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Short Communication

Reporting on X-ray Films by Radiographers will Always Remain Task-Specific and Limited In Scope: A Critical Discourse

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ABSTRACT

The number of radiologists is still very low especially in developing countries. It becomes even worse in the rural areas where there are no radiologists at all. Radiographers are the first people to contact patients who need X-ray services and clinicians often first contact radiographers to offer an opinion. Many patients have died simply because the radiographer has not alerted the clinician of an emergency due to limited training. Therefore, training radiographers to interpret on some selected X-ray images has become a necessity. However, owing to their limited medical knowledge, there is still debate that radiographer reporting will always remain limited and only task-specific.

Keywords
X-ray films; Radiographers; Patho-physiology; Diagnostic tests; Anatomy; Histology; Physiology

In this discourse, the term `radiographer` has been used to refer to those technologists that traditionally are supposed to operate the X-ray machine and produce X-ray images for the radiologist to report. These radiographers were previously not trained to interpret X-ray images, though there are current trends where the radiographers especially at post-graduate level are trained to interpret some selected X-ray images. This discourse has been contextualized from the perspective of a developing country from Sub-Saharan Africa where the title `radiographer` is used. However, some of the observations pointed out may be of greater interest to not only the other developing nations, but also to the more developed world to stimulate debate as to whether radiographers should actually be trained and allowed to report on some selected X-ray images cognizant of key legal implications that may arise as a result of this decision.

Often, patients have gone for long hours without reports on their films even in accident & emergency departments (A&E) where reports should be issued immediately.[1-3] Reporting by radiographers has been initiated partly due to the increasing work load in X-ray departments and the shortage of radiologists.[4,5] By extending this role to radiographers, it is believed that patients would be served better and quicker. The need for radiographers to report on images was observed as early as 1968 arising out of the fact that there were few radiologists and only less than 30% of medical students wished to pursue radiology as a career.[6] Since then, this need has continued to be emphasized over time.[7,8] However, despite the historical and current trends in advocating for radiographers to report on some selected X-ray images, they lack adequate medical knowledge and skills to provide reports. The proceeding discourse is based upon the observation by Donovan and Manning[9] that ``*successful reporting by….radiographers will always be task-specific and limited in scope*``. Throughout the discussion, reference will be made to the appendicular skeleton.

Limited knowledge in medical disciplines is the major obstacle for radiographers wishing to take on reporting plain X-ray images.[9] Radiologists are able to apply clinical reasoning drawing on the medical training they received to interpret X-ray films in a given clinical context. Consequently, radiographers are likely to be limited in the scope of their reporting. The observation by Donovan and Manning[9] that reporting by radiographers will remain limited in task and scope therefore seems to be justified due to the following reasons.

Medical disciplines like anatomy, histology and physiology are not taught to radiographers in detail. Other disciplines like pathology, micro-biology, pharmacology, biochemistry and disease epidemiology are never taught at all. Limited knowledge in these medical subjects is a major challenge for reporting radiographers, because their clinical reasoning of the patient`s condition is limited.[10] Radiographers can at times fail to know what to look for on an image and the reasons why they should look for it. Sometimes radiographers fail to interpret the context of the examination and lack the expertise to relate image findings to the clinical context. All this is because of limited medical knowledge which is needed to get an effective opinion on an image. When faced with clinical situations that need application of medical knowledge, the radiographer may be unable to do this.[11]

There are several examples to illustrate this limitation in medical knowledge: In evaluating a fractured radius, a reporting radiographer may have been taught to search for presence of fat pads. However, such a radiographer may lack medical knowledge of the patho-physiology that leads to the fat pads. In another example, much as trained radiographers may recognize a tumour presence in the humerus, they might be limited to just describing what they are observing, whereas as a radiologist relies on the medical knowledge of tumour pathology to describe patterns and even look out for areas of possible spread. In another example, a radiographer may fail to associate steroid therapy used in asthma with loss of bone density in the appendicular skeleton,[12] which requires knowledge of pharmacology. This therefore justifies limiting the scope.

Secondly, reporting on appendicular images requires radiographers to interpret and understand medical provisional diagnoses made as well as clinical information provided by the referring clinicians. This information gives useful schemas to interpreting images. It provides history of the patient`s condition which needs to be interpreted in relation to the image. Such information may include: patient`s age, gender, occupation, origin, medical history, etc. Certain disease patterns are associated with different types of people, gender or even age. Some fractures are more likely to be seen in certain age groups or in certain categories of people. Steroid drugs used in asthma may cause loss of bone density in appendicular skeleton.[12] However, radiographers are never trained in clinical medicine and therefore lack knowledge and skills to effectively apply this epidemiological data.

It is increasingly becoming difficult for clinicians to give in-depth clinical information on X-ray request forms partly due to increased patient load. Subsequently, radiographers may need to solicit for more clinical history from patients as they interpret images. Radiographers are disadvantaged because they were never trained in clinical clerkships like radiologists. Although radiographers can talk to patients to justify examinations and views to be taken, they may not be able to solicit for deeper relevant clinical history pertaining to the condition as a way of assisting them to interpret the image. Radiologists sometimes arrive at their conclusions after re-taking patient`s history. Asking relevant clinical questions to guide their interpretation is a skill many radiographers may possibly not have in sufficient depth.

Radiographers may also lack the needed skills in basic physical examination. Taking an example of limbs, there are various limb movement tests radiologists can use to give them clues on what type or which part of a bone is injured and relate this to the radiographic image appearances. This they are able to do because of their medical background in testing limb movements. Although radiologists do not do this all the time, they may at times rely on such skills especially in challenging interpretation scenarios. Many radiographers are never taught such skills which may disadvantage them in these situations.

In addition, majority of the radiographers may not be adequately trained to interpret medical diagnostic laboratory investigations that the patients present with. Deeks[13] observes that in many cases, radiologists combine their ability to interpret test results such as endoscopy, pathological, histological and biochemical laboratory tests (like, WBC, RBC, ESR) to guide their evaluation of images. Since radiographers never receive in-depth training in interpreting diagnostic laboratory tests, this may sometimes limit their ability to relate image findings to laboratory tests.

Lastly is the inability to effectively communicate results and suggest appropriate and acceptable recommendations. Owing to their limited medical knowledge, radiographers may find it difficult to identify clinically relevant information to include in the X-ray reports. This could potentially lead to over or under diagnosis which may be detrimental to the patient. It may also possibly lead to unnecessary recommendations for further investigations. Recommending for other investigations may require one to have medical knowledge of how such an investigation will assist in patient management. Recommendations in a radiological report may also include such things as suggesting alternative treatment or drugs. Radiographers are in most situations not in position to do this since they never train in pharmacology, which could further limit their reporting tasks.

There are several limitations for radiographers to report on X-ray images. However, in places where there are no radiologists at all, clinicians still call upon radiographers to give an opinion. This is true for many developing countries. Therefore, despite the many limitations for radiographers in as far as reporting on X-ray films is concerned, the debate needs to focus on perhaps limiting their scope of reporting to only specific cases and then train them to refer the rest of the cases to the radiologists. The argument that radiologists are few is not justification enough for radiographers to report on all X-ray images. This is because the responsibility of giving out an authentic X-ray report still lies with the radiologist. In addition, the radiography regulatory bodies and professional councils may not be ready to handle this extra responsibility of licensing and regulating reporting radiographers. Subsequently, this is likely to result into legal litigations if the X-ray report by the radiographer leads to patient mismanagement. Furthermore, allowing radiographers to report would mean that the radiography training period should be increased so that reporting modules are included in the curriculum. This also has financial implications and one cannot be certain that radiographers will be ready to take on more years of rigorous training in order for them to be able to competently report on X-ray images.

Although the intention of this discussion is to open up debate around this subject, one should be cognizant of the fact that the radiologist has the ultimate responsibility to the patient and not the radiographer. The radiographer just assists the radiologist to fulfil this role. If radiographers are to take on any form of reporting roles, they should be directly under the supervision of a radiologist on duty. Rather than advocate for radiographers to report on all X-ray images, one would perhaps begin by advocating for the training of more radiologists or for remunerating radiologists better so that they are attracted to rural health settings. In addition, radiographers should perhaps only be limited to identifying abnormal X-ray patterns and raising a flag for the radiologist to confirm and write a competent report later on.

One would also probably just limit radiographers to interpreting certain types of X-ray images such as fractures in A&E departments. Therefore, before one can propose ways of making radiographers to ably report on X-ray images, the focus should rather be on proposing ways of making radiographers work closely with the radiologists in a collaborative manner for the benefit of the patient. Efforts by policy makers should be put on creating an enabling environment for attracting more radiologists to places where they are not found and also attracting more medical doctors to take on radiology as a specialty.

There are various training models that have been presented to equip radiographers with basic image reporting skills. The College of Radiographers of the UK[11] for example recommends that radiographers should be taught skills to interpret basic medical laboratory diagnostic tests that may appear in clinical notes. In addition, there is need to introduce aspects of film reporting at undergraduate level for radiography students. This is likely to open up opportunities for further training on a wide variety of film reporting for interested radiographers at postgraduate level. Even for the already qualified working radiographers, the key factor to consider is continuous professional development (CPD) in reporting skills. Radiographers should be given time, opportunities and support to pursue postgraduate courses in film reporting. CPD can also be achieved by allowing qualified reporting radiographers to attend conferences, workshops, seminars, clinics and educational sessions within departments. By participating in all these activities, radiographers can get exposed to various reporting tasks and eventually acquire more knowledge, skills and experience. Imaging departments should also perhaps allocate radiology mentors to those radiographers who are training in reporting. The mentors could be radiologists or senior reporting radiographers. The role of the mentors would be to supervise the reporting radiographer, arrange tutorials with them and to check all reports for quality in relation to the image, patient`s condition and clinical history before flagging them off.

However, despite the various training programmes proposed, ultimately, the radiologist is responsible for the patient and at the moment, it should remain like this with the radiographers playing a supporting role in the interpretation to avoid any legal implications of opening X-ray image reporting by the radiographers. Therefore, reporting by radiographers is likely to remain limited in scope due to the nature of their training that does not equip them for this role. More ways still need to be identified on how to make radiographers competent in reporting before they can be fully allowed to report by the regulatory bodies in the various countries.

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Systematic Review

Enterprise Imaging: The Next Frontier in Healthcare Technology–A Liturature Review

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ABSTRACT

Aim

A review of the literature was performed to evaluate, review and discuss the imaging systems of picture archiving and communication system (PACS), vendor neutral archive (VNAs) and enterprise imaging.

Method

A search through the databases of PubMed, OvidMedline, Scopus and Embase was performed utilizing several keywords relevant to image storage in various combinations of "OR" and "AND". Articles were carefully assessed according to inclusion and exclusion criteria where only articles published in the last 10 years were obtained to collect recent information. Additionally, articles found from the reference sections of electronically sourced articles were also reviewed.

Results

The review revealed that traditional PACS suffer from several limitations of data storage, migration and maintenance. VNAs improve upon this situation by allowing images from different departments to be shared easily and extend this ability to in between organizations. Physical copies of images are no longer needed and applications such as teleradiology and mobile imaging are possible. Enterprise imaging attempts to provide a format that allows for organizations to govern the management of image sharing and storage between institutions using a set of 7 characteristics that define an efficient system.

Conclusion

Image storage technology has experienced several advancements in recent years. Traditional PACS imaging has allowed for image capture, viewing, storage and analysis but is unable to perform effective image sharing across institutions. VNAs have provided a system to surpass this limitation by normalizing proprietary digital imaging and communications in medicine (DICOM) formats used by PACS vendors. With the advent of new technology, enterprise imaging has been developed as a system that enables the management of multi-departmental and multi-institutional image sharing in one system.

Keywords

Enterprise imaging; PACS; Vendor neutral archives; Image storage; DICOM; Cloud PACS.

INTRODUCTION

Traditional picture archiving and communication systems (PACS) allow users to create images, store them in large data banks and then retrieve them for viewing or processing.[1] For many years this has been the standard system that health institutions have used to manage their image data within their imaging departments. However, each PACS vendor utilizes their own proprietary 'digital imaging and communications in medicine' (DICOM) standard format to increase their own system performance significantly.[2] Due to this, DICOM files from independent institutions are in different formats unrecognizable by other PACS. Vendor neutral archives (VNA) have been developed to address this fundamental issue. To remove the restrictions on health institutions, they normalize the proprietary DICOM format to allow for image exchange.[3] They have also improved on other issues of PACS including the removal of upgrading the entire system and in the case of cloud-based software the need for physical storage centres.[3] These developments have all lead to the evolution of enterprise imaging. Enterprise imaging offers improved efficiencies in data management through the creation of a comprehensive program intended to facilitate multi-institutional image sharing. The key characteristics of enterprise imaging and strategies to the implementation of the system are discussed and explored in this liturature review. Several white papers created by the Healthcare Information and Management Systems Society (HIMSS) and Society for Imaging Informatics in Medicine (SIIM) have addressed strategies and key characteristics that define what enterprise imaging is and how it should be implemented.

METHODS

For this liturature review we performed a search through the databases of PubMed, OvidMedline, Scopus and Embase. We utilized the following keywords: "enterprise imaging", "enterprise medical imaging", "PACS", "Cloud PACS", "Picture archiving and communication system", "Information storage" and "vendor neutral archives". These terms were utilized in various combinations using both "OR" and "AND". Combining search terms with 'AND', Pubmed produced 623 results, OvidMedline produced 53 results, Scopus produced 648 results and Embase produced 76 results. Articles were then carefully assessed according to inclusion and exclusion criteria (Table 1). Peer-reviewed research articles, journal editorials and seminal papers were included to provide a broad understanding of each information storage system. Only articles published in the last 10 years were obtained to collect recent information. Abstracts of articles were reviewed to assess the relevance before a full-text review was performed. Additionally, appropriate articles found from the reference section of electronically sourced articles were also reviewed. After a thorough review, 40 articles were selected to be apart of the liturature review.

Table 1. *Inclusion and Exclusion Criteria*

Inclusion	Exclusion
• Published between 2008 and present	• Published before 2008
• English Language	• Not in English
• Available in full text	• Not available in full text
• Reliable source	• Articles not focussed on information storage aspects of PACS, VNAs or enterprise imaging
• Focussed on either PACS, VNAs or enterprise imaging	
• Included challenges and issues associated with image storage systems	

RESULTS AND DISCUSSION

Review of PACS

For a modern healthcare institution, there is a high demand for data infrastructure that can provide quick, easy and reliable access to imaging results and store large and complex data files for patient records. PACS serves as a computer database that aids the storage and transmission of large and complex images from multiple imaging modalities.[1] The protocol behind the transmission and storage of images is dictated by a fundamental standard known as DICOM. DICOM allows for communication between medical imaging devices and the application server, which enables clinicians to locate and observe specific saved images.[4] The implementation of PACS in hospitals and healthcare organizations has greatly improved the imaging storage situation. PACS provides a secure, relatively portable and instant access to patient data across multiple imaging platforms.[5] This has reduced the costs associated with image storage and produced long-term savings from the elimination of films due to the online and digital format of images.[1,5] Furthermore, the workflow in radiology departments has greatly increased due to the simplification of patient data that radiologists can now access.[1,6] Additionally, improvement of PACS technology can support offsite teleradiology and computer assisted diagnosis (CAD).

Current Issues of Traditional PACS

PACS has streamlined many processes within a single hospital network, however due to its local nature and the huge amount of data it stores it has also produced issues with storage, maintenance and data migration that conflict with the requirements of modern imaging. Many articles agree that the large storage needed by PACS leads to varying issues in its efficiency.[2,3,5,7] A report by Maluf and Rajendran showed that 80% of data volume in electronic records were taken up by medical images which supported 60% of all patient diagnoses.[3] To facilitate this, a large PACS storage system should be implemented to maintain patient image history. However, a study by Costa et al[5] noted that imaging in cardiology and X-ray created huge volumes of data which also lacked interoperability as they were distinct PACS products.[5] Horii further expands this noting that other imaging subspecialties including ultrasound and nuclear medicine lacked proper visualization in PACS.[2] To make up for these shortcomings, PACS software and hardware can be upgraded to accommodate larger storage capacity and image visualization. However, upgrades can be costly, time-consuming and disruptive. PACS interfaces with many systems in the hospital ranging from hospital information systems (HIS) and radiology information systems (RIS) to billing and administrative systems.

System upgrades require interfaces to work cooperatively with each other however vendors on either side of an interface will only take responsibility for their side of the interface. This results in situations where new additional software interfaces do not match up with original software interfaces due to small differences.[2] When issues arise, maintenance must be carried out by the PACS vendor. However, these are specialized problems that require a dedicated PACS engineer. Thus, this requirement typically results in workflow disruption and loss of image and report viewing.[8]

Data migration of PACS images either from an old to a new system or in between healthcare institutions has presented many unsolved issues that affect the entire healthcare system. Each PACS system utilizes an individual proprietary form of DICOM formatting which optimizes their system performance.[2] The special DICOM formatting can then cause lengthy and expensive situations when hospitals need to transfer their PACS images to a newer system. Data mismatch requiring manual intervention can occur in this upgrading period when patients with similar names are regarded as the same patient.[2,3] Patient images introduced from a separate vendor into the PACS system can also hinder the data migration as they may contain their own private DICOM formatting.[8]

This issue is prevalent in the sharing of data across different institutions with different PACS vendors.[9] Some healthcare institutions still rely on the transmission of patient images through physical computer disc (CD) copies.[9] These disks are no longer being used in medical imaging storage.

In a study by Al-Hajeri et al,[10] they identified that radiologists determined a lack of support for mobile access and integration with other hospitals systems as a significant issue. They also pushed for web based PACS solution and mobile phone PACS access. Although these results have only been gathered from local hospitals in Kuwait, they represent that multi-institutional image sharing is an issue recognised internationally.

Cloud PACS

Cloud PACS is an evolution of PACS technology to provide a simple, scalable and accessible form of PACS for healthcare institutions. The utility is derived from cloud computing, where several widely distributed data centres house physical processing units that allow for virtualized processing and storage of information outside of the medical institution and accessible online.[11] Several articles and journal editorials observe that the integration of PACS to cloud based software would provide many benefits.[12-16] These include the multi-institutional access to patient image history, accessibility to remote radiologists, seemingly limitless data storage and elimination of investment into local data storage equipment and maintenance. Cloud PACS also opened the possibility of removing viewing software entirely and utilizing web-based architecture to view images on web browsers and mobile devices.[17-19]

Several previous articles also focussed on a functional aspect of the system that can be improved. This underlines that although Cloud PACS is useful, it is still far from perfect. Cloud PACS is not a local network and outsources the storage and processing power. In two articles published by Silva et al[5] they described methods to tackle latency and secure DICOM data relay issues.[15,16] Latency issues are due to huge amounts of image data that must transfer to the cloud *via* encrypted channels to maintain security.[15,20] Cloud providers will also have access to the confidential patient data which can raise some security and data privacy issues.[16] Because of this, providers have strict legal and ethical regulations they must abide by so that users as confident in their provider. However, this differs from private to public cloud computing services as the former is more well developed and is less accessible to the public.[21] Improvements proposed by Silva et al[5] may present advancements in the right direction however an article by Godinho et al[7] presents a practical challenge.[15,22] Implementation can only be justified by testing and investigation. As Cloud PACS manages communication from several geo-distributed locations, massive volumes of data will have taxing effects on bandwidth. Thus, if a test were to be achieved in a real medical institution setting, it may prove disruptive to day to day activity as some tests require saturating the network with requests.[22] Nevertheless, Godinho et al[7] also proposes a method to enable real world simulations without the disruption.[22] Cloud PACS remains a fairly new advancement to solving image storage issues but as the previous articles suggest, there are many factors that still present issues that need consideration.

Vendor Neutral Archives

VNAs are a recent advancement in information exchange technology that aimed to solve the multi-institutional problem that affected traditional PACS. Onsite or cloud-based VNAs made image exchange possible by normalizing the proprietary DICOM format of individual vendors for storage but still enabled images to be sent out in their original DICOM format.[3,23-25] The introduction of a universal viewer, or univiewer, removed the need to learn new viewers for each PACS. This improved physician preference, mobility and viewing flexibility. Additionally, upgrades to PACS to view different modalities, i.e. computed tomography (CT), magnetic resonance imaging (MRI), cardiology etc., was removed as different image modalities could each be supported and retrieved easily from VNA storage. Costs from maintenance and information technology (IT) support were outsourced to the vendor of the VNA, in the case of cloud-VNA this infrastructure cost was greatly reduced.[3] Thus, hospitals could support multiple PACS viewers and exchange images between institutions with different PACS vendors.

Workflow and efficiency of the imaging department were then greatly improved. Previously, physicians and radiologists would spend time to alternate and learn different PACS systems or unpack new image software to view outside images from a CD. With the aid of a VNA, physicians could continue using the PACS viewer they were most comfortable with and view images from different imaging departments easily. Furthermore, it allowed a best-of-the-breed strategy to picking new PACS viewers as radiologists could choose which system was the most suitable for them without being limited to a single consistent PACS across disparate imaging lines.[3,25,26]

Issues of VNAs

Although VNAs removed some significant concerns for using PACs, it brought several inherent issues. On-site VNA storage requires two data centres to be constructed and maintained with each centre containing a copy of the data. Thus, the initial infrastructure deployment cost could surmount the budget of a hospital.[27] It will ultimately come down to the long term plan of the health institute. If the institution intends to maintain a relationship to one PACS vendor or if they are too small to warrant this investment, then the upgrade may be unfeasible.[3] However, if purchased then the institution may go through their last data migration for all their images. As VNAs allow the combination of a multitude of PACS viewers, the institutional executive will be required to look after multiple PACS vendors. This is a disadvantage of the best-of-the-breed system selection as opposed to using a single PACS vendor for every image modality.[3]

In an article by Margolis, Westphalen & Haider,[28] they noted that the non-DICOM compliance of mpMRI image data was not supported by VNAs. The data they obtained from mpM-

RI combined with transrectal ultrasound could aid identification of prostate cancer. However, the metadata produced was non-DICOM compliant and urgent information on prostate cancer was still managed through CDs. This article highlights that certain non-DICOM compliant data files are not covered by VNAs and can present serious issues for the investigation of prostate cancer. Although a specific imaging combination is stated in this article it represents that VNAs are not infallible.

Articles by Bialecki et al[24] and Karthiyayini, Thavavel and Selvam were found that proposed additions to VNAs which could improve on inherent issues.[24,27] Bialecki et al noted that object storage technology could be an alternative to VNAs.[24] Object storage technology improved search queries to very specific information involving the patient, the type of illness and identification of pathology in the report. However, the article concludes by noting that the technology would be a better complementary add on to VNAs as it could be implemented in a non-disruptive manner as a powerful search engine. Although it was a case presentation, the article lacked results from a large-scale study and would require a follow up study to prove the practicality. Karthiyayini, Thavavel & Selvam presented an idea that had potential to be implemented in future VNA advancement.[27] Cloud computing enables a shared pool of computing resources for private, community and public sectors. By combining VNAs and cloud computing, disadvantages of onsite VNAs could be resolved. Placing both data centres into cloud-based storage could reduce the initial infrastructure deployment cost. Employing a platform-as-a-service format for the secondary data centre and a software-as-a-service format for the primary centre would enable the customer to only spend cost on an as-needed basis. This implementation is noted to provide flexibility for physicians to access images from anywhere with the interoperability of exchanging information between different institutions and departments. However, with the use of cloud-based software, security can become the primary concern as databases are now in the cloud as opposed to a physical on-site storage system.

Enterprise Imaging

In this transitional period of image storage technology, enterprise imaging represents a step away from traditional PACS and towards systems for multi-institutional image sharing. The onset of VNA technology provided a key foundation for providing a non-proprietary approach to archiving and data management that enterprise imaging can be based off.[29] However, from the literature studied in this review, there exists no one clear cut definition for enterprise imaging. Roth et al[30] identifies enterprise imaging as a set of strategies or initiatives to support clinical imaging workflows and management of IT infrastructure in an optimized format.[30] Petersilge provides a refined interpretation where enterprise imaging uses a central VNA to gather many hospitals and different care services lines into one single imaging system for image movements.[31] Another interpretation defines that it is the incorporation of all medical images into a single archive that is integrated into the electronic health record (EHR). However, the one agreed upon goal is for an image system utilized by health organizations to provide streamlined access to a longitudinal patient medical record encompassing both DICOM and non-DICOM images from disparate service lines. The function of enterprise imaging is similar to that of a VNA however enterprise imaging is distinguished as it represents a refined regulatory format for health organisations to implement and follow.

Seven characteristics of enterprise imaging: A collaborative workgroup made up of members from the Healthcare Information and Management Systems Society (HIMSS) and Society for Imaging Informatics in Medicine (SIIM) identified enterprise imaging as the next frontier in imaging systems. In preparation they developed a series of white papers to guide the implementation of enterprise imaging into healthcare organisations and identified 7 key characteristics of enterprise imaging.[30,32-36] However, of the series of 7 white papers only two focus on specific key elements, Governance and EHR enterprise viewer, whilst another introduces the characteristics.[30,32,33] It may be extrapolated then that these two key elements were highlighted as important aspects of enterprise imaging and that the other characteristics did not need as much guidance.

Governance: Governance is required to ensure care coordination and proper health information technology integration. There is not one unified definition or perspective of governance. Roth, Lannum and Joseph[32] state that although many articles have suggested the need for governance there are very few on the actual structure and implementation.[32] To provide a united definition, Roth, Lannum and Joseph and Roth, Lannum and Persons explain that governance is a decision-making body, framework or process that oversees and develops strategies for the enterprise imaging program.[30,32] The body would oversee the development of the agenda, technology, information, clinical use and financial aspects of enterprise imaging. Successful governance would involve active cooperation of clinicians in the implementation of clinical systems.[32]

Enterprise imaging strategy: Governance would then produce a strategic roadmap to the implementation of enterprise imaging. This would include financial considerations on what technology is available and what is required to facilitate the transition. The same would be done for redundant technology such as legacy viewers or PACS.[30]

Enterprise imaging platform: From the strategy, the infrastructure, modalities, devices and integration points should be provided. The central repository is often VNA based, however the organization may opt for a PACS if they intend on maintaining a single vendor. Several key considerations should be made such as whether the repository can handle DICOM and non-DICOM clinical images and video. The archive should be modality, modality vendor, specialty, service line and viewer agnostic. It should support standards-based access from DICOM, health level 7 (HL7) and web services. Furthermore, point of care modalities, handheld devices, software and image exchange gateways should be supported.[30] With this considered it can promote the importance of the EHR transitioning into a longitudinal medical record.

Clinical images and multimedia content: Enterprise imaging separates images into their use by the performing providers. Thus, instead of being categorized by modality, type of image or operational workflow it is based on 4 broad categories. These are diagnostic, procedural, evidence and image-based clinical reports.[30] Rather than being firm rules they are general categories that allow for one image to fall into more than one category. Diagnostic: images that confirm a clinical suspicion or provide differential diagnosis. Procedural: images captured before, during and after a procedure that act as a guide for surgical approach and documentation. Evidence: like 'procedural' it acts as documentation of the current state or progression of treatment and pathology. Image based clinical reports: where delivery of images contain textual information as well.[30]

EHR enterprise viewer: The enterprise viewer attempts to provide a single viewer to all images saved in the electronic health record or centralized archive.[30] To achieve this, the enterprise viewer must be a thin-client or zero client application that can be used on any device to display and manipulate images and documents stored in the EHR or separate centralized archives.[33] This allows access to diagnostic image creators, surgical specialties, general providers and patients.[30] However, as enterprise infrastructure allows the consolidation of many disparate service lines, specialty viewers from legacy systems can still be used depending on radiologist choice. Advantages of a thin-client or zero-client enterprise viewer include single viewer access to the HER, diagnostic image interpretation by specialties and clinics without a dedicated PACS, physician to physician collaboration, patient portal image viewing and medical education.[33]

Image exchange services: It is essential that enterprise imaging allows for inbound and outbound services of images including standardized DICOM and non-DICOM.[30] This provides the function of true multi-institutional image sharing. Images stored and indexed in VNA can be pre-fetched onto a local PACS in the original proprietary format for viewing.

Image analytics: By defining and standardizing all the imaging metadata, it provides a repository of data that can be analysed.[30] Thus, business and clinical reports can be formed from this data for study statistics and image acquisition patterns.

The white papers produced by the HIMSS-SIIM collaborative workgroup provide a detailed and informative guideline to the structure of a successful enterprise imaging format.[30,32,33] However, it can always benefit from specific studies into the actual implementation of an enterprise imaging format using the 7 characteristics as a template. As it stands, these white papers provide the current leaders of a healthcare organisation the foundation to understand enterprise imaging.

Workflow changes of enterprise imaging: A new form of imaging workflow known as encounter-based imaging may be introduced as enterprise imaging is adopted. However, this is dependent on the institution, what they aim to achieve and whether any departments would benefit from this workflow. Traditionally, order-based imaging is conventional in radiology. This followed a systematic format where referring physicians prescribe a specific standardized study to be performed at a radiology department to achieve a differential diagnosis.[34] The radiology department would receive the order, obtain the image and the radiologist would send their diagnostic report back to the physician. However, certain departments that acquire visible light images or recordings may not fit into this workflow. For departments such as dermatology, emergency of some surgical settings, they may be required to acquire photographs of moles, skin lesions or moles on presentation of the patients.[34] As this is not known before the patient arrives an order cannot be set prior. Furthermore, the orders that use standardized general locations such as 'Humerus' in radiology may not be applicable when the mole is in a more specific location of the upper arm. With the potentiality for multiple moles in dermatology it would be highly inefficient to order multiple image orders of different body specific locations. Encounter-based image capture would allow image acquired by the dermatologist to be manually inputted into the patient's electronic health record allowing for ease and specificity. However, the risk of misspelling patient or study information exists with manual typing. For encounter-based image capture to function properly there needs to be mechanisms that enable delivery of image specific information as part of the image metadata such as body part identification, acquiring specialty or procedure description. As it stands, encounter-based imaging is not a well-documented or well implemented system in EHRs. As only one white paper produced by Cram, Roth and Towbin exists that outlines the potential uses of an encounter-based workflow, more research into the efficiency of this system in departments such as dermatology is required to highlight the benefits.[34]

Different applications of enterprise imaging: Enterprise imaging is not one single system format, , preferably it is an idea on image sharing and storage optimisation as demonstrated by Bian, Topaloglu and Lan and Erdal et al[35,36] Bian, Topaloglu and Lan discuss the development of an enterprise imaging repository (EIR) for implementation into a nuclear medicine department at the University of Arkansas for Medical Sciences (UAMS).[35] The need arose from the issue of poly ethylene terephthalate (PET)/CT storing huge amounts of images to an old PACS server that was cost inefficient. The equipment identity register (EIR) utilized a universal web-based viewer, integrated into the ADT (Admission, discharge and transfer) system of UAMS and accepted a variety of image formats including non-DICOM standard formats. This followed several characteristics of enterprise imaging including: Enterprise imaging platform, enterprise viewer and image exchange services.[30] As evidenced, the EIR did not utilize a VNA but followed the stratagem of storing all medical image files in a central location with ease of access and sharing. However, the article only covered images created in a nuclear medicine department of one organization. It can be further improved by testing the technology on different departments and reviewing the processing of non-DICOM standard images in another study.

Erdal et al[36] demonstrated a study on the development of radiology and enterprise medical imaging extensions (REMIX) platform at the Department of Radiology in The Ohio State University Wexner Medical Centre.[36] The REMIX system was a collection of hardware and software modules that presented custom code and add-ons to vendor-based software. It aimed to enhance cancer related imaging and research by mining cancer radiomics

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data and providing a platform to build predictive models relating image features to tumour phenotypes. Although REMIX does not strictly deal with conventional imaging it presents a unique adaption of enterprise imaging in research that allows for datasets of multiple institutions to be extracted and analysed. However, the study provides a proof of concept and for the functionality to be fully realized, the study should be tested again involving datasets of multiple hospitals.

Challenges and limitations of enterprise imaging: Enterprise imaging although useful is not without faults. Several articles have identified issues that range from technical considerations to workflow issues. HIMSS-SIIM have attempted to provide solutions to challenges identified in their white papers but these remain as guidelines.[37,38]

Although a minor issue, there are some image producers who do not appreciate the accessibility of patient images or the integration into a longitudinal medical record. These image producers believe that only the diagnostic report is the significant product and that images are only important to the diagnostic interpreter.[31] It may be interpreted as a natural stubbornness to change and an issue that does not require much intervention. A hurdle that every organization transitioning to an enterprise imaging format is still data migration.[2,3,8,39] However, it should be reaffirmed that although it may be costly and time consuming, if transitioning to cloud based or VNA stage it may be the last data transfer ever.

Several functional issues of enterprise viewers were raised by Roth et al[33] Although enterprise viewers can support a majority of images they cannot support every single format today and formats developed in the future. Thus, they should not be termed 'universal viewers' as it carries a different connotation. Another issue is that some enterprise viewers may carry basic to specialty image interpretation tools whilst other viewers only support necessary tools.[33] It may be a reasonable conclusion then that the enterprise viewer is more suited to a general group of users and will not be able to suit every single provider. Furthermore, different viewing environments may be required by radiologists or cardiologists and an enterprise viewer may not present images in an ideal state without the need for manual intervention.

Some technical limitations are identified in a white paper by Clunie et al[37] They identify that with diagnostic imaging, some ECG systems will maintain raw data in proprietary formats and only allow a post processed image of the waveform through. Similarly, ophthalmic imaging devices do the same but only allow software analysis to be achieved through vendor specific software. Other imaging specialties including obstetrics and gynaecology present another issue with lack of vendor conformance on DICOM standards. This further accentuates that some specialty groups can raise issues in enterprise image storage as seen in previous studies.[9,28] Additionally, linking all imaging to the same procedure in situations where both DICOM and non-DICOM imaging are used has proved difficult to achieve in the electronic health record (EHR). These issues highlight that there may be a reluctant acceptance that not all raw image data can be acquired and that the EHR requires further refinement.

Enterprise imaging aims to provide acceptance of non-DICOM images, however visible light images or recordings can create unique issues for effective image storage. Visible light (VL) images involve images captured on a camera in settings such as dermatology or emergency to document physical appearances of skin lesions or wounds respectively. However, in integration to enterprise imaging storage, VL requires the support of true colour images, different metadata requirements and acquisition workflow as opposed to conventional radiology.[37] Images that undergo lossy compression can lose accurate detail and start to blur on review. Lossless compression can preserve this image information but will result in larger file sizes.[37]

Towbin et al identifies seven workflow issues associated with visible light images.[38] Workflow: organisations will be required to decide on whether an order based or encounter based image capture workflow system should be utilised. As some departments, such as dermatology, do not know whether they will take an image prior to patient presentation or may be required to take multiple pictures then order based image capture can prove inefficient.

Patient identification: Camera images will typically lack unique patient identifiers inside the image. Solutions such as patient identifying stickers or imaging patient identifiers before and after the image acquired can be used in some situations. However, this method is prone to human error and cannot be used in situations where a sterilised field is required.

Information of the image: Measurements that could be typically taken with normal viewers are redundant in cases with photographs as pixel spacing and zoom factor are not standardized. To combat this, if a measurement tool such as a ruler is in place then measurements can be taken. Colour standardization will also be an issue as lighting, shadowing and camera settings will vary with every image. Thus it will be difficult to colour correct on a computer. Similar to before if a physical tool such as a colour wheel is introduced then the computer can recognize this tool and perform colour corrections efficiently. However, physical tools present in image will suffer the same problems as Patient identification.

Reporting: Bi-directional image and report viewing will be required as photographs can often be taken after the report in dermatology as opposed to being taken before in conventional radiology. This allows for easy image and report association and viewing. Metadata: essential information such as body part region, department and procedure description is lost with VL images. To counter this effect, if the body type and study type information is included in an encounter based image workflow then some important metadata can be retained.

Legal concerns: Photographs that document child abuse or sexual assault can bear privacy issues. In this case the organization will need to create permissions for access but image sharing will magnify this issue.

Mobile viewing: Mobile viewing with the advent of mobile devices such as smartphones, more and more physicians are using their devices to document pathology. This raises a range of legal issues as their phones become carriers of patient sensitive data. However mobile applications could be created to facilitate this.

Clunie et al and Towbin et al have highlighted a variety of technical and workflow issues with visible light images.[37,38] However, both these white papers are unable to provide solutions for each issue. Solutions provided are general and although these papers serve to guide organizations on what issues they may face, further research may be required to solve specific issues raised.

An exciting challenge presented by Dinov describes how big healthcare data lacks any reliable means for data analysis or research.[40] As enterprise imaging will gather significant amounts of data and only continue to expand in size and complexity, data analysis may be problematic. As previously noted by Erdal et al,[36] data analysis can provide models for pathology and image analysis. However, although Dinov is hopeful that analysis technology will encounter great advances in the future, enterprise imaging will present unique issues of associating DICOM and non-DICOM images for collaborative analysis.[40]

CONCLUSION

Technological advancement has allowed for significant changes in the healthcare imaging industry. Multi-institutional image sharing is no longer a limitation for many healthcare organizations who are still using a traditional PACS model. With the arrival of enterprise imaging, a format to achieve accessible healthcare imaging to both radiologist, radiographer and patient is possible. However, the transition to an enterprise imaging model is a great or deal that an organization must be willing to undertake before reaping the benefits.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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RADIOLOGY

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Retrospective Research

Amygdala Basal Activity Differs in Hospitalized Pediatric Psychiatry Patients Compared to Control

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ABSTRACT

Introduction

Patients with psychiatric disorders needing inpatient care often display aggression, fear, anxiety. These emotional proccesses are typically ascribed to the amygdala, as indicated by multiple publications. However, very few of these studies have been done with patients of the pediatric or adolescent population. The goal of our research was to analyze a hypothesized increase on the activity of the amygdala in patients being admitted for a psychiatric reason.

Method

We retrospectively analyzed a group of 168 patients with a primary psychiatric diagnosis that were hospitalized at Nicklaus Children's Hospital, Miami, Florida between the years 2010 and 2017 and who had a resting state functional magnetic resonance imaging (fMRI) as part of the neuroimage work-up for psychiatric symptoms. Primary diagnosis included major depressive disorder, bipolar disorder and schizophrenia. The comparison group consisted of 75 hospitalized pediatric patients with intractable epilepsy and no past psychiatric history. This comparison group was chosen due to the large number of imaging studies available done in an identical hospital setting.

Results

The results of our study showed a considerable increase in the frequency of identified networks in the amygdala in psychotic patients *vs* comparison group with intractable epilepsy. The percentage of patients with identified networks that show an increase in amygdala activation in the epileptic group was 10.7%. The percentage of patients that showed an increase in amygdala network activation in the psychiatric group was 50.0%.

Discussion

This study suggests that children with severe psychiatric conditions requiring in-patient care have a statistically significant increase in basal amygdala activation compared to a control group with intractable epilepsy. Our findings require further development and refinement to ascertain which specific etiologies or symptoms are more related to the finding. This may ultimately evolve into a radiological biomarker for a specific psychiatric condition with potential to guide future treatment.

Keywords

Psychosis; Amygdala; Resting state-functional magnetic resonance imaging (rs-fMRI); Magnetic resonance imaging (MRI); Independent component analysis (ICA); Default mode; Connectivity; Epilepsy.

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INTRODUCTION

Current data suggests that the amygdala is a central hub for emotional processing, decision making and fear. Very little research has been done that focuses on the pediatric and adolescent amygdala of psychiatric patients while in the hospital setting. We seek to analyze two specific groups of pediatric patients with resting state-functional magnetic resonance imaging (rs-fMRI). It is our hypothesis that patients who were hospitalized for a psychiatric cause would have increased perfusion as seen on functional magnetic resonance imaging (fMRI) when compared to a group of patients with intractable epilepsy. Patients with psychiatric disorders needing inpatient care usually complain of fear, anxiety and aggression.[1] There are multiple studies reporting structural and biochemical amygdala changes in patients with schizophrenia,[2] bipolar disorders,[3] and mood dysregulation.[4] A 2010 publication used emotional auditory stimuli to analyze brain activation in patients with schizophrenia. They found an increase of activity in the parahippocampal gyrus and the amygdala during the emotional session.[5] Auditory and gustatory hallucinations have been also found to be associated with amygdala activation.[6,7] It has been reported that patients with schizophrenia have augmented connectivity between the amygdala and the visual cortex.[8]

Despite these findings, there is not a clear explanation of the role played by the amygdala in psychosis. Even in the event of observable increased fMRI activation of the amygdala in psychiatric patient, it is difficult to know if the observation is the cause or the effect of the fear, anxiety or aggression. Patients with intractable epilepsy are subject to chronic very stressful situations that in some non-infrequent occasions may even threaten the patient's life. In the present study, we want to compare in a pediatric population the frequency of activation of the amygdala in rs-fMRI studies between a group of patients received in our inpatient service of psychiatry and a group of patients with intractable epilepsy.

The amygdala is known to be involved in the fear response in a typical neurological circuit. Rs-fMRI is currently a recognized tool for non-invasive mapping of eloquent cortex. Its usage is mostly limited for pre-operative work-up in cases of tumors or epilepsy surgery. The standard fMRI requires the performance of certain tasks during the MRI acquisition. A variant of fMRI known as rs-fMRI may provide information of several functional areas including motor, sensory, visual and auditory without the involvement of any task. The technique may also provide insight in more complex networks that most likely relate to elaborated cognitive functions. These include executive functions, salience networks, basal ganglia, cerebellum and the default mode. The latter has called the attention of the scientific community as it decreases its activity when the subject is involved in a cognitive loaded task. One of the most popular techniques to extract these networks is called independent component analysis (ICA). ICA identifies groups of spatially correlated voxels that are oscillating in synchrony with other remote voxels groups. This phenomenon is known as spontaneous brain oscillations. The frequency of these oscillations is characteristically found between 0.01 and 0.1 Hz. Each extracted group sharing a single profile of oscillation is a functional network. Some of these networks are more stable than others (mostly those depicting unimodal brain functions) while others are less stable not appearing in all volunteers nor in all sessions of the same subject.

The amygdala network is an unstable network. There are no reports of formal assessment of the frequency of this activation. Our group has classified the networks obtained by rs-fMRI activation on 40 normal subjects and found that the amygdala network is only present in 10% of cases. It usually activates along with the ventral aspect of the anterior striatum[9] and is usually symmetric.

METHODS

Psychiatric Group

For the sake of this study, a psychiatric case was defined as one requiring psychiatric inpatient attention, as judged by one of our Institution's staff psychiatrists. Diagnoses that are included in the psychiatric group are bipolar disorder, schizophrenia, major depression with and without psychotic features. The study was approved following Research Ethical Board review.

We retrospectively analyzed a group of 168 patients with a primary psychiatric diagnosis that were hospitalized at Nicklaus Children's Hospital, Miami, Florida between the years 2010 and 2017 and who had an fMRI performed due to psychiatric symptoms. Patients were diagnosed by a psychiatrist of the hospital staff. The diagnoses were either confirmed at admission or while on the inpatient floor. Symptoms experienced included hallucinations, delusions, aggressive behavior, mood dysregulation and suicidal ideation. In this study, participants were included based on the following criteria: (1) Patient's primary diagnosis is psychiatric; (2) Patient was experiencing hallucinations delusions or mood instability at the time of the imaging; (3) Patient's age was between 6 and 17 years of age. Exclusion criteria included: (1) history of epilepsy; (2) current or previous brain lesion or neurosurgical intervention; (3) incomplete results from movement or artifact noise; (4) history of substance use disorder. The patients had a mean age of 13.36 with a range from 6 to 17-years-old at the time the imaging was done. Of the 213 initial patients, 168 were included in this study. These patients had a mean age of 13.45 with a range from 6 to 17-years-old at the time the imaging was done. Forty-five patients were excluded from the study due to concurrent brain lesion, history of epilepsy, or other systemic condition. The patients were further categorized by sex and handedness.

As a comparison group, we randomly selected 104 patients in whom a primary indication for imaging was intractable epilepsy in absence of psychiatric symptoms. For this group, the inclusion criteria included: (1) History of intractable epilepsy; (2) Patient age at time of imaging was between 6 to 17-years-old. Exclusion criteria included: (1) concurrent psychiatric diagnosis; (2) neurosurgical intervention or visible lesion on imaging; (3) incomplete results from movement or artifact noise; (4) history of substance use disorder. The mean age of the comparison group was 11.06 with a range of 6 to 17 years of age. Twenty-nine patients were excluded due to age, neurosurgical intervention or lesion. Of the75 patients included, 25.3% required sedation with propofol 100 µg/kg/m. The patients were further categorized by sex and handedness.

Table 1. *Demographic Characteristics of the Sample*

	Control	Psychiatric
Variable		
N (initial)	104	213
N	75	168
Age mean	10.99	13.45
Age range	6 to 17	6 to 17
Age SD	3.6	3
Male	35	97
Female	40	71
Right Handed	62	151
Left handed	10	15
ambidextrous	3	2
Not determined		2
Sedated	19	48
% Sedated	0.25	0.29

N prior to exclusion=N (initial)=317; N included in study=N=243; Total patients excluded=74

M Technique

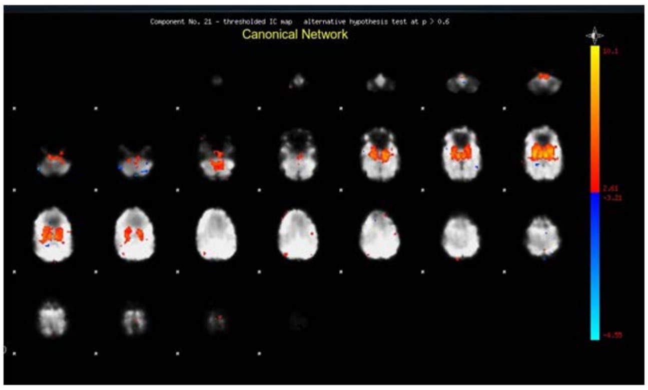
Patients in both groups had a resting-state fMRI sequence, and a three dimensions (3D) volumetric anatomical magnetic resonance imaging (MRI). All cases were scanned with the same MRI machine, an Intera Philips Medical System 1.5 T MR Scanner (Philips Health Care, Netherlands). Axial T1-weighted MRI 3D volume was acquired for anatomical reference with a field-of-view (FOV) of 240X240 mm, voxel size 1X1X1 mm, 120-176 slices in one slab, and the following acquisition settings: repetition time (TR): 25 ms, echo time (TE): 3.8 ms and flip angle of 30 degrees. The resting state (rs-fMRI) consisted of a blood oxygenation level dependent (BOLD) sensitive sequence with the following settings: 200 time-points, FOV 240 mm, matrix 64X64 voxels (voxel size 3.6X3.6X6.0 mm), 14-21 axial interleaved slices with no gap, TR: 2000 ms, TE: 60 ms, flip angle: 65 degrees, standard shim mode. Patients were instructed to keep their eyes closed and focus their attention on the breath, trying to feel the air flow in the nostrils.

rs-fMRI Processing

For each patient, the rs-fMRI data, was analyzed utilizing the fMRI Melodica tool, from Forecast Systems Laboratory (FSL) 4.1.9.[10] The tool provides ICA extraction of spontaneous brain networks. Data was re-aligned, normalized, and spatially smoothed by use of a Gaussian kernel of full width at half maximum of 7 mm; and then band-pass filtered (0.01<f< 0.1). Cases with motion average (x, y, z translational plus 3 rotational) of more than 2 mm were discarded for further processing.

The activation of the amygdala was assessed by one of the authors based on visual inspection, and (1) comparing the patient results with prior established findings[9] taken as template, and (2) the Online Brian Atlas Reconciliation Tool, available at http://qnl.bu.edu/obart/explore/AAL/. The amygdala network (as presented in the neural components yield by the ICA) consist of the whole amygdala, the accumbens nucleus, hypothalamus, ventral thalamus and the striatum (Figure 1).

Figure 1. *Example Image of Amygdala Activation with Intensity Depicted by Pixel Color*



For those patients under sedation, only those who showed activation of the primary visual network were included. Annotations of the melodic tool yield included number of neural components, number of networks judged canonicals, number of networks judged as non-canonicals and a categorical binary determination of the involvement of the amygdala as present or absent. The amplitude of the amygdala activation in each patient was annotated and documented based on the canonical network intensity within the amygdala provided by the tool.

Comparisons

Statistical comparisons of amygdala activation between groups were performed by means of Chi-square (two-tails) test. The comparison between the groups and the effects on amygdala activation of age, gender, handedness, and need for sedation were investigated with 2X2 tables running the Fisher exact test interactions were judged with a threshold of $p<0.05$.

RESULTS

There were no statistical differences between gender ($p=0.11$), handedness ($p=0.12$) and sedation/non-sedation ratio per group ($p=0.6$). The age group averages differ on our two groups. The psychiatric group is 22.2% older than the epilepsy group ($p<0.01$). In spite of our effort to minimize age as a variable factor, the patient average in the psychiatric group was higher. We believe the primary reason behind this is the age of onset for pediatric psychiatric diseases. The symptomatology in all included psychiatric diagnoses are more frequently expressed at pre-adolescent/adolescent ages.

The results of our study showed a considerable increase in the frequency of identified networks in the amygdala in psychiatric patients *vs* the epileptic control group. The average number of unique networks identified in the psychiatric and epileptic group was 11.75 and 12.66 respectively. The percentage of patients with identified networks that show an increase in amygdala activation in the control group was 10.7%. The percentage of patients that show an increase in amygdala network activation in the psychiatric group was 50.0%. The statistical analysis of results can be found on Table 2.

Table 2. *The Statistical Differences Between Both the Epileptic and Psychotic Patient Populations*

	Control	Psychiatric
Neural Networks		
Range	4 to 25	5 to 28
Average	11.75	12.66
SD	4.41	5.42
Canonical		
Range	3 to 22	3 to 20
Average	9.16	9.65
SD	3.88	4.64
Non-canonical		
Range	0 to 9	0 to 12
Average	2.56	3.06
SD	2	2.24
Amygdala activaion		
N=	8	84
%	10.7	50.0*
Activaion max		
Mean	7.73	7.34
STDev	4.97	4.8

(*)Amygdala Activation Statistical Difference:

Chi square: P=0; Z for 95% CI=1.96; Pearson's=35.793
Intensity Act: Z score; t-test: 0.876 (95% CI=-3.924<0.3<3.894, Wald)

The interactions between groups (epilepsy *vs* psychiatric), condition (sedation) and ICA outcome is shown in Table 3. No interaction was observed between group and number of networks, number of canonicals or non-canonicals in either of the conditions.

Table 3. *Interactions between Group and Sedation for ICA Outcome*

	Epilepsy		Psychiatric		
Averages	N=	SD=	N=	SD=	*p*=
Sedate	19		48		
#Networks	11.63	4.78	17.4	5.53	0.17
Averg canonicals	8.53	4.74	13.72	4.79	0.3
Averg non-canonicals	3.05	2.22	3.7	2.73	0.29
Non-sedate	56		120		
#Networks	11.79	4.33	11	4.34	0.51
Averg canonicals	9.38	3.57	8.23	3.68	0.78
Averg non-canonicals	2.39	1.91	2.84	2.01	0.21

The effect of sedation on the ICA yield is shown in Table 4. No significant statistical differences were seen in the epilepsy group. Sedate psychiatric patients show more non-canonical networks as compared to non-sedate individuals in the same group (p=0.035; CI 95%=1.96. CI dif: 0.085<0.97<1.854). The rest the interactions were discarded. The significant difference on the psychiatric patients seems to be dragged by 3 outliers with values beyond 3 standard deviations of the mean.

Table 4. *Statistical Differences of ICA Yield with Respect to Sedation*

Group	
Epilepsy	***p* value of Mean Dif**
Sedate *vs* Non-sedate	
#Networks	0.9
#Canonicals	0.474
#Non-canonicals	0.253
Psychiatric	
Sedate *vs* Non-sedate	
#Networks	0.192
#Canonicals	0.693
#Non-canonicals	0.035

Numbers are p values derived from statistical analysis (t-test) from columns in Table 3

Numbers are p values derived from statistical analysis (*t*-test) from columns in Table 3.

The effect of sedation in amygdala activation is summarized in Table 5. There was more frequent activation of the amygdala seen in the psychiatric group under sedation (p=0.032).

Table 5. *Effect of Sedation in Amygdala Activation*

Amygdal Interactions	Epilepsy	Psychiatric
Sedated		
N=	19	48
#Act	2	19
Non-sedated		
N=	56	120
#Act	6	65
(Fisher exact test)	0.325	0.032

DISCUSSION

The present rs-fMRI study supports the hypothesis that children with severe psychiatric conditions have a basal amygdala activation when compared to a similar population with intractable epilepsy. The epilepsy group showed amygdala activation at a much lower rate (10%). This rate of activation is congruent with matching age normal subjects from observational data previously obtained.[9] To the best of our knowledge, this is the first publication of this finding utilizing rs-fMRI based on ICA in the pediatric population.

Core to the major psychiatric conditions including psychosis, aggressive behavior, and delusions is the dysregulation of emotion. The involvement of the amygdala in emotional processing seems well established. A PubMed search utilizing the words "amygdala" and "emotion" yields 8808 results (search date:

05/10/2018). But what do we mean by "processing emotion"? There is probably not a single response for this question. Most modern approaches see the amygdala at the center of processing responses related to the "most significant objectives of the sub ject." According to Pessoa L, et al[11] in doing so, the amygdala may evaluate "what is it?" and "what to be done?" These questions result in the construction of emotions in a process intertwined with cognition.

Our study findings are congruent with previous evidence that show an abnormal level of amygdala activity in the presence of psychosis and/or mood dysregulation. Anatomical and functional abnormalities in the amygdala of psychotic patients have been noted across modalities including MRI,[12,13] and positron emission tomography (PET)[14] studies that consistently show altered connectivity patters and activation compared to controls. The findings are, however, disparate, suggesting a complex interplay of different subject-related variables. For example, different expression of a gene related to serotonin transporter correlates with amygdala activation in response to fearful and happy faces.[15] In a study of patients with intermittent explosive disorder, the left amygdala responded greater to angry faces in an fMRI study as compared to normal subjects and patients with the same condition but having history of alcohol abuse.[16] A 2016 study found estrogen levels in women seem to modify the amygdala connectivity in women.[17] Patients with depression have less amygdala activation on fMRI involving negative valence stimulus as compared to healthy controls.[18] In a group of adolescents, responses to negative valence distractors revealed increased amygdala activation with respect to healthy controls.[19] Adolescents with bipolar disorders seem to have lower threshold for amygdala activation from emotional face processing in fMRI when compared to control subjects.[20] Another group of adolescents with anxiety disorders showed greater amygdala activation than matching controls, in a fMRI study in which a social preference task was given.[21]

Not in all studies relating amygdala activation or connectivity with major psychiatric disorders show hyperactivation. Decreased functional connectivity in rs-fMR between the amygdala and the frontobasal areas has also being informed in a group of patients with major depressive syndrome.[22] Also, in a review of the literature it has been found that the task-related amygdala activation, and amygdala connectivity are diminished in patients with schizophrenia.[23] Although we focused our attention in the amygdala activation, independent components often have shown a ganglio-basal connectivity. Indeed, as shown in Figure 1, amygdala activation extends dorsally including areas of the ventral striatum (including areas of the nucleus accumbens) and the caudate nucleus. Medial structures most likely related to mammillary bodies and hypothalamus were also seen involved. Interestingly, we did not find connectivity to the basal aspect of the frontal lobes, cingulate, insula and preseptal areas as frequently described in other studies or rs-fMR and amygdala activation in psychiatric patients with bipolar disorder, depression.[24-27]

Our connectivity findings are based on independent component analysis and not in ROI-based connectivity as seen in most of the studies referenced above. Similar ICA methods used in adults with cocaine-user disorder showed amygdala connectivity to putamen, pallidum, caudate, thalamus and hippocampal areas.[28] This pattern of activation is greater in patients with history of trauma.

The complex and multifactorial interactions that mediate amygdala function in emotion processing and response may obscure our understanding. Nevertheless, all the previously mentioned studies and our own results are concordant with the core role this structure has in conditions where emotional regulation is impaired.

Pitfalls

This study has some potential shortcomings. First, there was a statistically significant difference of age between the epilepsy and psychiatric groups. This has a clear explanation. The age of onset for schizophrenia and or mood disorders with associated psychosis tend to skew the patient average age towards late adolescence, while intractable epilepsy are usually related to congenital anomalies that are manifesting early on life and that require early intervention. This explains the discrepancy and the difficulty to match the sample. However, we feel that both groups represent cohorts of adolescent and pre-adolescent children with similar neuro developmental maturation. Moreover, the frequency of amygdala activation found in the epilepsy group is the same than the frequency found in the normative group whose age mean (12 years, SD 4.2) was in between than those of our groups.

Another potential shortcoming is the need for sedation in a significant percentage of both the groups. Interactions of sedation were found only in the psychiatric group. Within this group, sedated patients showed more non-canonical than canonical components and more amygdala activation. It is difficult to speculate about these findings with just the results of this study. Although the doses of sedative were parallel between the groups, the epilepsy patients had the rs-fMRI series about 15 minutes into the session (after the task-related fMRI), while the psychiatric patients had this within the first 5 minutes. The effect of this difference, if any, is not known. We did not measure the blood levels of sedation. However, we made a physiological threshold of brain "reactivity", assuming one of the most stable networks, the primary visual, was present. Each case that required sedation was kept within a narrow window of sedation, enough to keep still, but not to the point of alteration the response of this network. The persistence of the amygdala network even under sedation suggests an ongoing primary phenomenon that put the finding at the origin and not at the consequence level and basically discards the effect of the environmental stressful features of the MRI exam.

For the purposes of this study, patient populations were grouped into two rather broad groups without further specifiers. Patients from the psychiatric group potentially had different diagnosis and or severity of symptoms at the time of imaging. The control group, although at a minimum had intractable epilepsy also were not sub-classified by diagnosis or severity.

Medication management was not taken in to account in the study and would also need to be addressed in future research. Many of the patients from the psychiatric group were on some form on antipsychotic treatment at the time the imaging was done. Anticonvulsants were used sparingly across both groups for epilepsy or mood stabilization. The psychiatric diagnoses themselves are based solely on clinical judgment at the time of the hospitalization and in some cases with limited patient history. The possibility of misdiagnoses cannot be excluded.

We did not analyze the effects of substance abuse, Attention deficit hyperactivity disorder (ADHD) or autism spectrum disorder. We acknowledge the difficulty to factor these important confounds. We were able to exclude known atrial septal defect (ASD), and substance use that were recorded as part of medical records but these confounders cannot be completely ruled out. However, to elucidate their impact will require a better understanding of the findings and a much larger number of subjects allowing meaningful stratification groups. Interestingly the same comorbidities, although likely in less degree, are associated with epilepsy.

In the psychiatric group whom met criteria for psychotic symptoms due to hallucination, the nature of the hallucinations was not taken into account. Much of auditory and visual hallucinations in schizophrenic patients are negative, evil or carry a negative connotation. This negative emotional valence could be further classified and correlations made with amygdala activation in these patients that may experience fear *vs* those with positive emotional response to the hallucinations.

Our findings require further development and refinement to ascertain which specific etiologies or symptoms are more related to the finding. This may ultimately evolve into a biomarker for a specific psychiatric condition with potential usage to guide treatment. Our aim was to demonstrate group differences on resting-state networks involving the amygdala. We did not strive to correlate the findings with state, traits, trajectories or treatment outcome. We are planning future studies to peruse that path.

CONCLUSION

In conclusion, we found a statistically significant increase in amygdala activation as seen on fMRI in the pediatric population with a positive history of psychosis. This may represent a heightened response to emotional stimuli caused by paranoia and or hallucinations. It could also be a compensatory mechanism by which increased perfusion to these affected areas result of a functional impairment from the underlying neuropathology.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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RADIOLOGY

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Systematic Review

MRI Brain Imaging in Assessment of Pediatric Head Trauma

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ABSTRACT

Purpose
Though computed tomography (CT) has been the mainstay imaging modality used in the initial evaluation of pediatric head injury, newer magnetic resonance imaging (MRI) techniques have proven to be more sensitive in identifying subtle findings of brain injury. Specifically, MRI has been used in differentiating subacute and chronic brain injury, and identifying the extent of encephalopathy, reactive gliosis, and hemorrhage related to the insult. In this literature review, we intend to present the current information about the use and benefits of MR in evaluating pediatric head trauma.

Methods
Literature search was done from Medline and PubMed for all peer-reviewed manuscripts from January 1990 and December 2018 using several keywords. The preceding searches included pediatric head trauma, pediatric TBI, imaging in head trauma, MRI in head trauma evaluation, and long-term effects of pediatric head trauma. After careful analysis, the most important points were chosen and summarized in this review.

Results
MRI has greater sensitivity in the detection of most types of head injuries, in comparison to CT – except skull fractures.

Conclusions
In the setting of head trauma, MRI provides an imaging modality with a unique ability to provide additional clinical information compared to CT examination.

Keywords
Traumatic brain injury; Diffuse axonal injury; Pediatric head injury; Magnetic resonance imaging (MRI) head trauma.

INTRODUCTION

Trauma is the leading cause of death in children over the age of one, and traumatic brain injury (TBI) is the leading cause of death and disability due to trauma, accounting for 70% of fatal injuries.[1] In the United States, every year there are 3,000 deaths, 50,000 hospitalizations and 675,000 emergency room (ER) visits related to blunt head trauma.[1] TBI is a major public health and socio-economic problem throughout the world, especially among children and young adults.[2] Even in patients who do not have any recognizable initial clinical manifestations, it can still have devastating long-term consequences on neurocognitive function and psychosocial behavior, if untreated. The use of computed tomography (CT) has increased in recent years, thus enabling early identification of TBI. Accordingly, many recent studies have shown an association between lifetime risk of developing cancer and ionizing radiation from CT exams. This lifetime risk of cancer is higher in young children when compared to adults.[3,4] Though CT has remained the mainstay imaging modality used in the initial evaluation of pediatric head injury, faster magnetic resonance imaging (MRI) techniques have proven to be more sensitive in identifying subtle findings of brain injury. Specifically, MRI has been used in differentiating subacute and chronic brain injury, and identifying the extent of encephalopathy, reactive gliosis, and hemorrhage related to the insult.[5-7] In addition, MRI is increasingly being used in the acute setting for stable patients who have a discrepancy between clinical symptoms and CT findings.[8]

There are many potential long-term sequelae in pediatric patients who suffer TBI including, long-term physical or intellectual disability, memory problems, behavioral problems, and cognitive functioning issues. Children with moderate to severe TBI have poorer outcomes in terms of executive functioning (attention, problem-solving), intellectual functioning, and to a lesser extent visual perceptual functioning. In addition, patients with moderate to severe TBI have been noted to have substantially more issues with education and long-term outcomes. More research is needed to determine how to improve therapy or rehabilitation in patients with these consequential outcomes following head trauma. In the meantime, quantifying and recognizing imaging findings early and correlating those with clinical symptoms seems to be of clinical value and MR plays a crucial and growing role in that respect. In this literature review, we intend to present the current information about the use of MR in evaluating pediatric head trauma.

EPIDEMIOLOGY

It has been reported that between 100-300 per 100,000 children and young adults are hospitalized with a head injury each year,[9-11] with many more outpatient and emergency department (ED) visits than admissions. In a 25-year longitudinal study from New Zealand, a birth cohort (n=1265) was found to have an overall prevalence of TBI of about 30%.[12] Abusive head trauma (AHT) is an important cause of TBI to recognize. AHT is seen more commonly in patients younger than the age of two years, with incidence in that group being described as 17 per 100,000 person-years (95% CI, 13.3-20.7 per 100,000 person-years).[13] Recognizing subtle features in the history or physical is imperative because infants with head injuries frequently have non-specific symptoms and often no history of trauma is provided. Injury could be a result of blunt force, shaking, or a combination of both. One retrospective chart review in the US found that AHT was not recognized in >30% of patients seen by a physician, and almost 13% of those were radiologically misinterpreted.[14] Of those with no demonstrable injuries on initial evaluation, 28% were reinjured. A study from the UK concluded that 52% of the head injuries in kids <1 year of age was due to suspected assault.[15] Although recognizing head trauma can be relatively difficult in the absence of a reliable patient history, suspicion of AHT should prompt one to consider using appropriate imaging studies to evaluate the brain for any structural damages. It is therefore vital for clinicians and imaging experts to be able to discern characteristic imaging features of AHT to inform the proper authorities about potential abuse.

Besides the obvious acute presentations of TBI in children, long-term consequences should be of clinical concern. Many studies have shown that severe pediatric TBI causes behavioral, cognitive, and academic deficits over the years.[16-18] Therefore, it is logical to assume that if intracranial injuries are diagnosed and quantified earlier, timely intervention, rehabilitation and other appropriate measures can be instituted to improve outcomes in those affected.

TRAUMATIC BRAIN INJURY

TBI can be categorized using various parameters, including severity, physical mechanism of injury (penetrating or non-penetrating, blunt or blast), anatomic type of injury (focal *vs.* diffuse), pathophysiology (primary or secondary), neuroimaging findings, prognostic classification, and more. The severity of TBI has historically been classified based on the Glasgow Coma Scale (GCS) of the patient when initially evaluated. It is a cheap, reliable source for gauging a patient's status using verbal responses, motor responses, and eye opening. GCS is a 15-point scale (table) that can be rapidly evaluated by a healthcare professional at the bedside of any patient and be used to guide acute management. Mild TBI is classified as a score of 13-15, moderate TBI is 9-12, and a score <8 on the GCS is considered severe TBI. However, the GCS does have its limitations; it is difficult to get a measure on very young patients (i.e. <2 years of age), as well as in patients who are intubated or have extracranial problems (such as electrolyte imbalance.). Also, due to the heterogeneous nature of some brain injuries, GCS does not provide details regarding the pathophysiology of neurologic deficits. In fact, nearly half of the patients with documented TBI on CT have GCS scores of 14 or 151. Therefore, neuroimaging plays a crucial role in determining prognosis and guiding the course of management. As imaging technology advances, there will be a greater opportunity to stratify patients into specific treatment cohorts that can improve long-term outcomes.

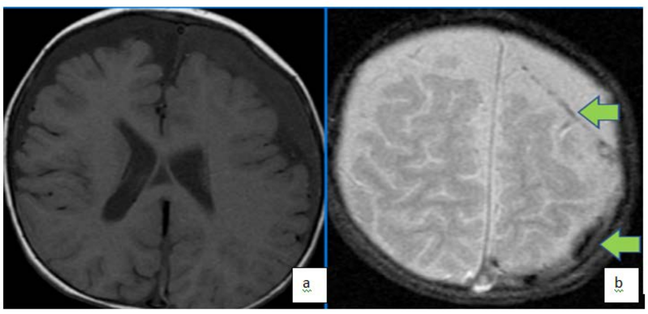
Pathophysiology of TBI can be broadly classified into primary and secondary causes. Primary TBI is the result of a direct blow to the head, rapid acceleration-deceleration injuries, penetration wounds, or blast injury – often; these types of injuries are readily identifiable at initial presentation. In contrast, the presentation of secondary TBI is complex because the symptoms are usually insidious in onset. Secondary TBI is due to one or a mix of several problems (electrolyte imbalance, hypotension, hypoxia and/or ischemia, or inflammatory response). On conventional imaging techniques including a non-enhanced CT (NECT), the imaging findings of secondary TBI can be can also often subtle or unapparent. In contrast, conventional and advanced MRI sequences could provide higher sensitivity for detecting minor changes of brain injury when compared to a CT.

DIAGNOSIS

Estimating the extent of injury in TBI patients can be difficult without the appropriate imaging techniques. Techniques such as angiography or venography with CT or MR may also be used in some cases when evaluating the integrity of the vessels of the brain. The primary diagnostic tool for assessing children with acute moderate-severe head injury (GCS≤13) regardless of GCS score in Emergency Departments is NECT.[19,20] Though serial CT scans may detect cerebral edema, MRI is more sensitive in detecting early cerebral edema.[21,22] Imaging in patients with mild head injury (GCS 14-15) is more controversial due to the risk of exposure to ionizing radiation and the relative susceptibility of younger patients to potential side effects of radiation; therefore, it is prudent to know which patients to send for a CT scan. There have been recommendations provided for head CT in children with very low risk of clinically-important TBIs, based on a prospective study by the Pediatric Emergency Care Applied Research Network (PECARN).[1] There are no available established guidelines for the use of MRI post-TBI, however, this is a subject of active clinical investigation.

For subacute and chronic TBI, MRI is recognized as the most appropriate initial examination.[20] The latter may especially be important in cases of AHT, since MRI allows for better dating of intracranial abnormalities, as well as stratify the degree of injury, and thus, may be relevant in determining the temporal course of brain injury (Figure 1). The features most distinguishing to recognize for inflicted TBI include, evidence of preexisting brain injury and retinal hemorrhages on MRI. It has been validated to be more sensitive than CT in detecting various phases of intracranial bleeding, and abnormalities of the posterior fossa and brain stem – especially with more advanced techniques including susceptibility-weighted imaging (SWI), and diffusion-tensor imaging (DTI).[23-26] Moreover, the lack of beam-hardening artifacts in MRI permits better assessment of the brain stem, posterior fossa, and cortical surface.[27] Newer advanced fast imaging techniques like parallel imaging include faster image acquisition, which can be used, for instance, to shorten breath-hold times resulting in fewer motion-corrupted examinations.[28] The two parallel imaging methods most commonly used on clinical scanners today, sensitivity encoding (SENSE) and generalized auto calibrating partially parallel acquisitions (GRAPPA), both of these have significantly reduced scan times and therefore have added value especially in pediatric imaging where motion is critical factor in generated good quality images. Additional advanced MRI sequences like simultaneous multi slice imaging are available but beyond the scope of current discussion.

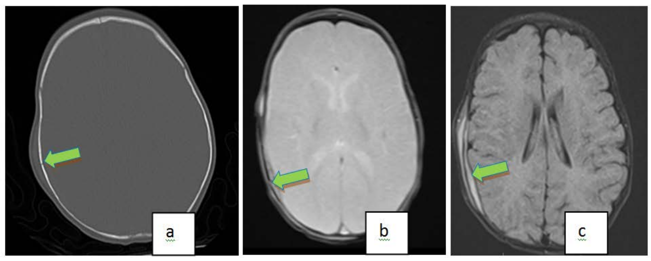
Figure 1. *Axial T1(a) and T2 (b) Weighted Images Demonstrate Bi-Frontal Chronic Subdural Fluid Collections (Low T1, High T2) with Foci of Low T2 in the Left Parietal Collection Supportive of Foci of Acute on Chronic Subdural in a Patient with History of Non-Accidental Trauma*



SKULL FRACTURES

Direct impact to the head may cause fracture of the calvarial bones. Various patterns of fractures can be seen, including linear (or comminuted), depressed, and basilar skull fractures, in descending order of frequency. Parietal bone is the most commonly fractured bone in the calvarium, followed by the occipital and frontal bones. Most small linear skull fractures don't have underlying parenchymal injury, and usually heal well without major complications, while patients with depressed skull fractures are more likely to have TBI.[29] Epidural are associated with parietal bone fracture and consequent tearing of the middle meningeal artery. Sequelae from basilar skull fractures include dural tear with associated cerebrospinal fluid (CSF) leak, impingement of a cranial nerve, and cranial nerve deficit.. Growing skull fractures are the result of large linear fractures that appear "*growing*" due to underlying tear of the dura mater and herniation of brain. As in most cases of TBI, NECT is the primary imaging modality of choice. Sensitivity of CT is increased with the use of three-dimensional (3D) reconstructed CT images, especially in cases of linear fracture.[30] Ultrashort echo time projection reconstruction MRI has been described to be as sensitive as CT to identify skull fractures[31] (Figure 2). MRI is also used in the analysis of growing skull fractures, which can better delineate the dural tear and bulging brain tissue.[32]

Figure 2. *Axial NC, CT with Bone Windows (a) Demonstrates a Right Parietal Bone Fracture with Overlying Soft Tissue Swelling in a 5month Old That Fell from Mothers Lap. Axial Gradient Echo Image (b) Also Shows the Right Parietal Fracture. Note the Underlying Intracranial, Extra Axial Hemorrhage on the Axial Flair Image (c)*



While MR is more sensitive in detection of most types of head trauma, CT with 3D reconstruction appears to be best modality for detecting skull fractures. MRI can be used as a screening tool in minor head injury (in conjunction with clinical exam and history) to identify parenchymal abnormalities and suggest the need for a CT scan. MRI can also be useful when the fracture itself is not well demonstrated on the MRI and in the presence of certain patterns of parenchymal injuries that occur with skull fractures. This could allow for the judicious use of radiation in the pediatric population while increasing the positive predictive value of the CT in detecting skull fractures for specific populations.

INTRACRANIAL HEMORRHAGE

Intracranial hemorrhage (ICH) is one of the common intracranial abnormalities following traumatic head injury; rapid imaging is required for early diagnosis, optimization of treatment, thus minimizing the potential for detrimental sequelae. ICH can be subdivided into extra-axial (epidural, subdural, or subarachnoid hemorrhages) and intra-axial (intraparenchymal and contusions), according to the anatomic location of the bleed relative to the brain. ICH can be assessed with ultrasound (US), CT, or MRI. Ultrasound is useful before the acoustic windows close (typically around 12 and 2-3 months for the anterior and posterior fontanelles, respectively). CT is quite sensitive and specific for elucidating acute hemorrhage and is enough to guide initial therapy. However, MRI has superior sensitivity for subtle hemorrhage and can provide the age of the hemorrhage. MR is particularly more sensitive in subacute injuries in comparison to CT. Each stage of ICH has a different appearance on MRI, as described on table 1.[33] Because of these differences in signals, MRI is beneficial in staging the examination.

Table 1. *Age of the Hematoma as Seen on MRI*

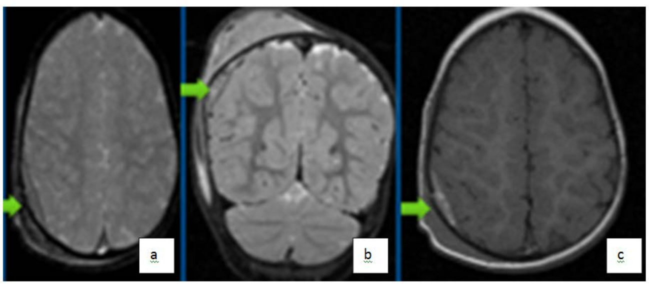
Stage	Duration	Content	T1 signal	T2 signal
Hyper acute	Less than 24 hrs	Intracellular oxyhemoglobin	ISO	Iso to hyper
Acute	1 to 3 days	Intracellular deoxyhemoglobin	ISO to low	Low
Early subacute	3 to 7 days	Intracellular methemoglobin	Hyper	Low to Iso
Late subacute	1 week to 4 weeks	Extracellular methemoglobin	Hyper	Hyper
Chronic	After 4 weeks	Hemosiderin	Low	Low

Of the many types of MRI techniques, susceptibility-weighted imaging (SWI) has been shown to be more sensitive than gradient recalled echo (GRE) sequence in the detection of ICH due to the ability to accentuate paramagnetic properties of hemoglobin blood products, therefore more clear depiction of micro hemorrhages.[21] SWI sequence has a longer acquisition time when compared to GRE and hence may be limited in use in the acute setting, especially in a moving child.

EPIDURAL

Epidural hematoma (EDH) are characterized by an accumulation of blood between the skull and the periosteal layer of the dura mater (Figure 3). It can be caused by laceration of one of the meningeal arteries (most commonly the middle meningeal artery) but in children it is more frequently due to tearing of the dural venous sinuses.[34] The onset of clinical manifestations may be delayed ("lucid" period) so rapid detection can be life-saving in these patients. Though venous EDH develop more slowly, arterial EDH expand more rapidly and can cause brain herniation (due to rising intracranial pressure) or ischemic injury if not diagnosed in a timely manner. Since the dura tightly attaches to the skull, EDH do not cross the cranial sutures. EDH most commonly appears on imaging as a biconvex lens-shaped extra-axial collection. If large enough, the lesion can cause a mass-effect with subsequent brain herniation. Small epidural can be missed on CT imaging due to volume averaging along the skull/CSF interface.

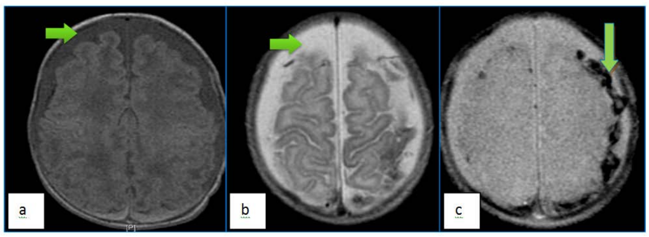
Figure 3. *Axial Gradient Recall Echo (GRE) (a) and Coronal T2 Weighted (b) Images Showing Subacute Right Parietal Epidural Axial T1 Image (c) Shows High T1 Signal from Subacute Blood*



SUBDURAL

Subdural hematoma (SDH) is a sequela of hemorrhage in the layer between the dura and arachnoid membranes, most commonly source is the bridging veins that run in from the subarachnoid space to the dural sinuses. Generally, it is found on the "contra-coup" side, in contrast to EDH, which is more commonly seen on the "coup" side. SDH may be seen in up to 80-90% of deliveries at term, especially when instrumentation such as forceps or vacuum extraction are used.[35,36] The most common cause of SDH in children <2 years of age is average handle time (AHT).[37,38] SDH carries a poor prognosis in many cases, three-quarters of these patients die or have significant disability due to direct compression or rise in intracranial pressure with subsequent herniation.[39] SDH differs in appearance from EDH in that the former can cross cranial sutures (but is still limited by the internal dural attachments), therefore it typically is seen as a concave, crescent-shaped lesion on imaging. Involvement of the posterior fossa, or at multiple locations is a red-flag for AHT and the proper actions need to be taken to assure child welfare. MRI is the preferred technique in subacute SDH, since the lesions appear hyperintense on T1 and T2-weighted images (Figure 4). Fluid attenuated inversion recovery (FLAIR) is the best technique for demonstrating small SDHs, especially in cases missed by CT.[40] Chronic SDHs are encapsulated and are characterized by their crescent-shape and low attenuation, ossification or vascularity of the lesion may be noted. A mixed pattern of attenuation could be due to new bleeding in an old site and could be suggestive of AHT. MRI is superior to CT in identifying the age of various blood products and thus, may be relevant in determining the temporal course of brain injury.

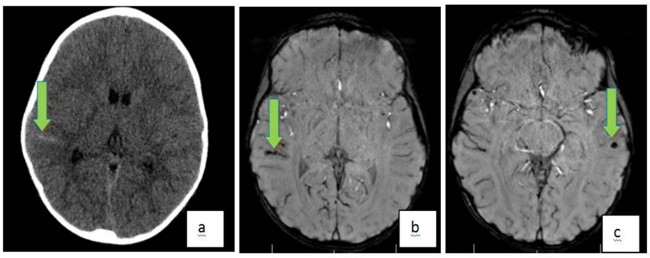
Figure 4. *Axial T1 (a) and T2 (b) Weighted Demonstrates Bifrontal Chronic Subdural (Low to Intermediate Signal on Both T1 and High T2), Whereas High T1 Signal Posterior (Bilateral Parietal) Subdural Collections Represent Acute Subdural Hemorrhages. Note the Blooming from Chronic Blood Products on the T2* Star Sequence (c)*



SUBARACHNOID HEMORRHAGE

Subarachnoid hemorrhage (SAH) is the accumulation of blood within the subarachnoid space, just superficial to the pia mater. It can be caused by injury to leptomeningeal vessels, or intraventricular bleeding with reflux into the subarachnoid space. A common site for SAH after head trauma is within the interpeduncular cistern or the lateral fissure.[34] Non-enhanced CT is the modality of choice for acute SAH due to its sensitivity in detecting blood. Cerebrospinal fluid (CSF) dilution of the hemorrhage causes difficulty in recognizing SAH. MRI study using the FLAIR technique has been shown to have a sensitivity at least equal to CT for the detection of acute SAH[27,41] (Figure 5).

Figure 5. *Axial NECT (a) Shows An Acute Subarachnoid Hemorrhage in the Right Superior Temporal Gyrus. Axial Susceptibility Weighted Images (SWI) (b) Also Demonstrate Right Superior Temporal Gyrus Subarachnoid Hemorrhage. In Addition, a Countercoup Parenchymal Contusion is Noted in the Left Temporal Lobe (c)*



INTRAVENTRICULAR HEMORRHAGE

Intraventricular hemorrhage (IVH) can have several causes, including tearing of the sub ependymal veins, or reflux from a SAH. Cerebral bleeding may also leak into the ventricular system causing IVH. FLAIR and DWI are highly sensitive MRI techniques in the detection of subacute IVH. Hemosiderin deposition in subacute to chronic hemorrhages may be seen as T2 hypo-intense lining along the ventricular system.[35]

PARENCHYMAL INJURY

Parenchymal injuries include cerebral edema, cerebral contusions, diffuse axonal injury (DAI), and anoxic brain injury. Inherent high tissue resolution on MRI offers a more robust visualization of small parenchymal abnormalities. MRI has been shown to be more sensitive than CT in visualizing these types of brain injuries.[6,42,43] MRI sequences with the greatest yield are gradient echo, fluid-attenuated inversion recovery (FLAIR) and DWI which should be included in all intracranial hemorrhage patients who undergo MRI.[44]

CEREBRAL EDEMA & CONTUSION

Cerebral contusions are a type of intracerebral hemorrhage that occur when direct impact to the skull causes trauma to the underlying brain and laceration of the intra-parenchymal vessels (Figure 6). It is most commonly due to non-inflicted trauma.[45] Large lesions are easily discernable with US in neonates, and with CT in older children. However, MR is more sensitive in detecting small contusions especially using SWI sequence. Contusions are usually found in the deep layers of the cerebrum and delayed findings are not uncommon, thus it is prudent to suspect this in cases when neurologic condition worsens. Large parenchyma in the acute phase are better evaluated on non-enhanced CT. In the subacute stage, parenchymal can have a ring enhancing appearance. In the absence of a well-documented history of trauma in children, this appearance may be indistinguishable from other etiologies of intracranial ring enhancing lesions.

Cerebral edema can occur due to a combination of both vasogenic and cytotoxic mechanisms. It is a feared complication following TBI since it is the most significant predictor of outcome.[21] DWI has been extensively used to evaluate cerebral edema and can provide valuable clues to the underlying mechanism[46,47] (Figure 7). Early detection and treatment is aimed at lowering ICP to decrease mass effect and potential ischemia and/or herniation.

Figure 6. *Right Temporal Hemorrhagic Contusions in a 16 Year Old Following Motor Vehicle Injury. Axial NC CT Image (A) Shows a Subtle Hyperintense Focus in the Right Temporal Lobe. Axial FLAIR (b) and GRE (c) MR Images Better Demonstrate the Blooming Right Temporal Hemorrhagic Contusion*

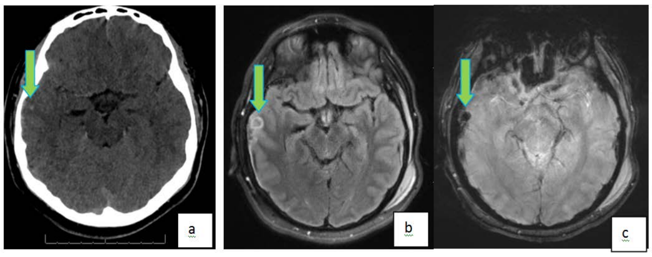
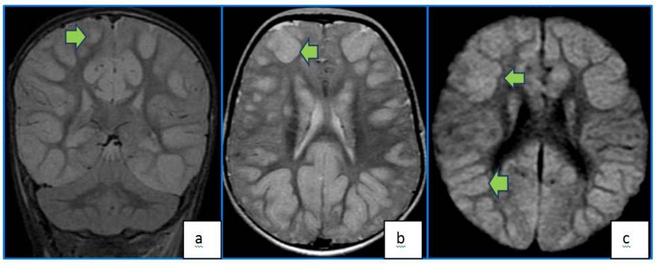


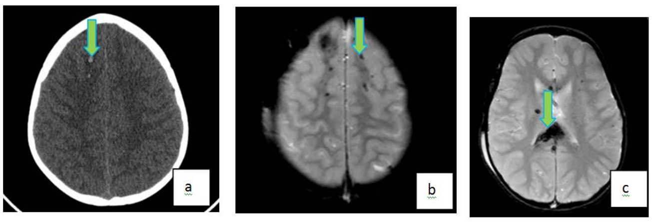
Figure 7. *Coronal T2 FLAIR (a) and Axial T2 (b) Images Demonstrate Diffuse High FLAIR And T2 Signal in Bilateral Cortices from Edema. Axial DWI Image (c) Demonstrates Cortical High DWI Signal Indicative of Edematous and Ischemic Changes as Well in a Patient with Post Traumatic Hypoxic Injury*



DIFFUSE AXONAL INJURY

Diffuse axonal injury (DAI) is one of the most common intra-axial injuries related to trauma; it is often a shear injury of the neuronal axons in white matter caused by acceleration-deceleration or angular forces (Figure 8). There is much research done on the clinical applications of MR for evaluating DAI cases, and it is the recommended modality for evaluating DAI.[24,48,49] Sequences used include T1-W, T2-W, T2-gradient echo, FLAIR, DWI, and SWI. DWI and SWI have been shown to be helpful in delineating cases of DAI, which would not normally be seen in CT or conventional MRI techniques.[50] On MRI, DAI is characterized by multiple, hyperintense T2/FLAIR lesions usually between 1 to 15mm in diameter, caused by microbleeds and local edema. In the acute stage, both hemorrhagic and non-hemorrhagic contusions can show restricted diffusion on DWI sequence. The most common regions affected include the corpus callosum, internal capsule, and fornix. DAI should be suspected in patients in whom symptoms are more severe than what is seen on CT. Though not a neurosurgical emergency, presence of DAI are associated with worse clinical outcomes in patients with TBI[51] and thus may warrant early detection & quantification. DAI is divided into three grades based on anatomic distribution in the brain. Grade I affect the gray-white interface. Grade II affects the corpus callosum in addition to the Grade I locations. In addition to the areas affected by Grade I and Grade II, Grade III lesions involve the brainstem. These grades are directly correlated to the clinical outcome. Unfortunately, as there are no specific treatments available for DAI patients at this time, the value of improved imaging diagnosis currently lies in the potential to better prognosticate clinical outcome.[52]

Figure 8. *Diffuse Axonal Injury in a 14 Year Old Following High Speed Motor Vehicle Accident. Axial NECT (a) Shows Two Hemorrhagic Foci in the Right Frontal Lobe. Axial GRE (b, c) MR Images Show Multiple Additional Foci of Susceptibility Within Bilateral Frontal Lobes, Predominantly Distributed Along the Gray-White Interface. In Addition, "Blooming" T2* Abnormality is Also Noted in the Splenium of Corpus Callosum*



Age of the subacute and chronic TBI, MRI is recognized as the most appropriate initial examination. The latter may especially be important in cases of AHT, since MRI allows for better dating of intracranial abnormalities, as well as stratify the degree of injury, and thus, may be relevant in determining the temporal course of brain injury as seen on MRI (Table 1).

CHALLENGES

One of the challenges of using MR in younger patients, particularly in those <6 years of age, is that these patients cannot remain still during the MRI exam, leading to motion artifact and poor image quality. Thus, MRI frequently necessitates use of sedation in these patients. In addition to the risks at the time of sedation, general anesthesia has the potential for causing developmental and behavioral problems in children. These risks are likely accentuated in patients with neurological injury. Therefore, rapid MRI sequences with shorter acquisition times are essential and have been developed to avoid this risk.[53] Nevertheless, the implementation of such protocols widely will require evidence of improved outcomes from prospective studies. Clinicians need to balance the benefit of an MRI with the potential negative aspects, such as longer scan time and need for sedation.

CONCLUSION

To summarize, in the setting of head trauma, MRI provides an imaging modality with a unique ability to highlight critical information that CT and other imaging modalities cannot delineate. MRI has greater sensitivity in the detection of most types of head injuries, in comparison to CT – except skull fractures. In addition, MR techniques have the added benefit of having no ionizing radiation, thus decreasing radiation exposure and theoretically cancer risk as well. However, MRI has been a challenge to incorporate into the acute setting given the high-cost, relative lack of availability and highly skilled training for operating and prescribing sequences. Despite the challenges, MR imaging continues to play a growing role in the acute and sub-acute evaluation of pediatric head trauma, however, large, prospective clinical data will be needed to show evidence that MR as the initial imaging modality after pediatric head injury will allow for better short and long-term clinical outcomes than CT.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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Book Review

IR Playbook - A Comprehensive Introduction to Interventional Radiology: A Book Review

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This textbook is intended to provide a sufficient level of resolution to acquaint both medical students and resident physicians with the field of interventional radiology (IR). It is divided into two main parts. The first part explores IR basics—including a very practical chapter complete with photographs and diagrams introducing common needles, catheters, wires, embolic agents, balloons, and stents employed by interventional radiologists. The second part deals with broad categories of diseases with the individual chapters focusing on specific disease entities and methods of treatment.

There is a Goldilocks amount of material for medical students and residents in this book. The information for understanding the fundamentals of and the routine services provided by IR is distilled into readable prose, high-quality radiologic images, and easy-to-understand diagrams making concepts accessible to novice trainees. Throughout the book there are convenient "How To" text boxes that contain concise descriptions of procedures in a stepwise fashion. Additionally, there are "Key Point" text boxes with high-yield facts for quick review. Moreover, one can be confident in the quality of knowledge gleaned from this book as many of the chapter authors are established leaders in the field of IR, for example, Dr. Alan H. Matsumoto coauthored the chapter on renal artery stenosis, Dr. Maxim Itkin coauthored the chapter on lymphatic interventions, and Dr. Michael D. Dake coauthored the chapter on aortic aneurysms—just to name a few. One thing missing are recommendations for further reading at the end of each chapter. Besides obligate references, it would be helpful to include a succinct list of go-to educational resources—such as other textbooks, articles, and educational websites—for medical students and residents to use. This would help cut down on the inefficiency of having to sift through all the available material and identify the best resources on one's own.

The first editor listed, Dr. Nicole A. Keefe, is currently an IR chief resident at the University of Virginia, and her coeditors are faculty in the Division of Vascular and Interventional Radiology in the Department of Radiology and Medical Imaging at the University of Virginia. They have compiled an educational resource that fills a void I have felt, namely, an IR textbook catering to medical students and residents. I am grateful for their contribution to IR pedagogy and will continue to use this book during my training.