Original Article

Magnetic resonance imaging in evaluation of spinal ejection injuries

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ABSTRACT

Radiological evaluation of the spine following aircraft ejection has always been complex and at times controversial. However, technological advances in the field of medical imaging and in particular Magnetic Resonance Imaging (MRI) have made this task easier. MRI with its multiplanar imaging capabilities and flawless delineation of spinal anatomy and pathology provides an accurate analysis of the injury, which is of immense help in the aeromedical disposal. The aim of this study was four folds; firstly to analyze using MRI, the pattern of spinal injuries sustained as a result of ejection, secondly to integrate the recent concepts of stable and unstable spinal fractures, thirdly to emphasize the significance of incidental / non-traumatic abnormalities detected on MRI, which are not directly attributable to ejection and finally to emphasize the importance and advantages of early MRI in assessment of the injured spine. A retrospective analysis of spinal MRI findings in 50 post ejection cases, who had reported to the Institute of Aerospace Medicine for aeromedical evaluation, was carried out. The location and nature of bony, ligamentous and cord injuries were assessed. The bony injuries were characterized as stable or unstable based on Denis's three column concept. The study revealed that MRI is the ideal imaging modality for evaluating post ejection injuries of the spine as it delineates ligamentous and cord injuries with incomparable accuracy. Further, it highlights that the three column concept of Denis for assessment of the stability of spinal fractures is superior to the two column concept of Holdsworth. The study also revealed the presence of incidental / non-traumatic abnormalities of the spine such as disc degeneration and lumbar spondylosis, which were not directly related to the ejection process. MRI has an increasingly important role in the evaluation of post ejection spinal trauma. It allows an accurate assessment of the extent of injury and course of further management, with the aim to provide early recovery. Incidental / non-traumatic abnormalities detected on MRI do present a challenge in the final aeromedical disposal of the ejectees. The ultimate aim in the aeromedical disposal of post ejection spinal injuries should be to conserve trained manpower but not at the expense of compromising flight safety.

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Aircraft ejection is a life saving event for a pilot, which occurs at his command and is usually a last resort. Safety and survival of aircrew following ejection has been an area of major thrust of flight safety programs the world over. The current sophisticated and advanced ejection seats with their increased performance capabilities attest to the goal of improving survivability of aircrew during escape from aircraft under adverse conditions. Engineering sciences have made major contributions to improving ejection seats, test personnel have rigorously demonstrated that these systems work well and medical personnel have contributed to this effort by historically defining the limits within which the human spine can tolerate the forces of ejection. In spite of all these efforts there has been considerable morbidity and associated loss of trained manpower as a result of aircraft ejection. It is estimated that 27-35% of all ejections lead to spinal injuries due to compression loading on the spine as a result of high G forces experienced by the pilot [1].

It is important to accurately assess and quantify such injuries sustained during ejection, with the aim to initiate early treatment so as to conserve

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trained manpower and at the same time assist early reflighting of the ejectee. Accurate assessment of spinal inury can only be achieved by Magnetic Resonance Imaging (MRI) as it provides excellent soft tissue resolution for demonstrating ligamentous injuries, paraspinal and intraspinal haematoma, spinal cord injuries and also depicts bony vertebral injury with a high level of accuracy [2]. MRI is the only single modality which can detect such a wide range of abnormalities.

The aim of this study was to analyze, using MRI, the pattern of spinal injuries sustained as a result of ejection and at the same time incorporate the recent concepts of diagnosing stable and unstable spinal injuries. It also reiterates the importance of MRI as the imaging modality of choice in the evaluation of spinal trauma.

Material and Methods

Spinal MRI findings in 50 post ejection cases, who had reported to Institute of Aerospace Medicine, Bangalore for aeromedical evaluation were analyzed. The standard protocol for spinal MR imaging was followed; all the cases underwent MRI in a minimum 0.5 Tesla machine using spin echo T1 and T2 weighted axial and sagittal sections. The location and type of bony, spinal cord and ligamentous injuries were evaluated in detail. All bony injuries were then categorised as stable or unstable based on Denis's three-coloumn concept of spinal injuries [3].

Results

On the basis of the MRI findings, the injuries were grouped into various categories. Out of the 50 post ejection cases that underwent spinal MRI, 33 had evidence of bony injuries (66%). These bony injuries were further characterized based on their location and type and are depicted in Table - 1.

Table - 1: Location and type of bony injuries (n=33)

Location	Number	Percentage
Cervical	2	6
Thoracic (T1 to 10)	7	21
Thoracolumbar (T11 to L1)	18	55
Lumbar (L2 to 5)	6	18
Type		
Compression fracture	29	88
Burst fracture	4	12

The patterns of soft tissue injuries including those due to the disco-vertebral junction are summarized in Table - 2. A total of 7 cases (14%) had evidence of soft tissue injuries like traumatic intravertebral disc herniations (Traumatic Schmorl's Nodes), ligamentous tears and traumatic disc prolapse. Incidence and type of spinal cord injuries are given in Table- 3. The fractures were then classified as unstable or stable based on the three-column concept of Denis and are depicted in Table - 4. The study also revealed that 30 of the 50 pilots (60%) evaluated for post ejection spinal injuries had incidental/non-traumatic abnormalities in their

Table - 2: Patterns of soft tissue injuries (n=50)

Type of injury		Number	Percentage
Intravertebral disc herniation (Acute traumatic schmorl's node)		10	20
Anterior disc herniation		8	16
Posterior/Posterolateral disc herniation		4	8
Ligamentous tear		8	16
ALL	6		
PLL	2		
Soft tissue injuries without bony injury		7	14
Traumatic Schmorl's node	2		
Ligamentous tears	3		
Traumatic disc herniation	2		

MRI of the spine and these findings, which were not directly related to ejection are summarized in Table- 5.

Table - 3 : Incidence of spinal cord injuries (n=50)

Type	Number	Percentage
Spinal cord oedema/ contusions	4	8
Spinal cord compression	3	6
Intraparenchymal haematoma	1	2
Extradural haematoma	1	2

Table - 4 : Stability of fractures (n=33) (Based on Denis three column)

Type	Number	Percentage
Stable	25	76
Unstable	8	24
Burst fractures		
D-7................1		
D-9................2		
D-11..............1		
Compression fractures at Thoracolumbar junction	3	
Compression fracture at D-8	1	

Table - 5 : Incidental / Non traumatic abnormalities (n=30)

Type of abnormality	Number of cases	Percentage
Disc degenerative disease	20	67
Spondylotic changes in spine	4	13
Facet joint arthropathy	4	13
Spinal canal stenosis	2	7

Discussion

Ejection once initiated produces forces between 12 and 20G, which act primarily in the long axis of the spine causing the seat to move upwards. A load of 18-20G applied vertically to the spine is tolerated when the trunk is supported in hyperextension, but as the body flexes, this tolerance is reduced to 3-10G. Forces in excess of this tolerance limit can lead to wedge fractures and in some cases, burst fractures [4] with retropulsion of vertebral body fragments into the spinal canal causing spinal cord injury. Many factors like the total weight of the occupant-seat assembly, the attitude of the pilot's body in relation to the seat, the aircraft velocity, relative airspeed at the time of ejection and the altitude of ejection determine the actual value of the force that an ejection seat will produce and subsequently the nature and severity of injury to the spine.

The cervical spine is generally not injured during ejection; however, injuries can be sustained as a result of axial loading compounded by the weight of the head assembly and due to accelerative or decelerative forces in the Gz plane. Axial loading/ compression injuries of the upper cervical spine cause disruption of the ring of C-1 (Jefferson fracture), this fracture is usually stable and rarely accompanied by cord damage because of the width of the neural canal at the C-1 and C-2 level is twice that of the spinal cord [5]. Fractures of the odontoid process (dens) of C-2 occur in one of three locations. Type I fractures pass through the uppermost portion of the dens, Type II fractures pass through the base of the dens and Type III fractures occur at the junction of the dens and body of C-2. Type I and Type III fractures are normally stable whereas Type II fractures are unstable [6]. Axial load forces applied to the head and upper cervical spine may fracture the posterior elements of C-2 leading to a Hangman's fracture. This is a relatively stable fracture unless accompanied by displacement, dislocation or fracture of the body of C-2, when it becomes an unstable fracture.

Fractures or dislocation of the cervical spine between C-3 and C-7 are caused by hyper flexion, axial load, rotation, or a combination of these forces. Typically these injuries result in instability. Hyperextension injuries to the cervical spine usually occur at the C-6-7 interspace. The extent of the injury depends on how much ligamentous and vertebral element integrity is lost, which can be accurately assessed by MR imaging. In the present study two cases (6%) sustained fractures of the cervical spine, one was Type-III fracture of odontoid process of C-2 and the other was fracture of the spinous process of C-6. Both the fractures were stable with no evidence of any ligamentous injuries.

The region of the vertebral column most susceptible to injury following ejection is the thoracolumbar junction between T-11 and L-1 vertebrae. In the present study 18 cases (55%) out of a total of 33 sustained fractures of the thoracolumbar junction, which is comparable with an incidence of 64.2% reported by Kraus et at [7]. The thoracolumbar junction is predisposed to rotational and compression injuries as it is situated between the rigid thoracic spine and the mobile lumbar spine. During axial loading the thoracic spine deforms in kyphosis and the lumbar spine in lordosis, resulting in the thoracolumbar junction experiencing pure compression. Moreover, the thoracic spine is protected by the rib cage and the lumbar spine by inwardly directed facet joints, which take up to 33% of the axial load and 45% of shear and torsional forces, thereby minimizing injury [8]. Injuries at other levels are usually related to forward flexion as a result of improper posture during egress and are less common.

Among the type of injuries sustained, compression fractures were the most common and seen in 88% of those who had sustained bony injuries. This finding is also substantiated by studies carried out by the United States Air Force that report compression fractures as the leading type of injury sustained in 468 ejections [9].

Compression fractures are due to axial loading of the spine and generally involve the anterior part of the vertebral body. Since they involve mainly the anterior column they are usually stable. These fractures, which are seen as loss of ventral height of the vertebral body can be appreciated on plain radiographs only when the loss of height is more than 30% [10]. Other findings on plain radiograph include kyphotic deformity and widening of the interspinous space. On MRI, acute fracture is seen as area of hyperintense signal, disrupting the continuity of normal low intensity signals of cortical bone; compression fractures are appreciated better and earlier on sagittal images [11].

Burst fractures are sustained as a result of axial compression or in combination with rotation and flexion resulting in disruption of the anterior and middle columns and are unstable [3]. These fractures are uncommon and account for 17% of all spinal fractures [12]; in the present study 4 pilots (12%) sustained burst fractures as a result of spinal ejection injury. These fractures, which can involve the posterior part of the vertebral bodies are associated with risk of damage to the osteo-ligamentous complex. Upto 25% of burst fractures have retropulsion of the bony fragments into the spinal canal leading to dural tears and spinal cord compression [12]. Burst fractures are seen on radiographs as loss of the anterior and posterior heights of the vertebral bodies, widening of the interpedicular distance and splaying of the facet joints. MR imaging is vital in accurately diagnosing burst fractures, demonstrating osteo-ligamentous injuries, which are seen as areas of hyperintensities on T-2 weighted images and presence of intra-canalicular retropulsed bony fragments causing spinal cord injury and compression.

Chance fractures are due to acute forward flexion of the spine during sudden deceleration, which causes the upper part of the spine to be pushed forward and distracted from the lower fixed part [13]. It involves a horizontal splitting of the vertebra beginning in the spinous process or laminae and extending through the pedicle and the vertebral body without damage to ligaments. These fractures are essentially the result of failure of the posterior and middle columns with intact anterior column, which acts as a hinge. Such injuries are unstable because of inherent risk of damage to the neural elements. Chance fractures account for 6% of total spinal injuries. Ejection injuries generally do not produce Chance fractures [13], there were no cases of Chance fracture seen in this study.

Injuries to the disco-vertebral junction are very important from the diagnostic point of view because they tend to be easily missed until specifically looked for. These injuries are a cause of persistent low backache and may subsequently lead to spinal instability and neurological complications, thereby preventing early return to flying. The chief structural unit between adjacent vertebral bodies is the intervertebral disc, which comprises a soft central portion, the nucleus pulposus lying eccentrically and posteriorly and the surrounding firm fibrocartilagenous ring-the annulus fibrosus, reinforced by the anterior and posterior longitudinal ligaments.

Anterior disc herniation as a result of ejection injury leads to elevation and tear of the anterior longitudinal ligament that can be seen on MRI as an area of hyperintensity on T-2 weighted images. This disruption of the anterior longitudinal ligament later on stimulates the formation of peripheral osteophytes leading to early degenerative changes in the spine called Spondylosis Deformans [14]. It is imperative to recognize this ligamentous injury, as it will have a direct bearing on the flying prospects of the pilot due to its propensity to cause spinal instability and early degenerative changes even in the absence of bony injuries.

In the present study, 8 cases (16%) sustained ligamentous injuries, out which 6 had tears of the anterior longitudinal ligament, which could only be diagnosed on MRI. Only 2 cases had tears of the posterior longitudinal ligament.

Posterior or posterolateral disc herniations following ejection lead to intraspinal herniations, which can cause neurological symptoms. In the present study 4 cases (8%) had evidence of posterior / posterolateral disc herniations with compression of the thecal sac or the exiting nerve roots.

Intravertebral disc herniations occur when the nucleus pulposus breaks through the vertebral end plates and extrudes into the vertebra; these lesions are called traumatic Schmorl's nodes and occur mainly in burst fractures but can be seen in compression fractures also. In the present study 10 cases (20%) had evidence of traumatic Schmorl's nodes, of these 6 were in compression fractures and the rest were in burst fractures. It is interesting to note that all cases of burst fractures had traumatic Schmorl's nodes. Traumatic Schmorl's nodes can be differentiated from those due to degenerative process of the spine by using MR imaging; acute traumatic Schmorl's nodes are accompanied by marrow oedema of the affected vertebra seen as hyperintense signals on T-2 weighted images. There is also enhancement of the surrounding vertebral body after injection of IV Gadolinium [15].

MRI can provide valuable information about the cord parenchyma that is not available by other imaging modalities. Intraparenchymal haematoma can be accurately distinguished from spinal cord oedema on the basis of signal characteristics on T-2 weighted images within few minutes after the traumatic event [16]. Acute haematoma demonstrates decreased signal intensities on T-2 weighted images due to deoxyhaemoglobin while early sub-acute haematoma is hypointense on T-2 weighted images and late subacute haematoma is hyperintense on T-2 weighted images due to presence of intra and extra cellular haemoglobin respectively. Cord oedema and contusion demonstrate increased signal on T-2 weighted images [17]. The distinction between acute haematoma and cord contusion has important prognostic significance, cases with cord haemorrhage usually have severe or complete lesions and are unlikely to recover complete neurological function. There was one ejectee in this study who developed post-traumatic syringomelia of the cord as a result of intraparenchymal haematoma. Cases with cord oedema or cord contusion, as seen in 4 cases in this study (8%) recovered full neurological functions. MRI is also useful in detecting and follow up of long-term sequelae of cord injury like myelomalacia and post traumatic cord cysts [18]. Epidural haematoma of the spinal cord is not a common post ejection injury and was seen in one case in the present study accounting for 2%. Epidural haematomas are mainly seen posteriorly because the posterior extradural space is larger than the anterior; these collections extend laterally and over a few segments of the cord [19]. On sagittal T-1 and T-2 weighted MR images the haematoma appears as a well defined biconvex collection of variable intensity resulting in anterior displacement of the cord. Within 24 hrs the haematoma is isointense with the cord on T-1 weighted images and hyperintense on T-2 weighted images. After 24 hours the signal intensities of these collections change as fresh blood undergoes changes into its degradation products. There is associated thickening and prominent enhancement of the meninges adjacent to the extra-dural haematoma after period of 2 - 4 weeks [20]. The prognosis worsens if the haematoma persists beyond 24 hours. This not only emphasizes the role of early diagnosis using MRI but also the importance of early decompression.

The concept of stable and unstable spinal injuries has undergone radical changes ever since the recognition of MRI as the modality of choice in imaging spinal trauma. Till a few years ago stability of spinal injuries was based on the two-column concept of Holdsworth [21] in which the spine was divided into a 2-column model; anterior and posterior. Fractures were grouped as unstable when the posterior column was involved or the involvement of the anterior column was more than one third of the total height of the vertebral body. This concept is no longer valid because injuries can be unstable without involvement of the posterior column (structures posterior to posterior longitudinal ligament) as in burst fractures, in which the neural elements are at risk.

Denis introduced the three-column concept of classification of acute injuries to the thoraco lumbar spine [3]. The significance of this system is its usefulness in determining the stability of various fractures based on the involvement of the anterior, middle or posterior columns. The anterior column consists of the anterior two-thirds of the vertebral body with the annulus fibrosus and the anterior longitudinal ligament. The middle column consists of the posterior one-thirds of the vertebral body with the annulus fibrosus and the posterior longitudinal ligament. The posterior column consists of the posterior ligamentous complex, which includes the supraspinous, interspinous ligaments, ligamentum flavum, capsule of the apophyseal joints and the neural arch.

Generally, one column involvement is a stable fracture except when the middle column is involved, in which case it is an unstable fracture because the neural elements are at risk of injury. Two column involvement may be stable or unstable depending on the involvement of the middle column; three column involvement is always an unstable fracture [3].

Usually, compression fractures are stable as only the anterior column is involved but when the middle column is involved it becomes unstable. All burst fractures are unstable as there is involvement of the anterior and middle columns. In the present study 8 fractures (4 burst and 4 compression) out of a total of 33(24%) were unstable and 25(76%) were stable in accordance with Denis's three-column concept. However, according to Holdsworth's two - column concept 6 (18%) fractures were unstable and 27 (82%) were stable.

There is a disparity in results based on these two methods of classification, which is expected because Holdworth's two column concept does not take into account the involvement of the middle column or damage to the osteo-ligamentous complex. The middle column is inherently responsible for providing protection to the neural elements and destruction of this column will lead to an injury being unstable. It is unequivocal that the three column concept of Denis is the most popular classification scheme for evaluation of spinal injuries because it is more objective and accurate as it assesses bony as well as ligamentous injuries [22].

Introduction of MRI in the evaluation of post ejection spinal injury has added to the sensitivity and specificity of detection of spinal injuries, but it has also posed problems in the aeromedical disposal of the ejected pilots. The disposal cannot be based solely on the MRI findings but should be in totality, taking into consideration the symptoms of the pilot, neurological deficits if any, range of axial movements and the stability of the fracture. The standards followed by the USAF [23] in evaluation of post ejection spinal injuries are based on the above guidelines with maximum stress being laid on stability of the fracture. Return to flying varies from 3 months to 2 years, depending on the stability of the fractures, however ejection seat flying is only considered after a period of 12 months in all cases. Cases of fully healed stable compression fractures, are given full flying category as there is no evidence to suggest that the damaged area is unduly susceptible to repeat fracture. The USAF has records of six pilots [24] with stable compression fractures who ejected a second time without suffering injury, one aviator ejected four times without subsequent injury.

Conclusion

It is reiterated that all cases of ejection should undergo magnetic resonance imaging of the spine as MRI excels in the evaluation of spinal injuries due to its multiplanar imaging capabilities and unmatched rendition of the bony as well as soft tissue contents of the vertebral column. It has an increasingly important role in the assessment of spinal trauma due to its ability to visualize clearly the spinal cord, nerve roots, ligaments, intervertebral discs and adjacent vascular structures. It allows an accurate assessment of the extent of injury and course of further management, with the aim to provide early recovery and conservation of trained manpower. Incidental / non-traumatic abnormalities detected on MRI do present a challenge in the final aeromedical disposal of the ejectees, however, it should be remembered that severity and not the mere presence of these abnormalities should influence the award of flying category. The ultimate aim should be to conserve trained manpower but not at the expense of compromising flight safety.

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