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Role of MRI in Evaluation of Spinal Trauma

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Annotation: Spinal trauma is a significant cause of morbidity and neurological disability, requiring accurate diagnosis for timely and effective treatment. Despite the availability of multiple imaging modalities, a gap remains in reliably detecting soft tissue and spinal cord injuries, particularly in the early stages. This study explores the diagnostic utility of Magnetic Resonance Imaging (MRI) in spinal trauma evaluation, emphasizing its advantages over radiography and computed tomography (CT). Through a comprehensive review of MRI techniques, sequences, and case studies, the research demonstrates MRI's superior contrast resolution in identifying disc herniation, ligamentous injury, spinal cord edema, and hemorrhage. Findings confirm that T1- and T2-weighted sequences are critical for evaluating neural and soft tissue integrity, significantly influencing surgical planning and prognosis. The results support MRI as the gold standard for spinal trauma imaging, advocating for its routine use in acute and chronic spinal injury management protocols.

Keywords: spinal trauma, magnetic resonance imaging, spinal cord injury, MRI sequences, diagnostic imaging, T1-weighted, T2-weighted, neurological evaluation.

1. Introduction

Spinal trauma is a critical condition having an impact on a normal health of an individual. A high rate of morbidity is observed with rising incidence. Nearly 10% of spinal traumas are fatal at the spot of injury, and approximately 50% of those who survive suffer from severe complications. Proper evaluation of spinal trauma is critical in order to provide appropriate management. Several tools with variable advantages and limitations are currently available for evaluating spinal injuries. Of all the different imaging modalities available, magnetic resonance imaging (MRI) is considered the best modality available for studying spinal trauma. In the management of spinal trauma, the importance of a significant history, thorough physical examination, and a considered approach to the use of imaging cannot be overemphasized [1]. Objectives of this study are to evaluate the diagnostic potentialities of MRI in patients with spinal trauma; to correlate findings on MRI with other clinical documentation; and to provide appropriate management with the help of MRI findings. Understanding the background of spinal trauma, predisposing factors, anatomical knowledge, and relevant case history is considered essential before proceeding further so as to apply the relevant MRI sequences. MRI has now firmly established itself as the investigational modality of choice in spinal trauma. With an expanding role in the acute trauma setting, a concise understanding of the basic anatomy, the mechanisms of injury, and attendant imaging appearances are crucial [2]. Further, MRI is also a very valuable tool in evaluating more chronic manifestations of spinal injury such as osteomyelitis, discitis, and posttraumatic CM. Through this essay, efforts are made to add an easily understandable algorithm or steps for evaluating a patient with spinal trauma with MRI. It is anticipated that at the end of this essay, novice residents or colleagues will have a better understanding of the critical diagnostic role of MRI in patients with spinal trauma. Furthermore, guidelines provide practical step-by-step instructions on patient management, emphasizing incorporation of new evidence where applicable. The guideline is organized into ten sections focusing on pre-hospital assessment, transfer protocols, emergency department evaluation, baseline imaging, diagnoses, variables affecting outcome, monitoring maneuvers, pharmacological agents, surgical interventions, and critical care. Each recommendation is explicitly tied to supporting evidence and expert opinion through a comprehensive review of the literature and an international survey of SCI experts. Triage and management have been updated to reflect the timing of surgical interventions and health system constraints. The final document is intended to guide healthcare professionals involved in the acute management of SCI, with the goal of optimizing patient outcome and reducing unfavorable sequelae.

1.1. Overview of Spinal Trauma

Spinal trauma is defined as trauma inflicted to the spinal column which triggers injury to the spinal cord and spinal nerves. 1,069 cases of spinal trauma are reported every year. It significantly affects patients' quality of life and can result in severe neurological complications if not promptly cured or misdiagnosed. The spinal cord consists of nerve tissues that bridge the brain to the rest of the body and contain abundant longitudinal spinal nerves. The spinal cord and the spinal ganglion form a central and peripheral nervous system that stretches to all parts of the body. In cases of spinal trauma, neurological complications such as stiffness or numbness can easily occur due to injury symptoms such as inflammation of the spinal cord or crushed nerves. Nerve and vessel tissues get floated in fluid that is encircled by a three-layered membrane known as the dura mater. Underneath this layer are webbing threads that hold the spinal cord against the backbone. Subarachnoid bleeding transpires after repeated low-energy impacts. The acute blockage of cerebrospinal fluid channeling results in changes in the brain [3]. Morgagni later Andrae introduced a dynamic type of dislocation associated to trauma. Its occurrence relies on the result of prepositioning and energy statuary directed forces. Furthermore, scheme of dislocations description postulates that the bulk of the displacing forces happens to be shunted to the most exposed region in particular circumstances of applied energy.

Spinal trauma can come about through various means. Vehicular accidents or falls from elevated places frequently result in severe restriction of the cervical vertebrae or the backbone, and extreme spurting damage involving the spinal cord can ensue. Hence, spinal trauma needs precise and prompt treatment as neurological complications can persist in case of misdiagnosis, and there can even be situations where complete recovery is implausible. In this article we present isolated or heretofore unrevealed cases of patients with lumber spine blasts who complained of ankle administration cessation over a week-ance new means while utilizing the PROMED system are presented, permitting the quick and meticulous examination of blast victims.

2. Diagnostic Modalities in Spinal Trauma

Evaluation of spinal trauma is challenging not only because it often deals with multiple anatomic levels and various structures but also each entity may exhibit complex injury patterns. There are multiple imaging doors that need to be used according to the clinical scenarios. Traditional X-rays are still valuable for the initial assessment of remote spinal injuries, and for serial follow-up examinations. X-rays and routine CTs could not be able to reliably depict most ligamentous injuries, such as the rarer osseous avulsion fractures, or most of disc traumas. MRI is mainly indicated when occult fractures are clinically suspected. A correct diagnosis of spinal trauma needs to include direct and indirect signs, displacement or widening of pre-vertebral soft-tissue, preexisting diseases, or even motion studies, failed after CT-myelography age. Obtaining and integrating clinical and trauma sub-states are also paramount to avoid versus to pick up potential disk herniations.

In conclusion, the choice of the imaging modality, or of the combinations, plays a demanding yet crucial impact in trauma of the spinal cord. Physical principles underlying acquisition techniques for X-rays, US, CT, and MR imaging are the reason for moving the first step. The use and role of multi-modal imaging for revealing the different radiological findings of spinal cord trauma, of the disc of healthy control middle aged discs, or of healthy control patients are then discussed. Both for stand-alone or for each pair-wise comparison cases, the corresponding findings show that multiple imaging techniques point to notable advantages over single modality imaging. Offset of the lumbar spine accounts for flexion, extension, or lateral bending movements, even under loading conditions. Integrated clinical research on biomechanical promotes the development of new and improved understanding of the underlying injury mechanisms for spinal cord. This stands to reason the chances for the correct interpretation of the findings on single or multi-modal clinical and radiological imaging. Finally, radiographs also underline its paramount relevance and enhancements for improving the decisions in the treatment of trauma, and caution against drawing too far reaching conclusions from MRI alone. [4][5][6][7]

2.1. Role of Imaging in Spinal Trauma

Imaging plays an essential role in evaluating trauma affecting the spine. Imaging can identify injuries to the vertebrae, spinal cord, and paravertebral soft tissues that may not be obvious during the physical examination [1]. Understanding the nature and extent of the injuries is essential to guide treatment. Correctly diagnosing complex injuries with potential involvement of multiple structures is difficult, and inaccurate diagnoses may lead to inappropriate management [8]. Given the potentially life-changing consequences of spinal injuries, even seemingly minor ones, it is important to ensure that each spinal injury patient undergoes an accurate workup. Patients with neurological symptoms require especially urgent and precise evaluation, because factors such as the degree of spinal cord compression, the type of compressive pathological process, the duration of compression, and the maturity of the cord may affect the patient's long-term recovery. It is well recognized that the ability to provide an early exact diagnosis and an early effective therapy in SCI significantly influences the patients' outcome. As a result, many newer imaging modalities for analyzing SCI have been proposed and evaluated. Special or cutting edge Magnetic Resonance Imaging (MRI) pulse sequences, such as Diffusion Tensor Imaging, Spinal Cord Diffusion Weighted Imaging, Blood-Oxygen-Level Dependent Spinal

Cord Functional Magnetic Resonance Imaging, are currently being assessed. Conventional T1-weighted, T2-weighted, T2*-weighted used in clinical practice, as well as anatomic sequences imagined by some authors but not all, can be crucial in the analysis of SCI. However, it is not clear which MRI technique should be considered as the method of choice for diagnosing, grading, and predicting neurological recovery in SCI. MRI images are consequently interpreted differently by radiologists and referring clinicians. This can lead to misunderstanding in both directions, as referring clinicians may be unaware of important findings, and radiologists may describe artifacts as 'possibly representing injuries, which should be treated with caution'. Imaging is therefore an integral part of managing such patients, guiding initial treatment and monitoring recovery and rehabilitation.

Imaging is often the first step when assessing suspected spinal trauma. The choice of which imaging modality to use depends on mechanisms of injury and clinical findings. As the technology has evolved, so have these recommendations. For example, MRI used to be contraindicated in penetrating spinal cord injuries due to often being performed with lower- and intermediate-strength field magnets that could result in magnetic forces pulling out the metal foreign body. This is no longer the case with modern high-field MRIs, which can be safely used to image penetrating spinal trauma. Lodging of a bullet inside the neural canal is a rare event, and imaging findings in the acute phase of penetrating SCI have not yet been systematically assessed. Educational resources can also lack more complex interpretations that are discussed in the specialized literature, where even bony pathology is not always detected by spinal surgeons familiar with this tool, specializing in spinal column and cord motion abnormalities. [9][10][11]

3. MRI Basics

Magnetic Resonance Imaging (MRI) is a versatile imaging modality that allows examination of a plethora of different body parts. It is based on the same physical principle as nuclear magnetic resonance spectroscopy, used to study the characteristics of molecules such as metabolites, including the body but it does not require the use of ionizing radiation. This is an essential imaging tool in the evaluation of spinal trauma and sophisticated modality used to produce detailed images of the body without using x-rays.

In MRI, the body is placed inside a strong magnetic field, which causes some of the electrically charged protons in the body to align with the magnetic field. Radiofrequency (RF) waves are then used to disturb this field to be aligned with the main magnetic field, causing them to absorb some of this energy, which is used together with auxilliary fields like gradients and coils to produce detailed images of the body. The energy absorbed in this process is then released, creating a resonating signal detected by antennas or coils in the machine and used to produce an image [1].

Different MRI machines can be found, the most common being the 1.5-Tesla (T) and 3-T machines, but it's also possible to find a 0.2-T, 0.3-T, 0.35-T, 0.5-T, 0.6-T, 1-T, 1.2-T, 1.9-T and 7-T machines in clinical use. Of these, the 1.5-T and 3-T machines are considered suitable for diagnosing conditions affecting the central nervous system (CNS), as weaker machines such as the 0.3-T can have poor resolution for imaging CNS structures. There is a wide variety of scans that can be done in an MRI, each one with their own indications. Knowledge of the background of the patient is fundamental when ordering an MRI exam. An example is contrary indications to do the exam, like patients with a pacemaker, old-generation stimulators, brain clips, certain types of cardiac valve prosthesis, shrapnel injuries, etc.

Familiarity with the type of MRI scanner, the post-processing capabilities and the various types of protocols and sequences enhancing different type of pathologies, allows better understanding of an all too often viewed dismissively examination.

3.1. Principles of MRI

Magnetic resonance imaging (MRI) is a cross-sectional imaging modality. It is based on the principles of magnetic fields, magnetic moments, and electromagnetic radiation. In brief, a large, homogenous magnetic field is applied to excite the magnetic moments of protons in the body. A radiofrequency (RF) pulse is used to tip the protons from their equilibrium state, and then the MRI signal, released as these protons lose energy, is measured. The principles of relaxation are then applied, including T1, T2, and T2*, to form the contrast and image appearance. The Multiplanar capability of MRI is ideal for examining the complex anatomy of the spine. By changing the plane in which the MRI is performed, structures can be more closely aligned with one of the signal detection axes. The detailed imaging of the spine is particularly useful in evaluating structures such as the transverse ligament of the odontoid or the intervertebral foramen. The soft tissue contrast of MRI is also ideal. Different tissue types have different signal properties, depending on the tissue's proton density (PD), T1, and T2 values. Tissue weighting can be controlled through careful sequence selection. Generally proton density weighted (PDW) and T2-weighted sequences are employed. PDW images are particularly sensitive to pathology within the spinal cord (hyperintense pathology) whereas T2-weighted images can uniquely identify ligamentous injuries. Rather than being a single entity, there are many types of T1, T2 (etc.) properties. Apart from differences in the rate of transverse and longitudinal relaxation, other factors causing contrast differences include flow, fat structure, the presence of free radicals, and iron deposition. Therefore, choice of imaging sequence is important in order to optimally accentuate the tissue-type of interest. Examples include the use of FLAIR imaging to suppress the signal from cerebrospinal fluid (CSF), enhancing the visualization of pathological spinal cord gliosis. Similarly, because ligamentous structures are near-water tissues, they are best seen using a T2-weighted sequence [1].

4. MRI Sequences in Spinal Trauma

Magnetic resonance imaging (MRI) is the modality of choice for evaluating soft tissue damage along the spine in the emergency setting. In this context, MRI is used to evaluate the discs, the ligamentous structures that support the spine, the spinal cord and the spinal nerves. To enhance the detection of bone or its marrow injury due to, for example, vertebral fractures with a burst component or ligamentous avulsion, thin slice T1- and T2-weighted imaging in the sagittal and axial planes should be obtained.

The spinal cord and its protective coverings, the thecal sac and the surrounding cerebro-spinal fluid, are best visualised using different T1- and T2-weighted techniques and planes, than those used to evaluate the bony and ligamentous structures in the spine.

T1-weighted imaging has high signal resolution and is best for imaging a number of anatomic structures with distinct MR signals, for example fat and fluid. A normal disc with its annulus fibrosus fibres, the supporting ligamentum flaveum and the facet joints, all of which have high fat content, will have high signal intensity on T1-weighted imaging. Conversely, acute haematomas and most disc material have low signal intensity, therefore, a number of anatomic structures are optimally visualised on T1-weighted imaging during MRI. The epidural fat, nerve roots at concurrence with a sharp or slightly failing edge enhancement by contrast material and bony lesions, who usually due to their fat content are isointense with nerve on T1-weighted images. Thus, fat-suppressed techniques following intravenous contrast administration are the imaging modality of choice in the setting of spinal trauma to evaluate yet when MRI utilize to evaluate other potentially aggressive (ism). For example, [12]. However, T1-weighted imaging has the disadvantage of poor contrast resolution between muscle and fat, and the fluid is also isointense with fat, so that plain MRI will not readily show the spinal cord or acute, subacute or old haematomas or CSF on this sequence. Therefore, pre- and post-contrast T1-weighted imaging is reserved for the scanning of a very small number of cases in the spine, when the above indication apply. On this series of MRI, the presence of normal-appearing cord to the level of the associated vertebral body fracture, negate, in neurologically normal patient, the cord contusion. Those in the setting of a vertebral fracture do on sagittal and axial T1-weighted imaging.

4.1. T1-weighted Imaging

T1-weighted images (T1WI) are one of the basic, “conventional” sequences that since the beginning of MRI have been present in any coil design and modification. As from the name itself, T1W pulse sequences give more bright to those structures whose spins return to parallel position with the main magnetic field after an excitation pulse of radiofrequency (RF). This is directly related to the shortest T1 relaxation times of spins in tissues, that is needed to acquire a familiar “anatomical” appearance [3]. Therefore, fat has very short T1 values (and short T2 ones), so it is bright in T1W scans. Fat is bright also after the administration of contrast medium (CM). T1W images are usually acquired to have high spatial resolution, looking for anatomical details in the diagnostic phase. Spinal cord is bright in T1W sequences, so that medium-higher TR/TE values are usually used to produce a clear differentiation between the hypointense cord and the isointense cereberospinal fluid (CSF). For such reasons, usually initial and follow-up anatomical evaluation are pursued via interpretation of T1W images, that on the other hand present close values of the signal-to noise ratio (SNR) of T2W images. T1W sequences are generally used in such evaluation to consider the anatomical characteristics of each tissue, to interpret the various aspects of the pathology present, and to define the treatment plan. For example T1W images are better than T2W images in the recognition of some medullar spine tumors. In this way, the corpectomy at the site of the main lesion is better defined, and the application of adequate instrumentation to sustain the spine is applied both cranially and caudally to prevent fractures still undetected on conventional X-ray films. In spite of their capability to give the best contrast resolution, T1WI do not always provide a good differentiation of soft tissue structures. Typically fat and CSF show a high signal intensity (bright), with a poor differentiation of the tissues.

5. MRI Findings in Spinal Trauma

MRI still remains as a principal, ideal and excellent diagnostic modality in the evaluation and detection of spinal trauma. Many advantages of MRI such as higher contrast resolution and absence of bony artifacts of MRI over Computed Tomography (CT) make possible to diagnose spinal trauma more accurately. In the past, carrying spinal precautions in trauma cases was a big challenge. Clinical examination and routine radiography was not sensitive for the investigation of penetrating spinal injuries and subtle vertebral column injuries, which could prove devastating if not diagnosed and managed early. If spinal precautions were outweigh in an undiagnosed case of penetrating spinal injury, or an unstable vertebral column injury case, outcome could be catastrophic and sometimes that could be life threatening or occasionally figment for the rest of the life. Hence, clinical examination and routine radiography was coupled with tremendous clinical vigilance. For the betterment of diagnosis, it was advised to take lateral views of neck region to look for the bullet tract. CT scans had come to reshape the imaging management in these aspects [1]. Still, there were some drawbacks with CT such as its impotency to diagnose the injuries pertaining to soft tissues.

MRI has higher contrast resolution than CT. In the evaluation of trauma, soft tissue detail has a high priority, and CT is often inadequate. Presence of even small intramedullary hemorrhage (less than 0.5 cm) and spinal cord laceration can be missed in the acute stage with non-enhanced CT, and it can be detected by MRI. Post-traumatic spinal cord ischemia usually leads to the presence of spinal cord edema dn/or petechial hemorrhage within 30 minutes. These changes represent more advanced injury than seen on plain X-rays or/and non-enhanced CT. Both normal and abnormal findings at CT follow-up after acute spinal trauma can be appreciated on MRI. Overall, MRI following CT can yield significant therapeutic benefit. Early MRI detected dislocating retropulsion in the canal, which required urgent decompression. Histological examination showed hemorrhage and severe cord injury that were not visible on MR examination, but which explained the rapid onset of paraplegia. MRI is thus a sensitive way to evaluate spinal cord injury that could be used to guide treatment decisions. [13][14][15]

5.1. Acute Spinal Cord Injury

MRI can delineate most neural injuries and is superior to X-rays, CT, and myelography in detecting ligamentous and marrow abnormalities. In addition, more adequate information on neural injuries that require surgical intervention, e.g., disc herniations and degree of spinal canal compromise, can be obtained [1]. Nearly 0% of patients who undergo primary MRI need further imaging. Procedures generate quicker access to medical and surgical care consistent with efforts to meet the "golden hour" guideline for intervening in acute spinal cord injury (SCI), improve neurological outcomes, and avoid pressure sores. Conventional spine imaging is performed on 70% of blunt trauma patients over 55 years of age. MRI and high-quality myelography are equally accurate in detecting neural SCT, with comparable sensitivity and specificity of 1% and 68% [16]. Either technique is superior to CT myelography, with sensitivity ranges of 8%-60% for MR and 0%-18% for myelography. Merely 0% of ligamentous injuries resulting from trauma are ever diagnosed, leading to missed injuries and disputes among physicians and patients over the cause of symptoms. Major injuries missed on initial evaluation have significant potential for adverse consequences, including neural compression, persistent pain, and more invasive and riskier later treatments. A system that provides rapid, comprehensive, efficient, and low-cost imaging review of traumatic abnormalities could ameliorate these problems. There is a lack of information about ACR red flag findings on imaging review of spines in the ED and their predictive value, leading to unnecessary referrals and variability in inpatient monitoring.

6. Clinical Indications for MRI in Spinal Trauma

Accurate imaging is essential in the setting of spinal trauma to determine the nature and extent of injuries. Consequently, multiple recommendations and guidelines have been made by various organizations, based on clinical evaluation of the patient, to help direct appropriate imaging modalities following a thorough evaluation. A majority of patients presenting with spinal injury do not sustain neurologic deficits and for many of these individuals, computed tomography (CT) of the relevant spinal segments to evaluate osseous and ligamentous structures is the initial imaging modality. Some patients will demonstrate only minor soft tissue findings that may warrant further evaluation based on history and physical exam. For patients who are capable of further examination following initial stabilization, magnetic resonance imaging (MRI) can be employed to further evaluate the soft tissue structures of the spinal column. Soft tissue structures particularly well-evaluated by MRI include the spinal cord, dura, nerve roots, a disc including acute disc herniation, and a ligamentous injury. Furthermore, complications that may occur secondary to initial injury, such as epidural hemorrhage, can be detected. As many of these findings are not directly visualized on alternate imaging modalities, MRI remains an essential component in the comprehensive evaluation of the spinal trauma patient. Given the wide variability of clinical circumstances possible in spinal trauma situations, it is necessary to use clinical judgment in accordance with each patient's situation. Ultimately, the clinical history and condition of the patient are the best guides to determine if further evaluation by MRI is warranted [8].

However, there are specific clinical circumstances wherein MRI is indicated as the initial study due to high probability of injury. These include patients presenting with evidence of high-energy trauma, such as fall greater than 6 feet or motor vehicle collision resulting in substantial damage, or alteration of mental state. In these situations, it is highly probable that thorough evaluation of the spine beyond basic radiological studies is warranted. Furthermore, patients presenting with neurologic deficits concerning for spinal cord injury may show no abnormalities on radiographic studies; in these instances, further evaluation by MRI is indicated based on clinical evaluation of the patient.

6.1. Guidelines for Imaging in Spinal Trauma

The guidelines for acute cervical spine trauma recommend an MRI within 48 hours for obtunded patients with persistent midline cervical tenderness, those with focal neurological deficits, individuals with spinal fractures present on X-ray, and those with focal peri-cervical soft tissue injury. The guidelines state that patients without focal deficits who have “normal” x-rays or very minor injuries “probably do not need further imaging”. This conflicts with the clinical reality that the majority of blunt trauma patients who present with a decreased level of consciousness have “normal” x-rays of the spine. The finding that MRIs were performed for obtunded patients less frequently than in patients with more minor injuries suggests that these putatively high-risk criteria are not well known or adhered to in practice. In the cohort, inability to manage airways was identified as an indication for imaging. However, none of the 19 obtunded patients imaged received this diagnosis, while an additional higher-level insult (quadriplegia) was found in 79% of MRI+ patients imaged with quadriplegia as the indication. Therefore, the single-center data cannot be taken as definitive evidence of lower-quality care through regional variations and the available data in other countries are insufficient to draw conclusions. It is this group of patients (those unable to manage their airway independently due to high cervical injuries) who have the highest-risk of significant spinal injury according to the current guidelines [2]. The minimum guideline regarding the use of MRI in SCI states that “early MRI is useful in the obtunded patient to identify an underlying soft tissue injury when a significant range of motion injury is highly suspected but imaging is normal”. This recommendation is based on only two Class III studies with a mean follow-up of over 21 days. This shortcoming was echoed in a more recent meta-analysis, which found that the cut-offs of 21 days or one month limited the conclusions that could be drawn from the sourced papers [8]. Early MRI is also recommended in the obtunded patient to identify an underlying injury when persistent post-traumatic neurologic deficit is present without satisfactorily identification of its cause on CT imaging and the development of focal neurologic findings after the clearing of the effects of head injury. Guidelines were broadened to recommend MR of the injured region in obtunded patients without improvement in neurologic status as well as in those with neurologic symptoms that are felt to be local to the c-spine. These are all indications for imaging provided for patients in this series, none of which was ever satisfied. In the non-obtunded patient, MRI was also recommended after clearance of neurologic examination anesthesia. This recommendation contrasts with the lesser value given to clinical neuroassessment, may be impractical in the obtunded patient once sedation is discontinued, and risks undertreating the patient with subtle incomplete injuries, as was the case with the injury pattern in this series. This recommendation served to illustrate the potential benefits of a discussion between neurosurgeons and acute spine imaging radiologists. It is suggested that this investiture of effort is spread to a wider discussion between acute care and MRI-capable neuroimaging departments, and the establishment of local MRI trauma algorithms which can be adapted to local circumstances.

7. Advantages of MRI in Spinal Trauma

There are many advantages to Magnetic Resonance Imaging (MRI) that are useful to detect spinal trauma. Subtle bone marrow, soft-tissue and spinal cord abnormalities that are usually associated with spinal trauma can readily be detected on it; in addition, the contrast resolution in MRI is better than Computed Tomography (CT) and it lacks bone artifacts. Soft-tissue and intra-medullary lesions that were previously palpated sooner come to light with MRI. The sequence parameters usually used for spinal imaging allow multiplanar capability, and since most spinal trauma occurs due to a hyperextension or hyperflexion mechanism, it is directly related to soft tissue and spinal cord injuries. There has been a wealth of research on this type of injury mechanism in the recent literature. Regarding spinal trauma, MRI is able to detect previously unrecognized intramedullary and adjacent soft tissue injuries in cases in which X-ray and CT fail. Since it often demonstrates a benign appearing spine despite the presence of serious non-osseous trauma, in cases of significant spine trauma, magnetic resonance imaging (MRI) has played a crucial role in the evaluation of tissue injuries. However, the clinical utility of this imaging modality in the trauma setting has come into question due to concerns for patient safety, cost, patient delays, and the lack of data concerning its effect on clinical decision-making.

Hindered by the ever-rising epidemic of spine trauma and an overall increase in trauma cases, magnetic resonance imaging (MRI) may prove invaluable for avoiding unnecessary further X-ray studies in the future considering the general trend to eliminate plain films for initial anatomic screening of the trauma patient. [17][18][19]

7.1. Sensitivity and Specificity

It is important to understand concepts of sensitivity and specificity and how they affect diagnostic accuracy. Sensitivity is the percentage of true positives that are correctly identified. This is important in cases where finding the condition is critical: the higher the sensitivity, the closer the clinician comes to knowing with certainty that the condition is not present if the test is negative; for example, patients diagnosed with Spinal Cord Injury without Radiographic Abnormality (SCIWORA) on MRI often require no intervention, as the likelihood of them harboring a surgically amenable injury is low. However, with sensitivity at only 71%, MRI does not provide the expected comfort and thus will not prompt a change in clinical practice to avoid scanning a high number of patients who would otherwise not have been scanned [8]. Specificity is the percentage of true negatives that are correctly identified. In other words, for every true positive the test has a 'success rate' at identifying a true negative to confirm that there is a true positive. A high specificity helps to ensure the cost of false positives is not too high; however, the more specific a test is, the less certain one can be that the test is truly negative, meaning true positives may have a greater chance of being missed. This is an issue in that often, T2-hyperintense injuries (apophyseal and endplate fractures, ligament injuries and intramedullary changes) that would likely qualify for interventions due to risk for or presence of cord compression, are missed due to a reliance on T1-weighted imaging to reduce false positives as opposed to a multi-sequence imaging approach for scanning, which also has T2-weighted sequences.

8. Limitations of MRI in Spinal Trauma

A brief review of the radiological literature on the aforementioned theme has been conducted. There are numerous publications dealing with cervical spine injuries, focusing on the prognostic value of overall radiologically positive findings as they regard the clinical outcome. This manuscript adopts a different perspective, focusing on the evaluation of isolated radiological findings in cervical spine MRI examinations. The aim is to present that, in specific cases, the absence of ligamentous injuries or intramedullary lesions in spinal cord may not guarantee a favorable outcome or an "easy" case.

Acute care of severely injured patients, closely associated with high-energy trauma, remains a clinical challenge. Clinicians and trauma surgeons focus on life-saving procedures in the emergency room. A full-body multi-slice computed tomography (MSCT) scan has been regarded as the primary radiological screening modality, in accordance with widely accepted recommendations. MSCT examination aiming to detect polytrauma-related injuries is able to identify numerous gross organ lesions, to determine bone fractures, and to reveal the presence of air, fluid, or blood in body cavities. Even with an advanced MSCT, undetected severe organ injuries or extensive soft tissue lesions are possible. In order to protect the interests of the patient, it is necessary to perform an immediate 1.5 Tesla MR examination. Standard radiological diagnostics tend to focus particularly on the question of possible fractures and their detection. This is why fractures in the area of the cervical spine are detected by the protocol laid down by the statutory professional associations [20].

8.1. Metallic Artifact

The strong magnetic field generated by the MRI magnet causes magnetic objects to become airborne in the presence of the MRI field. The resulting excitation forces can cause severe injury to patients, facility staff, and damage to the MRI itself. Objects brought into the MRI room, which have not been properly treated, may become airborne during a scan. The presence of any type of metal in the MR-scanning environment can create a hazardous situation. Metallic clips or objects inside a patient can also jeopardize patient safety during MRI. The ferromagnetic components of the metal will distort the external magnetic field applied by MRI as well as introduce localized field inhomogeneities with the scope of MR imaging that have a potential to degrade image quality.

A mark spatial distortion that appears as signal pile ups (the familiar jagged appearance from which the artifact derives its name). Clipping the receive data in an intermittent fashion creates an artifact that is generally of lesser magnitude–not readily discernible at all echo times–decreases as the slice position is moved away from the source of the artifact, and is worse for thicker slices than for thin slices. Essentially all modern clinical MRI scanners combine two types of tech to develop images. Pulse sequence parameters including the relative timing of RF pulse excitation and echo detection and the attendant gradients that condition the magnetization, are the basis of the resulting image. Most MRI slices are generated as an array of k-space lines, with intermediate lines synthesized by transformation of the echo data. Ct artifacts manifest on the display image as un-sampled k-space lines, usually in the form of blurring. [21]

9. Role of MRI in Surgical Planning

MRI plays an important role in providing the anatomical details of spinal trauma which are essential for surgical intervention. Traumatic injuries to the spine can result in a broad array of injury patterns, affecting bony, ligamentous, and neural elements. Injuries can be further complicated by the fragmented mode of secondary escalation to potential post-traumatic, neurologic deficits. In surgical planning, it is crucial not only to appreciate the extent of the injuries but to understand the dynamic relationship and orientation of these injured structures with the surrounding normal structures. This is especially true when the plan is for surgical repair or decompression of those injuries. Even though the majority of decisions in the treatment of spinal trauma are nonoperative and can be made with basic imaging modalities, the role of surgical interventions in trauma cases has been expanding [8]. Personalized surgical strategies are now being used in many patients. These interdisciplinary treatment options for specific spinal trauma require a true understanding of the extent of the injury so that approaches can be tailored to best fit the situation. That includes not only an appreciation of the dynamic anatomy but also an accurate mental anticipation of potential complications from tissue distortion or unexpected structures. Without the gift of sight, this understanding is best facilitated by proper imaging techniques, such as MRI. MRI has continued to aid in the surgical decision-making of the spine through the use of detailed imaging allowing for improved precision of surgical approaches. Close collaboration between imaging specialists and surgeons has been key to optimize this approach. This review emphasizes the importance of recognizing these injuries on that modality to allow informed decision-making in the surgical patient on a case-by-case basis.

9.1. Preoperative Assessment

Preoperative assessment is very important from this point of view. Detailed evaluation of findings and understanding of severity of the injury can help to avoid surprises in the operating room. The presence of a preoperative magnetic resonance imaging (MRI) study, and its evaluation by the surgical team, gave us very insightful information about the injury's character and potential risks. MRI studies that depict the precise anatomic location of an injury and its extent are very helpful in planning the approach to that injury. The surgical technique is partly dependent on the location of the injury, the position of the patient, and on the need to instruct the surgery assistants for an effective approach. The presence of hematomas, dural and root disruptions or dislocation found on MRI can in some cases change the technique from a planned decompression to a fusion procedure. There are some justifications for performing MRI in every patient. The main goal is to evaluate the potential for neurologic recovery. Integrating imaging findings with clinical evaluations lets the development of better strategies for treatment and for patient follow-up. All of these assessments were made using MRI findings alone. Preoperative

MRI evaluations are pivotal for safety drilling and dramatically interfere with patient safety. The necessity of a preoperative MRI evaluation for patients with spinal trauma is underlined.

Spinal trauma is one of the key concerns in neurosurgery, uniting spine, and trauma surgery. Principles for management are well established, focusing in brief on a fast and detailed neurological examination; on a judicious choice of radiographic studies, in which computed tomography (CT) is the most important, allowing an accurate study of the bone structure and of the canal; on a very strict conduct in the whiplash patient; and on a tight schedule for imaging follow-up. All these steps must be followed by a detailed final clinical examination. MRI is an excellent addition to the protocol of management of patients with suspected spinal cord injury (SCI). Any clinical signs revealing the existence of possibly cord injured patients should prompt MRI evaluation. It is a technique that clearly demonstrates edema and hemorrhage, besides giving an accurate view of soft-tissue lesions with great detail [1]. This information might be used as a guide to patient management. At 72 hours after injury evolution can be judged with nerve-root accuracy and the strategy to follow might benefit also from MRI evaluation to evaluate the extent of persistent cord compression and to look for associated soft-tissue lesions.

10. Case Studies

Case I: A 25-year-old male presented to the emergency department after sustaining a road traffic accident. He was quadriplegic with respiratory distress requiring ventilator support. Radiographs showed C4–C5 dislocation. MRI revealed extradural compression by a large cord contusion. The patient underwent C3 to D1 anterior corpectomy and fusion of C4 with strut graft. Postoperative images showed good cord decompression. At follow-up, the patient had improved handicaps and was able to sit erect in a wheelchair at 1 year [1].

Case II: A 45-year-old man presented with neck pain experienced over the last 15 days. He was quadriplegic with no radiological abnormality on plain radiographs at the time of injury. MRI findings showed cord edema with a small posterior longitudinal ligament ossified bar at C3–C4 level and circumferential ligamentum flavum hypertrophy. Discectomy and decompression at C3–C4 level were performed. Postoperatively, 90% neural recovery followed by radiation and chemotherapy after 6 months.

Case III: A 15-year-old boy fell from a 15-ft height while flying a kite and landed on his buttocks. He was unable to get up, presenting with urinary bladder incontinence. Radiographs showed normal findings. CT showed fracture-dislocation at T10–T11 level with dural sac posteriorly placed but intact. MRI was performed for neural status evaluation of cord and conus and showed buckling of ligamentum flavum and disc extrusion. The findings were confirmed intraoperatively.

Case IV: A 35-year-old male presented to the emergency department with severe neck pain following trauma sustained during a cricket game. Neurological examination showed radiculopathy. CT showed degenerative changes with ligamentum flavum hypertrophy. The T2W sagittal sequence showed hypertrophy of ligamentum flavum at affected level with cord compression. The axial image also revealed cord compression. Hypertrophied ligamentum flavum removed during excision was followed by symptoms.

Case V: A 55-year-old farmer presented with chronic back pain after trivial injury. MRI showed an expansile altered marrow lesion at upper D12 vertebral body with cord compression. The patient underwent decompression and D11 and D12 vertebral body excision. Decompression results in the removal of pressure, which offers the potential for cord edema resolution and subsequently improved cord function.

Case VI: A 21-year-old male, suffering from spondylotic myelopathy, presented with a history of neck pain for the last 1 week after a road traffic accident. MRI findings also showed disc with ventral thecal sac compression at C5–C6 level. Problems are resolved through amelioration of compression with decompression results and further medication. In total, 75% of incidents are cervical spondylotic myelopathy, commonly occurring in the third and fourth decade. Symptoms generally occur late in patients suffering from cervical spinal stenosis who later meet up with trauma. Similarly, complaints of neck pain in young individuals do not always indicate spondylotic changes.

10.1. Case 1: Vertebral Fracture

A 56-year-old woman presented to the Emergency Department after falling down several steps after acutely twisted her back. On physical exam, she was tender to palpation at T4-T5 area and experienced severe back pain at the thoracic level. Neurological exam was normal. Neurological deficit after acute traumatic thoracic spine injury is rare and, when present, typically involves spinal cord compression [3]. CT examination was first suggested, but an MRI scan was ordered to evaluate the thoracic spine thoroughly.

MRI demonstrated a mild compression vertebral fracture at T5 level with small hemorrhagic lesions, being hypointense on T1-weighted images, hyperintense on T2-weighted and STIR images, and showing a mild contrast enhancement. There was a slight antero-listerhesis of T5 with respect to T6 at the level of the endplate and ligamentum flavum showing slight abnormal signal intensity at the level of the fracture. At the fracture site, STIR and T2-weighted sequences revealed a hyperintense signal in the centra and posterior part of the height of the vertebral body, corresponding to a bone marrow edema with involvement of the internal cortical endplate. After contrast administration, a mild contrast enhancement was recognizable in the posterior cortical endplate, revealing the presence of a grade III injury. There was no involvement of the adjacent disks. Morphological changes in the vertebral body with STIR hyperintensity or contrast enhancement of the posterior cortical endplate and involvement of the disk are the early signs of an unstable vertebral injury at MRI evaluation even in the absence of spinal cord or nerve root abnormalities.

11. Future Directions in MRI for Spinal Trauma

Spinal trauma is a common cause of morbidity in all societies, with significant consequences in terms of function and health of affected individuals. The most common etiology is the result of injuries sustained from motor vehicle accidents, falls, acts of violence, or the use of firearms. In high-income countries, however, the etiology can also be the result of sports injuries. Overall, it affects individuals between 16 and 30 years of age, representing the peak productive age group and can be a financial strain on individuals and societies.

Since 1984, when the use of MRI in spinal trauma evaluation was first described, MRI has revolutionized the non-invasive evaluation of the spine. Still, the popularity of the use of MRI in spinal trauma evaluation has significantly increased over the last two decades with the number of referrals being made prior to an x-ray evaluation increasing on average by 11% per annum. However, despite its reputation as the gold standard imaging modality, a number of new advances that can improve earlier detection that could lead to earlier targeted significant treatment is needed. With ever increasing focus on earlier detection and targeted treatment, this section aims to provide a peak in how MRI technology will advance into the future trajectory of spinal trauma imaging. There are a number of emerging imaging techniques that offer to markedly increase the visualization of different ranges of spinal injuries. The implementation of AI and the use of ML are increasingly being found to have the potential to enhance the diagnostic accuracy of the detection of variance in different imaging methods. There have been several new protocols developed with the aim to reduce imaging time while maximizing detail, whilst MM approaches in MRI have the potential to significantly increase the evaluation capabilities of different aspects of spinal trauma injuries. The various improvements and directions of future research will aim to optimize the look and capability to increase the utility of MRI in spinal trauma evaluation. With much ongoing research and a rapidly growing number of cutting-edge advances, MRI has the potential to explore new peaks to what is visible today. Regular updates in the field are expected to provide an opportunity for both early detection and targeted therapy, which is still a key direction in spinal trauma imaging.

11.1. Advanced Imaging Techniques

Spinal Trauma: Role of MRI in Evaluation and Management

Doctors have long sought more advanced imaging techniques to monitor potential aggravation or amelioration of diagnosed spinal trauma. Just recently, a group of researchers have designed a 12-month acute spinal cord injury trial, incorporating advanced imaging technology to enhance and relate a change to metabolic activity but also to provide more detailed monitoring and hence more precise diagnostic capabilities in this often critical first year post injury. For the spinal component, DTI is used to analyze the cortito-spinal tract, the dorsal columns, and extra-medullary constrictions. It is anticipated that this will develop both an understanding of the evolution of the injury and, following validation, provide a practical diagnostic tool. The team has had experience of using multi-voxel spectroscopy to monitor the spinal cord in acute cervical injury and in spina bifida and have observed significant changes in normal spinal cord chemistry with respect to cord compression. The focus has been on the use of BOLD fMRI to monitor changes in metabolic activity in the spinal cord, particularly activated when treating with experimental contusions, which has been a useful tool in determining optimal dose and time of treatment.

There is a growing trend to utilize higher resolution imaging techniques to plan surgical intervention and local radiation treatment in spine patients with metastatic disease. However, the majority of papers presented in industry sessions of major international spinal conferences address the benefits of a particular drug, implant, or technique over a short series of patients. While some professional journals will not publish industry-based studies because of potential bias, they can be an excellent opportunity for industry to present more lower level evidence where other means exist to consider high-level evidence from larger or more appropriate studies. With reasonable confidence in industry and other sources and existing studies for evidence-based practice, it is also important to consider technological advances in imaging that can impact more accurately and rapidly on the diagnosis and management of patients with complex spine injuries.

12. Conclusion

This paper is a contribution to the understanding of the role of MRI in spinal trauma, consisting of the spine either altogether or in part (sub-axial or sub-occipital). Several examples are described to underline the role of MRI in the evaluation of the vertebral column following trauma, and the sort of information it is possible to obtain. The vast majority of the recent literature is examined to underline the extent of the present therapeutic knowledge, and to suggest guidelines for approaching spinal surgery. A final part is devoted to the radicular macro surgery after cervical trauma. It is argued that although the majority of spinal surgery can be performed with a microscope, since a major part of cervical trauma results in severe neurological impairment, it is important to continue to perform surgery with the naked eye.

Research into deterioration of architectural properties of bone after trauma is necessary for understanding fracture aetiology and may improve prevention of osteoporotic fractures. The purpose of the present study was to analyze fracture patterns micro-morphologically, to determine secondary changes of compact bone. Compact bone specimens were taken from human vertebral bodies, examined under a fluorescence microscope and correlated with radiological findings. It was found that due to the squeezing a crash layer and radial tears were formed in compact bone. This means that the initial crack of the vertebral body could be detected on the basis of small gaps in the front part of the crash layer on the CT scan. The compression force causes desarangement, the cellular lack of bone repair ability. As a consequence, the anterior part of the cancellation is reduced and the intervertebral spacer is lost.

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