presented electronically in one place.

The client application was deployed on a web server and tested with different user definitions and information. Tests were held in different devices and different platforms. Viewing data, manipulating its parts, and inserting new data into the system were performed successfully. The system has been used in a psychiatry department to maintain EEG records [27].

3.1. Clinical data and multimodality display

The history module shown in Figure 2 includes data related to the clinical histories of patients who are candidates for epilepsy surgery. It provides minor but important details in decision making. Patients' histories are kept electronically instead of on traditional papers. When it is asked to update, old data are replaced with new ones. If desired, old data can be maintained in the comment section individually. Since the system is for epilepsy surgery, the patient's history is organized accordingly.

Further details of the surgery are presented in the planning module, such as the operation side and region, electrode types, planning mapping, and intracranial application mapping.

The advantage of the proposed system is that anatomical, functional, and electrophysiological modalities are merged in one place so that users can comprehend the results without extra effort. Viewer formats of MRI, fMRI (Figure 3), and EEG recordings (Figure 4) are readily available. It is also possible to download the original recordings in order to perform further analysis.

4. Conclusion

Patients with epilepsy disorder undergo an extensive investigation before epilepsy surgery to minimize its risks. Advances in technology and medical imaging techniques have improved presurgical evaluation and increased the possibility of pinpointing the part of the brain that caused the seizure. Despite these improvements, no web-based system includes multimodal medical imaging to evaluate patients' suitability for surgery. Therefore, we have developed this state-of-the-art health information management system for planning epilepsy surgery that is accessible independently. In order to protect patient confidentiality, the system is closed to public access

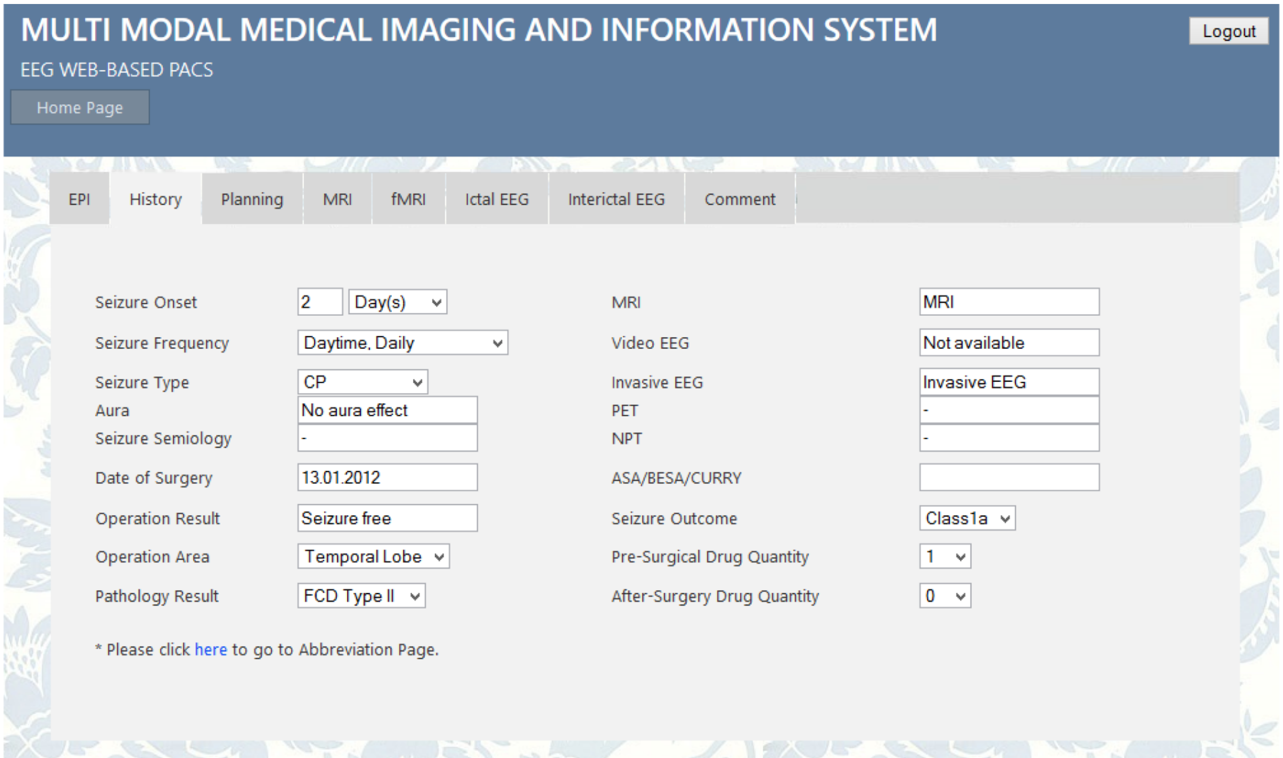

Figure 2. Clinical history of the patient for epilepsy disorder. It contains information about seizure, the operations patient had, medical image reports if exists. Some of the attributes are standardized and abbreviated.

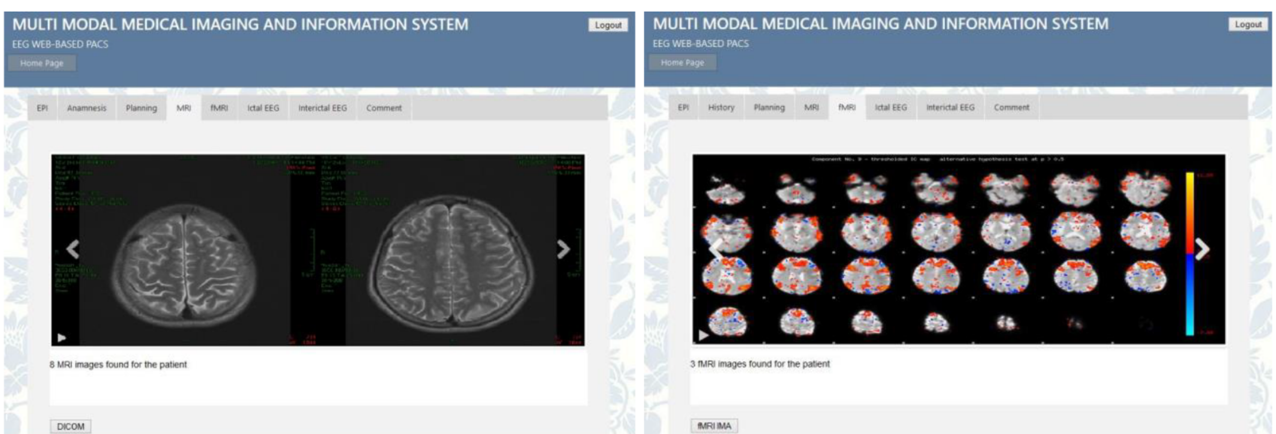

Figure 3. MRI and fMRI viewers in the system. Visible form of MRI is obtained from MRI viewers, and visible form of fMRI is obtained from SPM and FSL software. Original recordings can be downloaded by clicking the button at the bottom of the page (only for authorized users).

and accessible only by authorized users who have different individual rights defined by admins. With this system, presurgical assessments can be collected in one location with online access via a user-friendly interface. It is thought that this approach will be an important contribution to the decision-making process and correct delineation of the epileptogenic zone in patients undergoing epilepsy surgery. It might also contribute to the development of decision-support systems by presenting some of the information in a standard form.

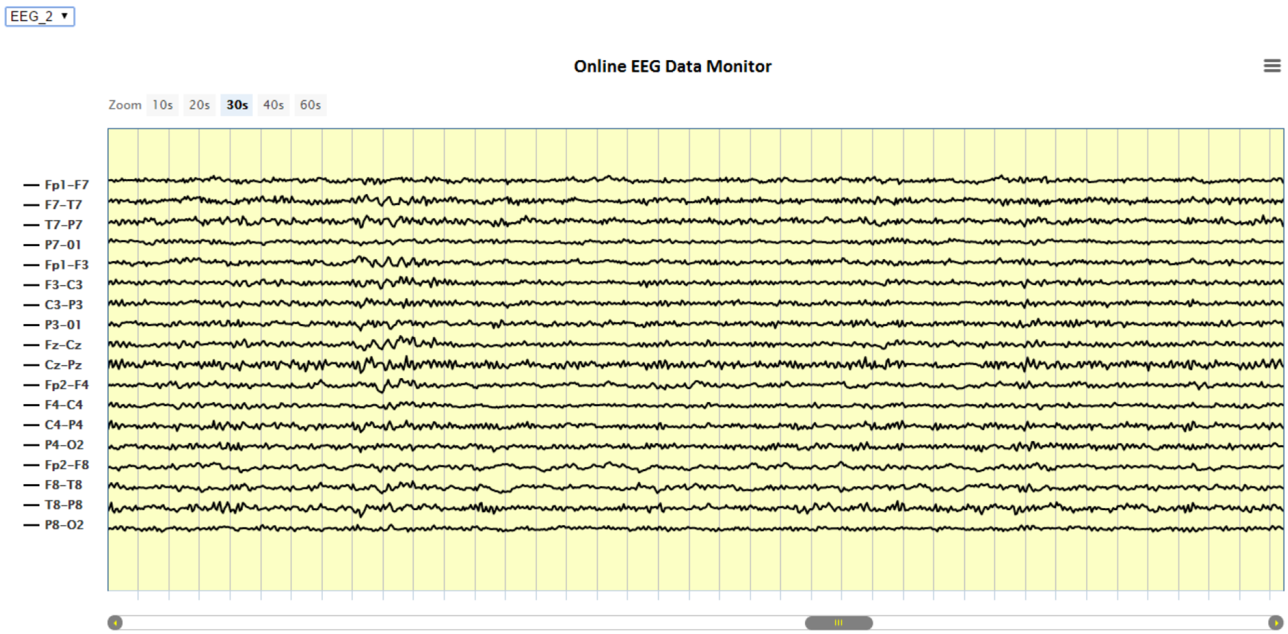

Figure 4. Full-screen online EEG monitoring at 30 s compression via the system. The time interval between any two vertical lines is 1 s. Users can follow continuous EEG using the scroll bar at the bottom of the page. If there is more than one record, the user can choose the record from the list at the top left.

The challenges we encountered while developing the system were (i) medical data were fairly big, (ii) security mechanisms were designed extensively to protect patients' confidentiality, and (iii) various EEG recordings exist online. This system is the first system that enables the display of online EEG recordings.

4.1. Future Plans

Currently, the EPI, history, planning, EEG, MRI, and fMRI modules have been completed. In the next phase, we plan to add diffusion tensor imaging, magnetoencephalography, and PET modules. It is anticipated that after the next phase the proposed system will comprise a complete solution for the presurgical assessment of epilepsy surgery.

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