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Integrating nTMS Data into a Radiology Picture Archiving System

Teemu Mäkelä · Anne-Mari Vitikainen · Aki Laakso · Jyrki P. Mäkelä

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Abstract Navigated transcranial magnetic stimulation (nTMS) is employed in eloquent brain area localization prior to intraoperative direct cortical electrical stimulations and neurosurgery. No commercial archiving or file transfer protocol existed for these studies. The aim of our project was to establish a standardized protocol for the transfer of nTMS results and medical assessments to the end users in pursuance of improving data security and facilitating presurgical planning. The existing infrastructure of the hospital's Radiology Department was used. Hospital information systems and networks were configured to allow communications and archiving of the study results, and in-house software was written for file manipulations and transfers. Graphical user interface with description suggestions and user-defined text legends enabled an easy and straightforward workflow for annotations and archiving of the results. The software and configurations were implemented and have been applied in studies of ten patients. The creation of the study protocol required the involvement of various professionals and interdepartmental cooperation. The introduction of the protocol has ended previously recurrent involvement of staff in the file transfer phase and improved cost-effectiveness.

Keywords PACS · Hospital information system · Radiology information system · Transcranial magnetic stimulation

T. Mäkelä (✉) · A.-M. Vitikainen
Radiology, HUS Medical Imaging Center, University of Helsinki and Helsinki University Hospital, P.O. Box 340, FI-00029 HUS Helsinki, Finland
e-mail: teemu.makela@hus.fi

T. Mäkelä · A.-M. Vitikainen
Department of Physics, University of Helsinki, P.O. Box 64, FI-00014 Helsinki, Finland

A.-M. Vitikainen · J. P. Mäkelä
BioMag Laboratory, HUS Medical Imaging Center, University of Helsinki and Helsinki University Hospital, P.O. Box 340, FI-00029 HUS Helsinki, Finland

A. Laakso
Neurosurgery, University of Helsinki and Helsinki University Hospital, P.O. Box 266, FI-00029 HUS Helsinki, Finland

Background

Navigated transcranial magnetic stimulation (nTMS) has been successfully applied in noninvasive presurgical mapping of motor- [1–5] and speech-related cortical areas [6, 7] and in planning dosimetry distribution in radiosurgery [8, 9]. As the Food and Drug Administration of the USA has recently approved presurgical motor and language nTMS mapping as a clinical tool [10], its clinical use is rapidly expanding. An nTMS device produces a localized magnetic pulse by passing a short, high-amplitude electric current through a specialized coil. When the coil is positioned close to the subject's scalp, the pulse induces electric currents in the cortex. Coil orientation is monitored in real time, and an estimated current distribution is visualized on preacquired 3-D magnetic resonance (MR) images.

If nTMS is targeted to the motor cortex, it generates muscle activation. This activation is recorded with electromyography (EMG). The EMG signals are analyzed off-line and are linked with the corresponding nTMS sites. Clinicians use nTMS for preoperative workup for patients with brain tumors or epilepsy. The identified functional landmarks of eloquent cortical regions are used in surgical planning. The landmarks are transferred into a neuronavigation system and used in the verification of functional areas by direct electrical cortical stimulation (DCS) during the operation. Presurgical nTMS mappings are carried out with an off-line device, and the data analysis is done on a separate workstation.

We wanted to create a routine for transferring the nTMS images (Fig. 1) into the hospital's picture archiving and communication system (PACS), where it is available for all end users. We wanted to 1) standardize and improve the fluency of the study procedure, 2) take advantage of the existing infrastructure for reliable long-term picture, referral, and assessment archiving, and 3) make the information secure and easily available to the end users for treatment planning and therapy. This included the need for straightforward and secure data transfer to the neuronavigation system in the neurosurgical operation room (OR) located on a separate campus.

Methods and Results

Existing Systems

The nTMS system (Nexstim Oy, Helsinki, Finland) produces files with stimulation locations, EMG responses, and a copy of the MR images used in the nTMS study. The data is analyzed on a Windows workstation running the analysis software. Two types of DICOM (Digital Imaging and Communications in Medicine)-compliant images can be produced. Static screen captures visualize the active nTMS sites on top of anatomical MRI at selected projections and peeling depths (Fig. 1a). The stimulated locations can be exported as voxel groups in a 3-D image stack (colored cubes in Fig. 1b). For example, the sites associated with EMG amplitude below a chosen threshold value can be excluded from the images. The coordinate space of the 3-D image stack equals that of the original MRI. This enables the fusion with nTMS results and anatomical images in the neuronavigation system (Fig. 1b, c) while preserving the precision of the results.

An external storage device (USB memory stick) is used for data transfer between the stimulator and the analysis station, in compliance with the manufacturer's recommendations. Keeping the stimulator off-line ensures that the mappings are not interfered by network traffic, such as operating system updates, infiltration attempts, or malicious software, e.g., viruses. The analysis workstation is connected to a separate subnet of the hospital local area network.

The Department of Radiology utilizes the hospital PACS (Impax; Agfa HealthCare, Mortsel, Belgium) for image transfer and storage. If a study is to be archived long term, it needs to be registered with a patient-specific referral from an adjacent radiology information system (RIS) (RADU; L-Force Oy, Helsinki, Finland). The studies are identified by a unique accession (AC) number. In an AC number absence or mismatch, the study is listed as unverified and eventually deleted.

The Department of Clinical Neurophysiology responsible for the nTMS studies utilizes a separate referral management system (QPati; Tieto Oyj, Helsinki, Finland), integrated with a

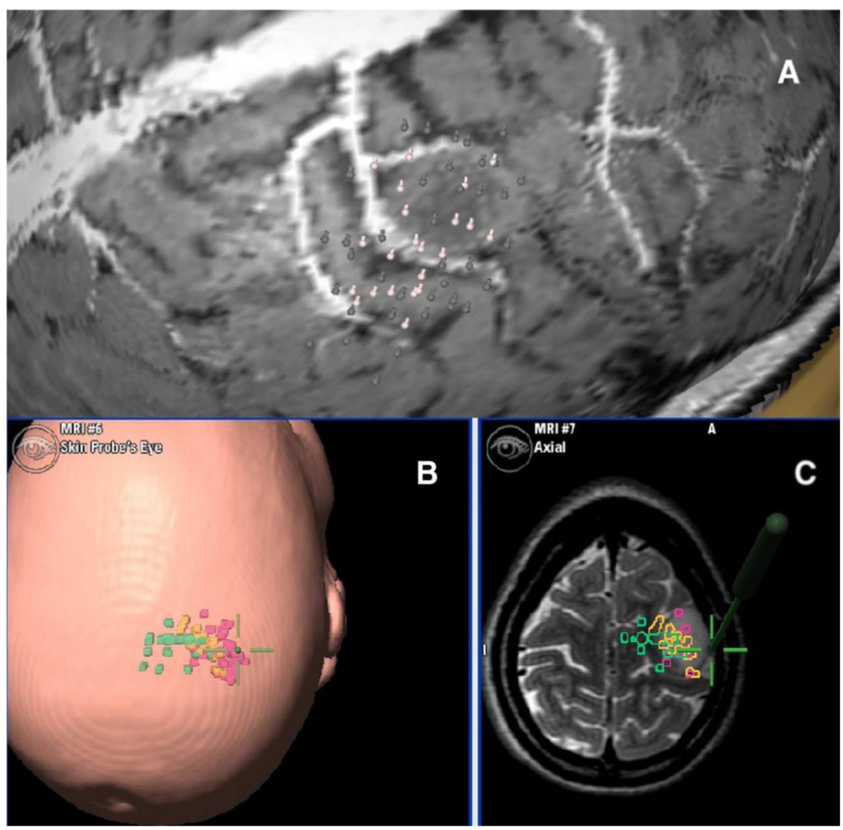

Fig. 1 **a** A static screen capture with stimulated sites of the left-hand representation area at a chosen peeling depth (Nexstim NBS System). *White markers* indicate the locations that produced motor evoked potentials whereas the *gray marker* locations did not. **b** Activations of different muscle groups are designated with *different colors* in the neuronavigation software (Brainlab iPlan). **c** The same data points represented on top of the anatomical axial MR slice in the neuronavigator. The *green crosshair* points to the position of the surgical probe in images **b** and **c**

laboratory information system (MultiLab; MyLab Oy, Tampere, Finland). Here, these two systems as well as their auxiliary software are called neurophysiology referral system (NRS).

In the OR at the Department of Neurosurgery, the DICOM files including nTMS results are transferred to the neuronavigation workstation (iPlan; Brainlab AG, Feldkirchen, Germany) and fused to anatomical images for presurgical planning by the neurosurgeon. During surgery, nTMS data facilitates motor cortex mapping with DCS by guiding the neurosurgeon to presurgically mapped motor areas. Combining nTMS and DCS results with neuronavigation enables intraoperative verification of presurgical nTMS data.

Limitations of the Existing Systems

As the referral systems for the neurophysiology and radiology studies are separate, RIS referrals and therefore proper AC numbers were originally not generated for the nTMS studies. Also, the motor cortex nTMS mapping did not have a proper standardized RIS study name. The stimulation station generated DICOM files with the metadata of the underlying MR volume. Therefore, the identical AC number and patient identification code would have grouped the new images with the original MR study in the PACS. This solution was unacceptable, as the existing MR volumes used in the nTMS are often requested for other clinical purposes and indications. Also, the nTMS and MRI studies usually have different reviewing doctors. Ambiguity about which of the series in the MRI study was used in the nTMS could have also been possible.

Solutions

We programmed in-house software with graphical user interface for manipulating DICOM file header information, creating color guides to accompany the images and to enable data transfer. The DICOM file management tools were based on the open-source software library DCMTK (OFFIS, Oldenburg, Germany) and the front end was created using Java programming language (Oracle Corporation, Redwood City, USA). The DICOM standard contains several requirements for image conformance [11], and specific conditions may be imposed by the local PACS. The essential minimum of DICOM header tag modifications, such as globally unique identifiers for images, series, and studies, is presented in the software flowchart in Fig. 2. The analysis workstation was not connected to the hospital's primary local area network. Physical network connections and bidirectional routing between the nTMS analysis workstation and PACS were set up by the Information Technology department. Study steps and the information systems involved are shown in Fig. 3.

The user chooses the data to be analyzed from the previously generated screen captures and stimulation data sets by pointing out the project folder from our transfer software. Data descriptions are selected from a list of proposed texts or entered manually. They are included as series descriptions in the DICOM files, which are visible when viewed with a PACS client. Explanatory color guides can be created with the software to identify stimulation data points in the screenshot captures. They are actualized as separate images and are included in the series. Study date and AC number are entered manually. Before modifications, the images are copied to a temporary folder to ensure that the original files are not affected. Finally, the files are verified and transferred to the PACS.

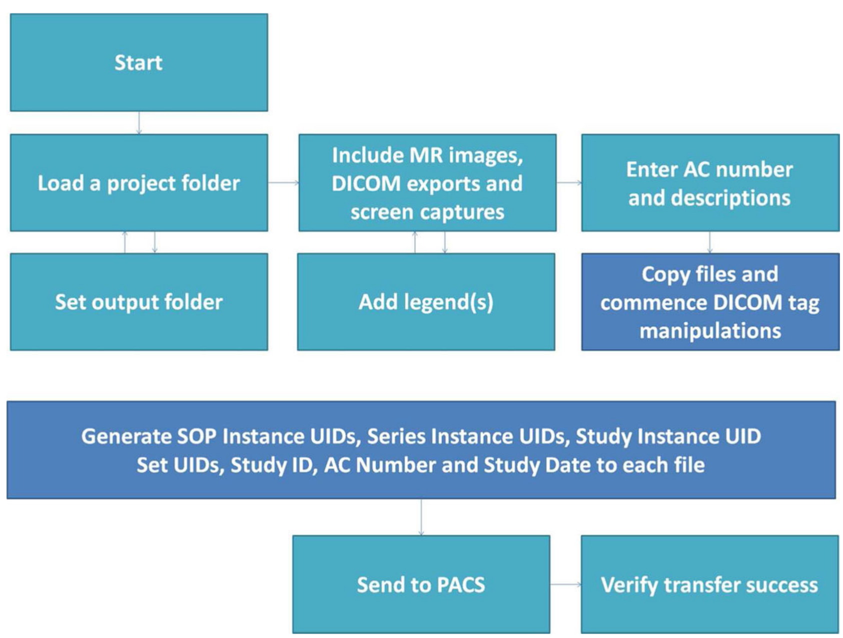

Fig. 2 The in-house software utilizes a suggestive and automated approach to produce a single consistent study for the PACS. Explanatory guides and data descriptions aid in interpretation of the stored images. Each file needs to be accompanied with a unique identifier (*UID*) for the Service Object Pair (*SOP*) instance,and consistent series and study identifiers, including a study-specific accession (AC) number

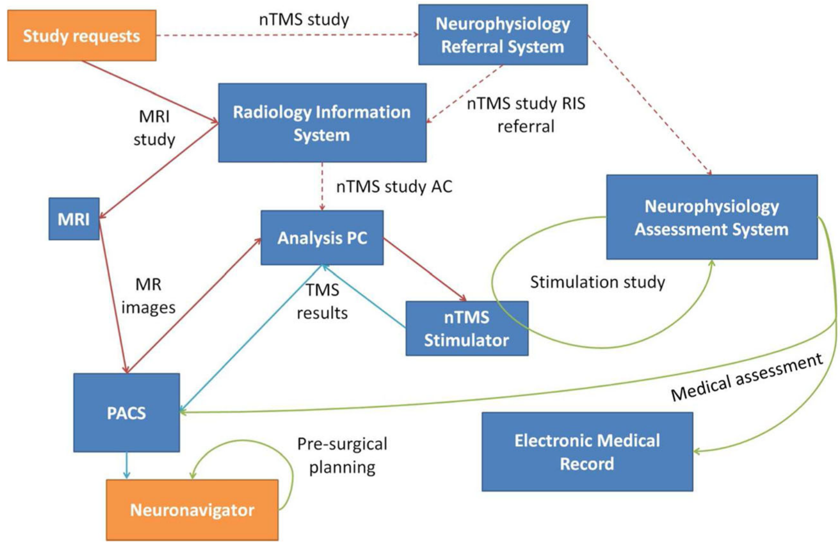

Fig. 3 A schematic representation of the information systems and operations involved in the described protocol for nTMS data integration

The AC number and its request propagate through three different systems: NRS, RIS, and PACS. When an nTMS study is ordered via the NRS, an auxiliary RIS referral is generated. When patient arrival is registered on the NRS, unique archiving codes linked with the patient identification data are produced by the RIS. This connectivity was realized by the referral system providers via postdelivery updates and configurations. As a limitation of the current system, the user has to retrieve the AC number via a RIS client and insert it manually into our software before PACS transfer. To address this issue in the future, DICOM Modality Worklist queries could be utilized. This would improve the fluency of the workflow and reduce the risk of entering erroneous study or patient information.

When an nTMS request or assessment is recorded to the NRS, a copy is automatically transmitted to the hospital district's electronic medical record and RIS. This enables revisiting and viewing of the assessment in adjunct to the accompanying study images with the PACS client alone.

The nTMS motor cortex mapping had not been associated as a (derivative) radiology examination. Therefore, we invented a new RIS study type identification code for it. The code is currently pending for the approval of the Association of Finnish Local and Regional Authorities who ensure nationwide radiological coding standardization.

We have implemented this workflow into preoperative workup for brain surgery and applied it successfully in ten patients.

Discussion

A large university hospital can have tens of specialized information systems with varying needs for intersystem communication [12]. Fragmented IT solutions may result in an overlap of functionalities and tasks between the separate systems. This challenges organization-wide data integration. Compatibility between different systems may have consequences on full utilization of the patient information, the fluency of interdepartmental workflows, safety, and cost-effectiveness. An integrated hospital information system with centralized storage adjacent to systematic data processing can contribute to patient care [13], medication safety [14], decision-making [15], and research [16]. Establishing and developing computer-driven hospital environments may require heavy customization and management of the local information systems as well as third-party software [17]. Here, we present the protocol and the steps required for transferring data from a specialized neurophysiological study into a radiology department picture archiving system in a large hospital district.

When adding a new modality to an existing information system network, it is important to grasp the modification requirements beforehand. This is further emphasized in a large organization where IT services and administrative privileges may be dispersed among different departments. Moreover, it is important to chart the information systems and corresponding communication logic involved in the process. We report our project to point out that a seemingly trivial task, such as data transfer to PACS, may require collaboration of different departments and private enterprises. As the use of nTMS in presurgical planning is rapidly increasing, our experiences hopefully aid other hospital units integrating their nTMS data to the clinical workflow. The described methodology is equally applicable for implementing data transfer protocols of other types of functional localizations producing point-like activation sources, such as magnetoencephalography applied for clinical localization of epileptiform brain activity (for a review, see, e.g., [18]).

Planning of neurosurgical procedures near or in eloquent cortical and subcortical areas often requires multiple functional and anatomical imaging modalities, and the ability to combine them reliably and flexibly. This is often done by the neuronavigation planning software. By using the hospital PACS for data storage and retrieval, the neurosurgeon is able to access the data at his or her convenience, regardless of time and place of presurgical planning, independently from physical storage media for data retrieval. This facilitates the presurgical planning during a busy clinical schedule and importantly improves data security. The ability for long-term reliable data archiving by a preexisting backed-up, network-accessible storage system is also a clear advantage of using PACS for nTMS data storage.

A multitude of implementations, both proprietary and non-proprietary, exists for DICOM file manipulations and transfer. By designing our own software, we were able to have a desired specific behavior along with data verification utilities. Moreover, the simplicity of the interface and suggestive automation reduce the possibility of user errors and expedite the transfer process. This enhances patient safety and data privacy. Regardless of time invested in development and extensive testing that is required for patient data applications, we found that tailoring the software was highly beneficial to the workflow. The need for physical transfer of USB sticks is no longer needed, and the staff resources are more properly utilized, thus increasing also the cost-effectiveness.

Ideally, both software and hardware manufacturers should provide conveniently adjustable output from their products. Although DICOM compliance is a minimum requirement for a medical imaging device, more extensive configurability and flexibility are highly appreciated. These would allow the provided systems to accommodate the varying needs of different organizations, data infrastructures, and end users.

Conclusions

We described a protocol established for transferring nTMS data into a radiology department picture archiving system and listed the required steps. The methodology was implemented and successfully applied in patient studies. In-house software for file manipulation and transfer adjacent to configurations between separate networking environments and different medical information systems was needed to enable the desired functionality.

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