"COMPUTED TOMOGRAPHIC EVALUATION OF CERVICAL SPINE IN PATIENTS WITH TRAUMATIC BRAIN INJURY"

By

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SDUAHER

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DOCTOR OF MEDICINE
IN
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Under the Guidance of

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation entitled **"COMPUTED TOMOGRAPHIC EVALUATION OF CERVICAL SPINE IN PATIENTS WITH TRAUMATIC BRAIN INJURY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. N. RACHEGOWDA., MD, DMRD**, Professor & Head, Department of Radiodiagnosis, Sri Devaraj Urs Medical College, Kolar, in partial fulfilment of University regulation for the award "**M. D. DEGREE IN RADIODIAGNOSIS**", the examination to be held in May 2018 by SDUAHER. This has not been submitted by me previously for the award of any degree or diploma from the university or any other university.

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Dr. GOWTHAMI MUNIYELLAPPA

LIST OF ABBREVIATIONS

a.k.a - also known as

AAPM - American Association of Physicists in Medicine

AEC - Automated Exposure Control

ALARA - As Low As Reasonably Achievable.

ALL - Anterior Longitudinal Ligament

AP – Antero-Posterior

ATLS - Advanced Trauma Life Support

CCT- Cranio-cervical Computed Tomography

CS- Cervical Spine

CSI - Cervical spine injury

CSR - Cervical Spine Radiography

CT - Computed Tomography

CTDIvol - Computed tomography dose index volume

DLP - Dose length product

EAST- Eastern Association for the Surgery of Trauma

EBCT - Electron Beam Computed Tomography

ETI - Endotracheal intubation

GCS - Glassgow coma score

kVp - kilo Volt peak

LAAA- Lateral Atlanto-Axial Articulation

LADI - Lateral Atlanto-Dental Intervals

LIST OF ABBREVIATIONS

mAs - milli Ampere second

MOI - Mechanism of injury

MRI- Magnetic Resonance Imaging

mSv - milli Sievert

NCCT – Non Contrast Computed Tomography

NEXUS - National Emergency X-Radiography Utilization Study

PLL - Posterior Longitudinal Ligament

RTA - Road Traffic Accidents

SCIWORA - Spinal Cord Injury Without Radiographic Abnormalities.

SPACE - Sampling Perfection with Application-optimised Contrasts using different flip-angle Evolutions

TBI - Traumatic brain injury

TLS - Thoracolumbosacral

ABSTRACT

Background: Cervical spinal injury should be considered in patients presenting with moderate to severe traumatic brain injury, necessitating prompt cervical spine care in these patients.

Aims and Objectives: To study the incidence of cervical spine injuries in patients with moderate-to-severe traumatic brain injury and to compare the sensitivity and specificity of cervical spine radiography with CT cervical spine in detecting cervical spine injury in patients with moderate-to-severe TBI.

Methodology: The study was conducted over a period of 18 months in 67 patients referred for CT to R. L. Jalappa Hospital. The patients with GCS<12 had an X-ray Cervical spine AP & lateral views followed by CT CS in addition to CT brain. The findings on X-ray CS were initially evaluated followed by CT CS. Both the findings was evaluated separately and compared.

Results: The study included total of 67 patients with male preponderance. Cervical spine injury was seen in 20 cases on CT. However, X-rays showed fractures in only 6 patients (30%). C7 was the commonest site of vertebral level involved. Simultaneous involvement of multiple vertebral levels was also noted.

The risk of cervical spine fracture in patients with moderate TBI was 26.9% (7 of 26 patients) and in patients with severe TBI was 31.7% (13 of 41 patients) suggesting that irrespective of moderate or severe head injury, the risk of cervical spine fracture remains high. CT detected findings in seventeen patients (25.4 %) which X- ray could not detect. The sensitivity, specificity, positive predictive value and negative predictive value of X-ray with CT as gold standard was 23.07 %, 95.12%, 75 % and 66 % respectively showing that although X-ray has a good specificity but had lower sensitivity, positive and negative predictive value.

Conclusion: Patients with moderate-to-severe traumatic brain injury are at high risk of associated cervical spine fractures. The sensitivity of cervical spine CT is higher than that of radiography and by performing CT of the cervical spine at the time of head CT may allow a more rapid radiologic exclusion of cervical spine fracture than by performing conventional radiography.

Key words: Cervical spine injury, Traumatic brain injury, Spinal injuries, Computed tomography.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The risk of cervical spine injury in blunt cranial trauma patients is reported to be between 1% and 3% for all and up to 11.5% for high-risk patients[1,2]. Delay in diagnosis or missed injuries may result in partial or full paralysis in up to 29% of injured patients[3].

Cervical spinal injury (CSI) should be considered in patients presenting with moderate to severe traumatic brain injury (TBI), necessitating prompt cervical spine care in these patients[4]. Patients with neck pain, tenderness or those with altered mental status require further radiologic evaluation[5].

The risk of cervical spine injury is associated with factors like mechanism of injury (MOI), presence of thoracolumbosacral (TLS) spinal, limb and/or facial fracture, patient age, GCS (Glassgow coma scale) score at admission, and the presence of hypotension[6].

The diagnosis of CSI can be difficult in patients with multiple injuries and/or an altered level of consciousness, often leading to delayed or missed diagnosis of CSI. A thorough neurological examination may be difficult because CSI can be associated with other acute polytrauma and life-threatening conditions, pharmacologic influences, paralysis, and alcohol[7, 8].

Computed tomography (CT) is an excellent method of screening trauma patients to confirm or exclude cervical spine fracture. The sensitivity of cervical spine (CS) CT is higher than that of radiography. Performing CT of the CS at the time of head CT may allow a more rapid radiologic exclusion of cervical spine fracture than performing conventional radiography[9].

Head injuries primarily are associated with increased mortality and morbidity. Head injury and cervical spine injury create a devastating duo. It is therefore of paramount importance for surgeons and emergency unit workers to be conversant with the relationship and management of these two conditions especially since they often present together.

At our institute we perform CS radiography in patients with head injury and suspected CS injury. As there is paucity of literature and our institute being the major trauma centre, we need to evaluate if use of CT CS will show a higher sensitivity of CS injury compared to radiography.

AIMS AND OBJECTIVES

1. To study the incidence of cervical spine injuries in patients with moderate-to-severe traumatic brain injury (TBI).
2. To compare the sensitivity and specificity of cervical spine radiography with CT cervical spine in detecting cervical spine injury in patients with moderate-to-severe TBI.

REVIEW OF LITERATURE

HISTORY OF SPINAL CORD INJURY:

In 2800 BC, Edwin Smith papyrus referred to spinal cord injury as a disease not to be treated. In 177 AD, Galen reported on his experiments in animals and described loss of movement and sensibility below the level of cord transection until breathing stopped at higher levels. In 1850-1851, Charles-Edouard Brown Sequard did an experimental work on hemisection of the cord[10].

Hadra in 1891 introduced the operative stabilization of the cervical spine, when he wired the spinous processes of a child who had a fracture dislocation with progressive neurologic deterioration. This is the first surgical procedure recorded in the literature.

Variations of screw insertion techniques have been proposed by Magerl and Anderson. Skull traction using modified ice tongs was introduced by Crutchfield in 1933. Nickel and Perry pioneered the halo device in the late 1950s, primarily to immobilize the cervical spine affected by polio. Its application extended to trauma cases, providing a better means of immobilization[10].

ANATOMY

Vertebral column

The vertebral column is a flexible column formed of a series of bones called vertebrae. The vertebrae are thirty-three in number, and are grouped under the names cervical, thoracic, lumbar, sacral, and coccygeal, according to the regions they occupy; there are seven in the cervical region, twelve in the thoracic, five in the lumbar, five in the sacral, and four in the coccygeal region (Figure 1).

This number is sometimes increased by an additional vertebra in one region, or it may be diminished in one region, the deficiency often being supplied by an additional vertebra in another. The number of cervical vertebrae is, however, very rarely increased or diminished[11].

The vertebrae in the upper three regions of the column remain distinct throughout life, and are known as true or movable vertebrae; those of the sacral and coccygeal regions, on the other hand, are termed as false or fixed vertebrae because they are united with one another in the adult to form two bones—five forming the upper bone or sacrum, and four the terminal bone or coccyx[11].

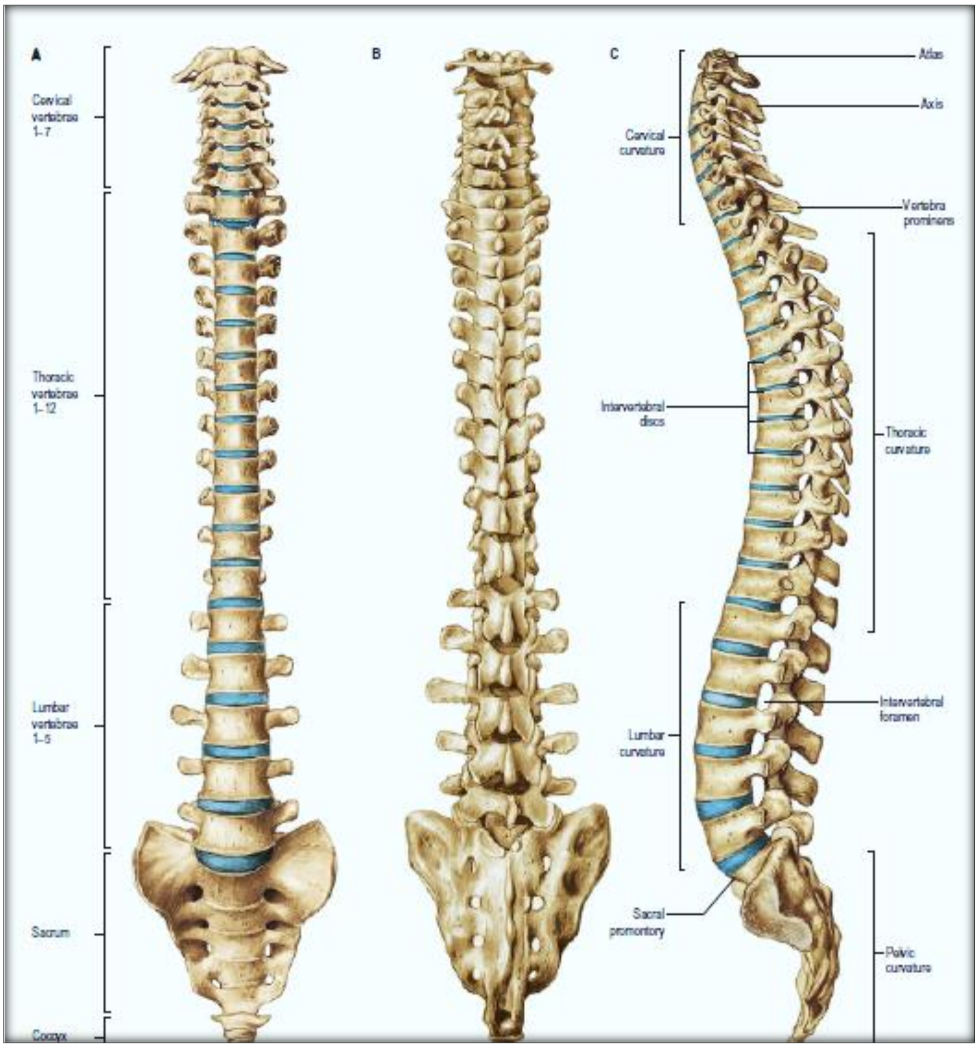

Figure 1. Illustration showing vertebral column with seven cervical vertebrae, 12 thoracic vertebrae and five lumbar vertebrae and 5 sacral vertebrae. Note the cervical, thoracic, lumbar and sacral curvatures.

The vertebral column is flexible because it is composed of many slightly movable parts-the vertebrae. Its stability however depends largely upon ligaments and muscles. Strength, however, is provided by the structure of the column and its constituent parts[11].

Cervical vertebrae

The cervical vertebrae (Figure 2) are the smallest of the moveable vertebrae, and are characterized by a foramen in each transverse process.

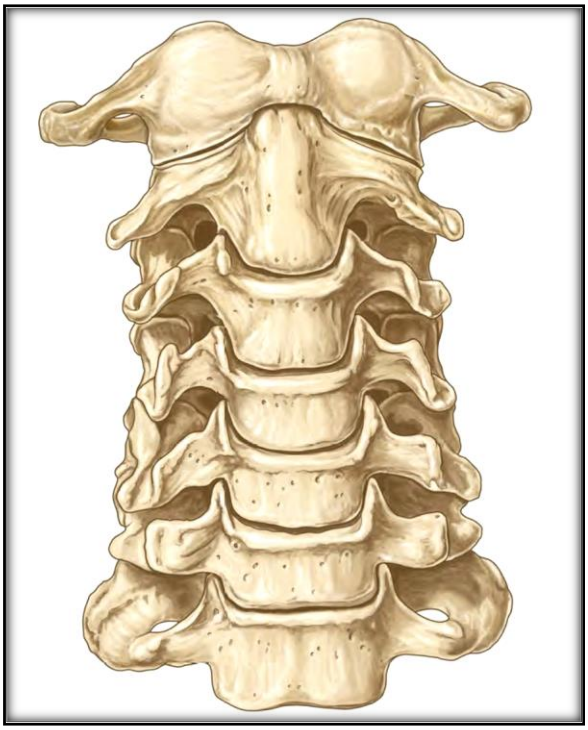

Figure 2. The cervical vertebrae (anterior aspect).

The first, second and seventh will be considered separately due their special features. The third, fourth (Figure 3), fifth and the sixth cervical vertebrae are almost identical, while typical in its general features and have minor distinguishing differences[12].

Parts of a typical cervical vertebra

A typical cervical vertebra (Figure 3) has a small, relatively broad vertebral body. The pedicles project posterolaterally and the longer laminae posteromedially, enclosing a large, roughly triangular vertebral foramen; the vertebral canal here accommodates the spinal cord. The pedicles attach midway between the discal surfaces of the vertebral body, so the superior and inferior vertebral notches are of similar depth[12].

The laminae are thin and slightly curved with two borders, a thin superior and a slightly thicker inferior border. The spinous process is short and bifid, with two tubercles which are often unequal in size. The junction between lamina and pedicle bulges laterally between the superior and inferior articular processes is formed by articular pillar ('lateral mass') on each side.

The transverse process is morphologically composite around the foramen transversarium. Its dorsal and ventral bars terminate laterally as tubercles. In all but the seventh cervical vertebra, the foramen transversarium normally transmits the vertebral artery and vein and a branch from the cervicothoracic ganglion (vertebral nerve).

The vertebral body has two discal margins. Anterior convex discal margin gives attachment to the anterior longitudinal ligament. The posterior surface is flat or minimally concave and gives attachment to the posterior longitudinal ligament. The central area displays multiple vascular foramina, of which two are relatively larger which are called as the basivertebral foramina which transmit basivertebral veins to the anterior internal vertebral veins. The superior discal surface is saddle-shaped, formed by flange-like lips which arise from most of the lateral circumference of the upper margin of the vertebral body; these are referred to as uncinate or neurocentral lips or processes[11].

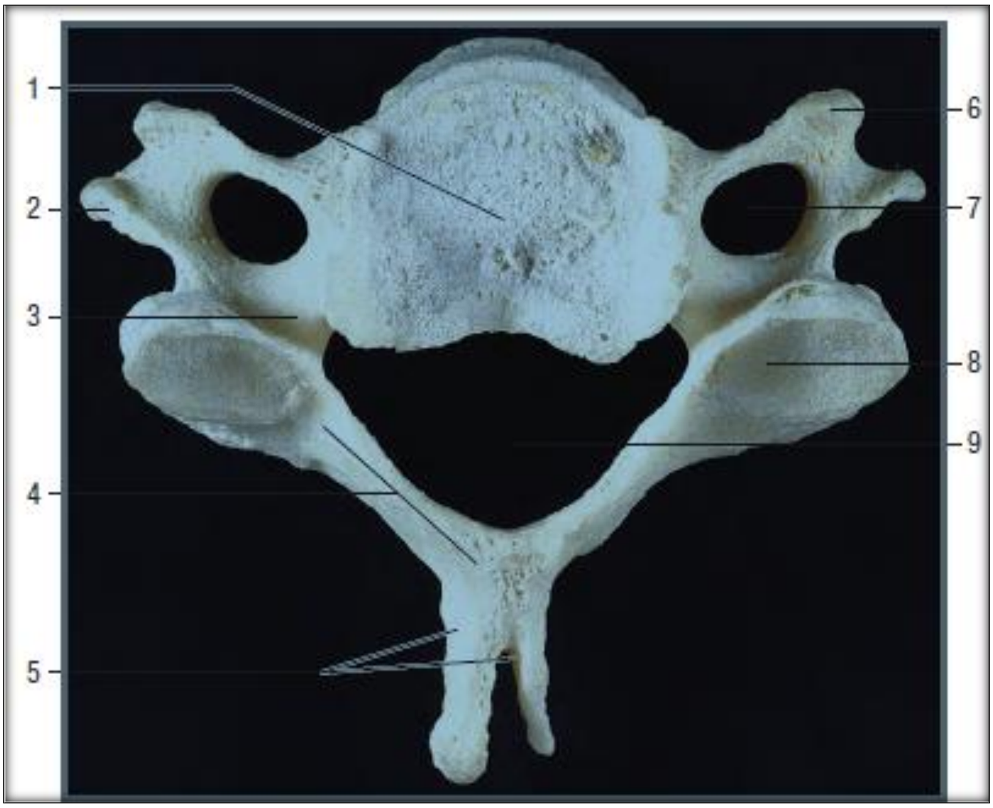

Figure 3. Fourth cervical vertebra, superior aspect. (1. Body. 2. Posterior tubercle of transverse process. 3. Pedicle. 4. Lamina. 5. Bifid spinous process. 6. Anterior tubercle of transverse process. 7. Foramen transversarium. 8. Superior articular facet. 9. Vertebral foramen).

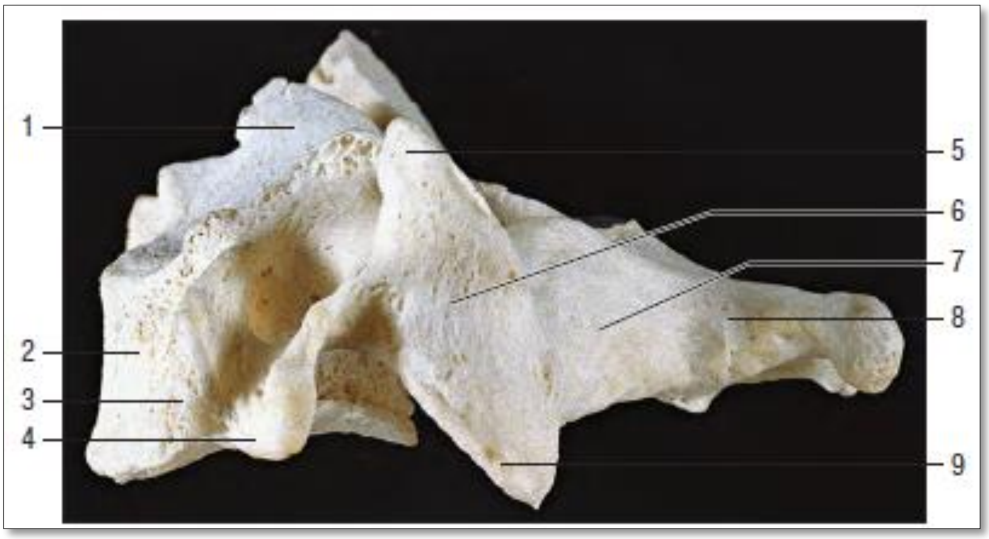

Figure 4. Side view of a fourth (typical) cervical vertebra, lateral aspect.

1. Uncinate process. 2. Body. 3. Anterior tubercle of transverse process.

4. Posterior tubercle of transverse process. 5. Superior articular process.

6. Lateral mass. 7. Lamina. 8. Spinous process. 9. Inferior articular process.

Atlas

Atlas is the first cervical vertebra; it is named after "Atlas", according to a Greek mythology, he who supports the heavens). The skull rests on it and articulates through the atlanto-occipital joint. Axis is the second cervical vertebra, it forms a pivot around which the atlas turns and carries the skull, and the seventh (C7) is a transitional vertebra. The third to the sixth cervical vertebrae are regarded as typical[11,12].

The atlas is the widest of the cervical vertebrae has neither spine nor body. It consists of two lateral masses connected by two arches, a short anterior arch and a long posterior arch.

On its upper surface, it has kidney shaped articular surface that articulate with the condyles of the skull. Atlanto-occipital joint allows for nodding movements but no rotation on the vertical axis can occur in this joint. On its lower articular surface which is flatter in configuration allow for rotational movement. The lower articular surfaces and the axis forms the atlanto axial joint.

Axis

The axis is characterized by the dens or odontoid peg (it is the vertebral body of the atlas developmentally), which projects from the upper part of the body. Dens articulate in front with the anterior arch of the atlas and posteriorly it is separated by a bursa from the transverse ligament of the atlas. The tip of the dens anchors the apical ligament to the front margins of the foramen magnum; the alar ligaments anchor it to the lateral margins.

The lower part of the axis resembles that of a typical vertebra its other characteristic feature is its prominent bifid spinous process, it has the smallest transverse processes of all the cervical vertebrae.

Third to sixth cervical vertebrae

They have a short broad body, a large triangular vertebral foramen, short spines with bifid ends and transverse processes are pierced by foramen transversarium through which the vertebral artery passes [11,12].

Seventh cervical vertebra (vertebra prominens)

The seventh cervical vertebra, the vertebra prominens (Fig. 5), has a long spinous process which is not bifid and is visible at the lower end of the nuchal furrow where it ends in a prominent tubercle for the attachment of the ligamentum nuchae, and the few muscles (Trapezius, spinalis capitis, semispinalis thoracis, multifidus and interspinales). The thick and prominent transverse processes lie behind and lateral to the foramina transversaria. The supra-pleural membrane is attached to the anterior border of the transverse process[11].

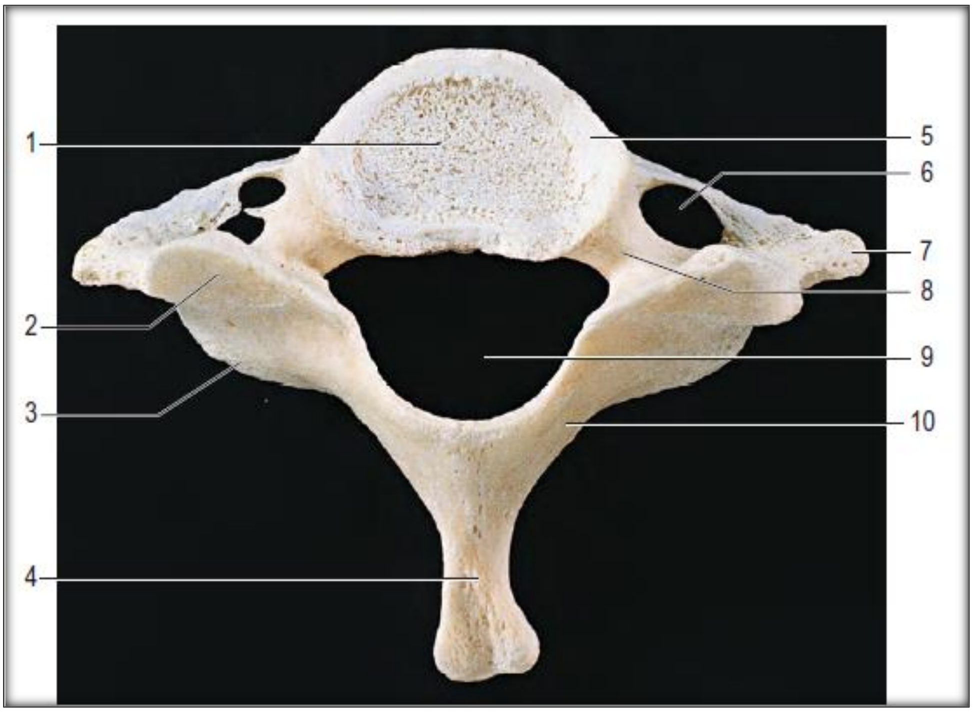

Figure 5. Seventh cervical vertebra, superior aspect.

1. Body.2. Superior articular facet. 3. Inferior articular process. 4. Spinous process. 5. Uncinate process. 6. Foramen transversarium 7. Transverse process. 8. Pedicle. 9. Vertebral foramen. 10. Lamina.

Articulations and ligaments

The bodies of adjacent vertebral bodies are held together by the:

1. Intervertebral discs:- The upper and lower parts are covered by hyaline cartilage and these two layers are united peripherally by a strong ring of fibrous tissue called the annulus fibrosus. Nucleus pulposus derived from the notochord is inside the annulus made up of semi liquid gelatinous substance [11,12].

2. Ligaments; -
   a) Alar ligaments: These are paired ligaments which attach the axis to the base of the skull (Figs. 6) and originate from the posterior surface of the upper third of the dens and inserts on the medial aspect of the occipital condyles or the anterolateral aspect of the foramen magnum. It is narrowest at its origin and wider at its insertion. They limit axial rotation and lateral flexion on the contralateral side. They are the strongest stabilisers of the atlas preventing anterior displacement and rupture of the transverse ligament[13].

   b) Cruciform ligament (cruciate ligament): Are composed of transverse and vertical parts which form a cross behind the odontoid peg (Figure 6). The vertical component is relatively weak and consists of a cranially orientated longitudinal band which inserts on to the upper surface of the clivus between the apical ligament and tectorial membrane and a caudally directed band which inserts on to the posterior surface of the body of the axis.

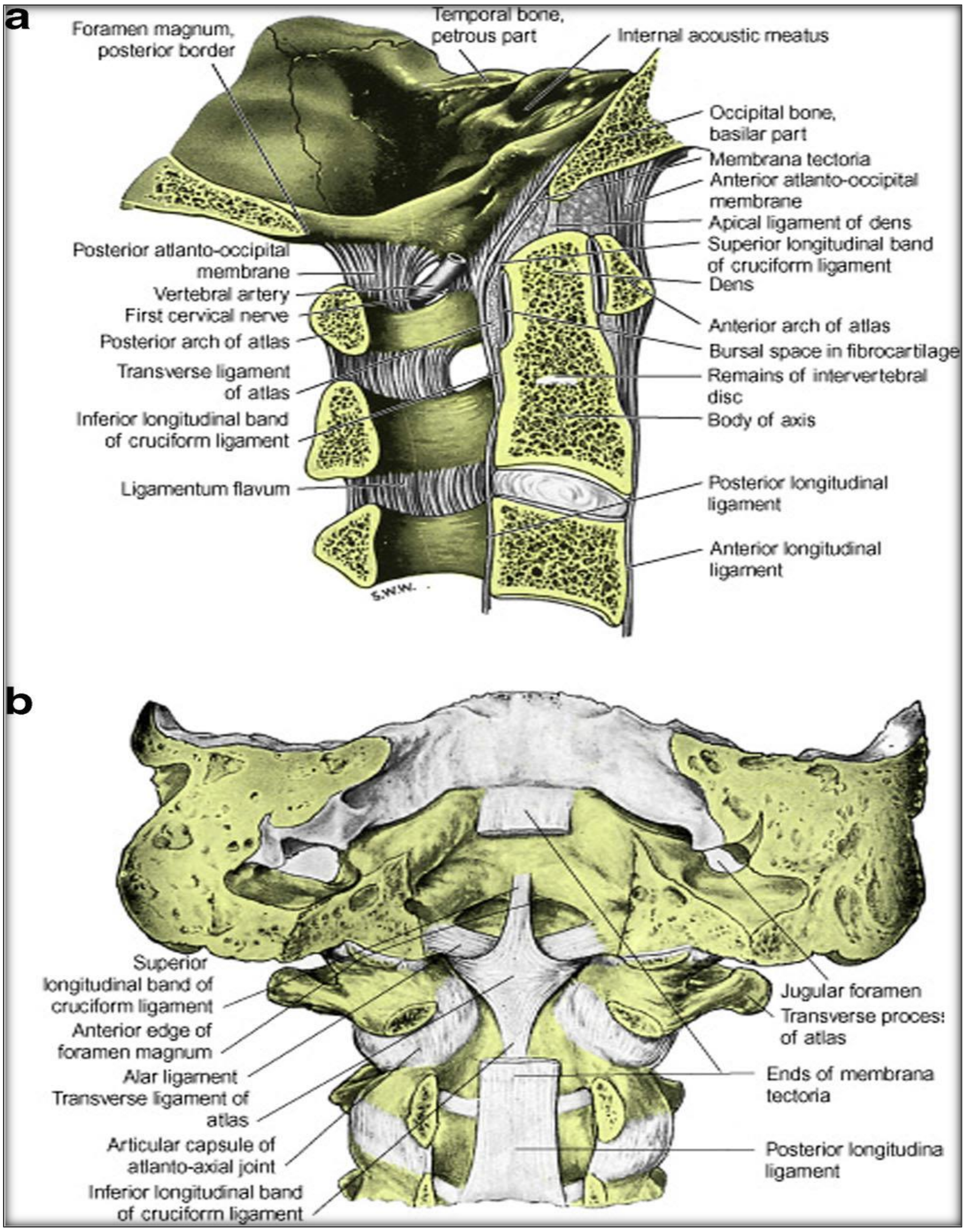

Figure 6 (a & b). Illustrative anatomy of the craniocervical junction osseoligamentous structures: a right lateral view of sagittally sectioned craniocervical junction in a median plane (i.e. viewed from right to left);

b. posterior view of the coronally sectioned craniocervical junction; the tectorial membrane was partly removed to expose the deeper ligaments.

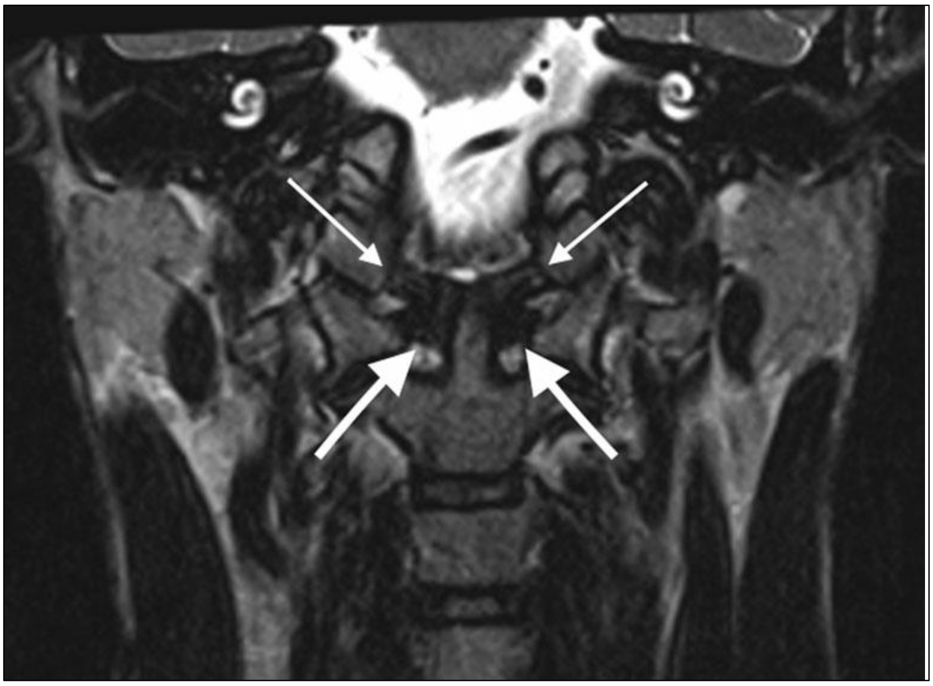

Figure 7. MRI (magnetic resonance imaging) coronal three-dimensional T2 SPACE (sampling perfection with application-optimised contrasts using different flip-angle evolutions) sequence image through normal craniocervical junction demonstrating normal MRI appearances of the transverse ligament (thick arrows) and alar ligaments (thin arrows).

c) <u>Transverse ligament</u> (also termed as the transverse atlantal ligament): The transverse ligament of the cruciform ligament is one of the crucial ligament in the body. It is the largest, thickest and the strongest of the craniocervical junction ligaments (and the strongest ligament in the entire spine) and, therefore, a primary stabiliser of the craniocervical junction. It arches behind the odontoid peg attaching to a tubercle arising from the medial aspect of each lateral mass of the atlas (Figs. 6 and 7). It stabilizes the craniocervical junction by fixing the odontoid peg firmly to the posterior aspect of the anterior arch of the atlas. It permits rotation at the atlanto-axial joints[13].

d) Tectorial membrane: This thin structure represents an upward extension of the posterior longitudinal ligament (Fig. 6). It attaches as far laterally as the hypoglossal canals and, at the level of C0-C1, merges with the atlantooccipital capsular ligaments (Arnold's ligaments).

e) Capsular ligaments: The capsular ligaments of the atlanto-occipital and atlantoaxial joints (which are paired synovial joints) are typically described as thin and loose ligaments.

f) Apical ligament: This ligament extends from the tip of the odontoid process to the basion and is situated between the anterior atlantooccipital membrane and the cruciform ligament.

g) Anterior atlanto-occipital membrane: This thin structure attaches the anterior aspect of the atlas to the anterior rim of the foramen magnum and is located immediately posterior to the prevertebral muscles. It serves to limit atlanto-occipital extension at the craniocervical junction[13].

h) Posterior atlanto-ocipital membrane: This broad ligament attaches the posterior arch of the atlas to the posterior margin of the foramen magnum and is continuous with the posterior atlantoaxial membrane and, subsequently, the ligamentum flavum.

An important consideration in trauma is the vertebral artery pierces the posterior atlanto-occipital membrane and then the dura mater before entering the posterior fossa.

i) Nuchal ligament (ligamentum nuchae): This is a cephalic extension of the supraspinous ligament and extends from the spinous process of the C7 vertebra attaching to the inion of the occipital bone. It limits hyperflexion of the cervical spine[13].

3. Other ligaments of the neural arch and spine; -
   a) Supraspinous ligament: is a strong band of white fibrous tissue joining the adjacent spinous processes. They are lax in the extended spine and taut in the flexed spine.

   b) Interspinous ligaments: are relatively weak sheets of fibrous tissue joining the adjacent spinous processes along their adjacent borders.

   c) Ligamentum flava: they join the contiguous borders of adjacent laminae. They have a high content of elastic fibres and are stretched by flexion giving increasing anti-gravity support.

   d) Intertransverse ligaments: are made up of weak fibres joining the transverse processes along their adjacent borders[14].

4. Facet (zygapophysial) joints;- Joints between the vertebral articular processes (zygapophyses). Articulating surfaces of facet joints are of the simple synovial variety and are covered by hyaline cartilage. They permit gliding movements.
   At the cervical level movements possible include extension, flexion, lateral flexion and a degree of rotation[14].

Blood supply of the vertebral column

The vertebra and the longitudinal muscles attached to them are supplied by segmental arteries. The ascending cervical, the intercostal and the lumbar arteries give multiple small branches to the vertebral bodies.

Venous drainage; -The richly supplied red marrow of the vertebral body drains almost wholly by a pair of large basi-vertebral veins into the internal vertebral plexus. Drainage of the neural arch and of the attached muscles is into the external vertebral plexus. The internal and external vertebral plexuses together drain into the regional segmental veins[12,14].

THE CONCEPT OF A THREE COLUMN SPINE

To assess the stability of cervical spinal column injuries below C2, in 1983, Denis proposed the 3-column model of the spine, which described both the functional units that contribute to the stability of the spine and the destabilizing effect of injuries to the various columns.

1. Anterior column

2. Middle column

3. Posterior column

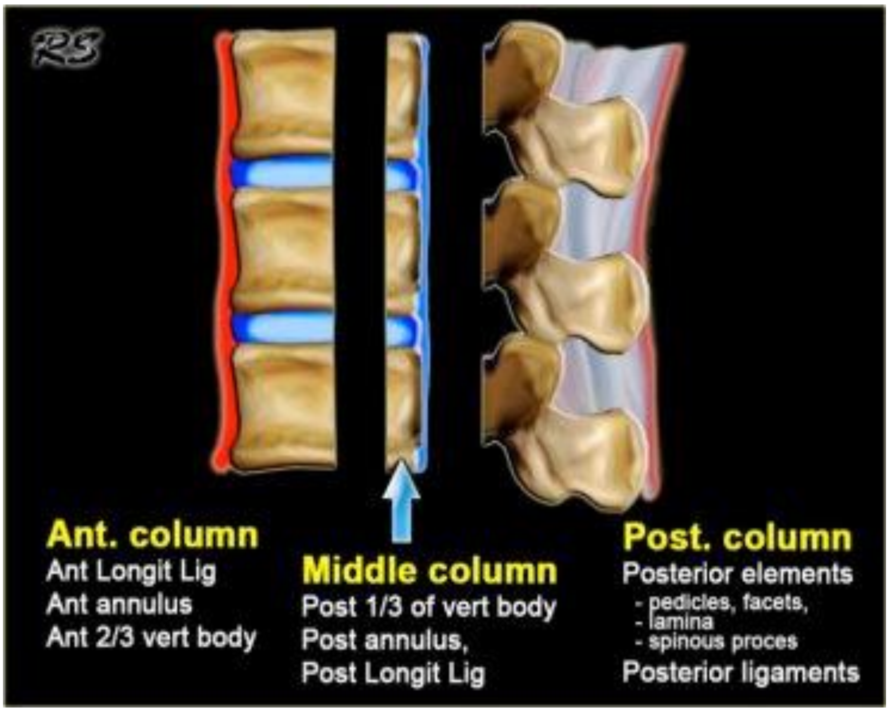

Figure 8. Diaphragmatic representation of components of each column.

Anterior column - consists of anterior longitudinal ligament, the anterior half of the vertebral body, and the related portion of the intervertebral disc and its annulus fibrosus.

Middle column - contains the posterior longitudinal ligament, the posterior half of the vertebral body, and the intervertebral disc and its annulus.

Posterior column - which contains the spinal canal, is formed by the bony elements of the posterior neural arch i.e. pedicles, transverse processes, articulating facets, laminae, and spinous processes and the ligamental elements, which include the ligamentum flavum, the nuchal ligament complex (supraspinous, interspinous, and infraspinous ligaments) that hold the posterior column in alignment and joint capsule of the intervertebral articulations. Disruption of 2 or more columns results in an unstable configuration as the cervical spine can move as two independent units, and there is a high risk of causing or exacerbating a spinal cord injury[15].

Whereas, if only one column is disrupted, the other columns maintain structural integrity making the risk of spinal cord injury less severe.

HEAD INJURY

Traumatic Brain Injury is one of the leading causes of mortality (about 20–30%) in all age group[4].

Head injury can be defined as any alteration in mental or physical functioning related to a blow to the head. Loss of consciousness does not need to occur. Severity of head injuries most commonly is classified by the initial post resuscitation Glasgow coma scale score, which generates a numerical summed score for eye, motor, and verbal abilities. A score of 13-15 indicates mild injury, a score of 9-12 indicates moderate injury, and a score of 8 or less indicates severe injury[16, 17].

Based on severity the head injuries are 80% mild, 10% are moderate and 10% are severe[18].

The males have higher incidence than females with a ratio 1.7:1[19].

CERVICAL SPINE INJURY

Cervical spine injury is defined as any acute fracture, subluxation, or both. Clinically significant injuries are defined as those requiring surgery or long-term stabilization with a collar or halo[20].

Mechanism of injury

Road Traffic Accidents (RTAs) are the most common mode of injury in industrialized areas accounting for 36% to 57%. Fall from trees, bicycles, sporting accidents and slips from mountain tops besides are more common than RTAs in hilly regions. In them, common causes of TBI include falls 51%, RTAs 21%, assault 14% and other minor causes are 14%. RTA is a predominant cause of head injury in adults, whereas fall is the commonest cause among children less than 10 years[4].

Incidence of cervical spine injury in head trauma

There is higher incidence of CSI with increase in severity of TBI, so requiring prompt care of cervical spine in all patients sustaining moderate to severe head injury[21].

In 1991, the rate of CSI among patients with (TBI) with a Glasgow Coma Scale (GCS) score of 8 or lower was 10.5% and 2.3% in the years 1994-2003[6].

Few studies have stated that the incidence of CSI among patients with TBI ranges from 1.7% to 8%[22,23,24].

The Advanced trauma life support (ATLS) course manual gives the incidence of cervical spine injury in head injured patients at around 5-10%. It also states that any injury above the clavicle should prompt a search for cervical spine injury, which may be present in up to 15% of such patients[25].

About 5%–10% of patients with blunt polytrauma sustain cervical spine injuries. Of the 10,000 spinal cord injuries that occur each year, approximately 55% involve the cervical spinal cord[26].

Common site of cervical level injured

The spinal injuries more commonly noted between C4 and C6 level because the cervical canal is narrowest at this level. The commonest CSI is dislocation of C5-C6 vertebra 33%, followed by C6-C7 29% and of which 20% patients have complete cervical cord injury[27].

In a study, most head injuries were associated with cervical spine injuries occurring at the upper levels C1-C3[22]. Shrago et al, found incidence of 56% in upper cervical, 34% in mid cervical and 10% in lower cervical spine[28].

FRACTURES

Cranio-cervical junction blunt traumatic injury

Basi-occiput fractures

Account for only 2% of cranial fractures but with high rate of mortality (24% to 80%) because of the proximity to the brainstem and the high incidence of neurological injury (particularly cranial nerve VI) and vascular injury. Patterns described are transverse, oblique and longitudinal. The transverse and oblique patterns typically result from lateral blunt force impact or crush injuries, and associated cranial nerve injury and internal carotid injury has been described. The longitudinal fractures result typically from an axial loading mechanism through the vertex and may be associated with vertebro-basilar vascular injury and brainstem infarction.

Occipital condyle fractures

The incidence ranges from 4 % to 19 %. On the medial aspect of the occipital condyle, there is a tubercle for attachment of the alar ligament. It is said that CT assessment is mandatory to establish or confirm the diagnosis. Classification system of occipital condyle fractures was described by Anderson and Montesano. According to this, there are three types of occipital condyle fractures. Type I is an impaction type fracture resulting in comminution of the occipital condyle with or without minimal fragment displacement and is stable, unless it’s bilateral. Type II fracture (Figure 9) is more extensive basi-occipital fracture involving one or both occipital condyles and is however a stable fracture.

The type III fracture is an avulsion fracture resulting in medial fragment displacement into the foramen magnum; in this fracture type, the contralateral alar ligament and tectorial membrane may been stressed resulting in disruption and making it unstable[13].

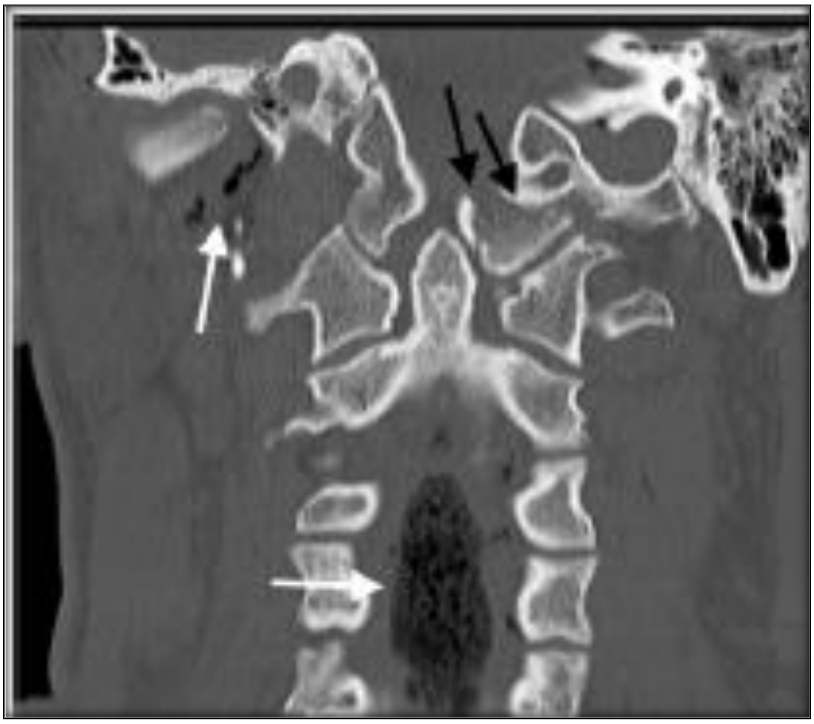

Figure 9. Type II occipital condyle fracture: coronal reformatted CT image of the craniocervical junction performed in a young male pedestrian struck by a bus. The fracture of the left occipital condyle is associated with extension into the right basiocciput (black arrows). Note the associated soft tissue emphysema and pneumorachis within the anterior epidural space of the cervical spine (white arrows).

Atlanto-occipital (occipito-atlantal) dislocation

Under normal anatomical conditions, the convex occipital condyles sit within the concavity of the lateral masses of the atlas.

The most important ligaments for stability of the atlantooccipital articulation are the cruciform and alar ligaments and the tectorial membrane.

As per Traynelis classification, atlanto-occipital dislocation is divided into three types.

Type I injuries represent anterior displacement of the occipital condyles in relation to the atlas. Type II injuries are distraction injuries with vertical displacement of the occipital condyles in relation to the atlas and type III injuries describe posterior displacement of the occipital condyles relative to the atlas.

Both the basion-dens interval (which is abnormal if greater than 10 mm in the adult and greater than 12 mm in the paediatric patient) and the condyle-atlas interval (which is abnormal if greater than 2 mm in the adult and greater than 5 mm in the paediatric patient) can be used to identify abnormality at the atlanto-occipital articulation; additionally, anterior displacement of the posterior margin of the odontoid peg and body of the axis relative to the basion greater than 12 mm or posterior displacement of the posterior margin of the same relative to the basion greater than 4 mm represents an abnormal relationship.

Fractures of the C1 vertebra (atlas)

These fractures can be seen in isolation, however are frequently associated with fractures of the axis and the subaxial cervical spine and closed head injury. Cervicomedullary parenchymal injury occurs more frequently when fractures of the atlas coexist with axis or subaxial cervical spine injury.

Jefferson's fractures

Was first described by Sir Geoffrey Jefferson, are classified as type I which are fractures involving the posterior arch alone, type II fractures which involve the anterior arch alone, type III (the classical Jefferson fracture) which are bilateral posterior arch fractures associated with a unilateral or bilateral anterior arch fracture, type IV which involve the lateral mass and type V which are transverse fractures of the anterior arch[13].

Fractures of the C2 vertebra (axis)

The incidence of neurological deficit and acute mortality associated with fractures of the axis approach 8.5 % and 2.4 %,

Odontoid fractures :

Anderson and D'Alonzo classified odontoid fractures into three types and with modification introduced by Hadley et al. who defined a subclass of the type II fracture.

Type I is a fracture through the upper part of the odontoid process; type II is the most common and occurs at the junction of the odontoid process with the body of the axis, type IIa subclass has additional chip fragments at the anterior or posterior aspect at the base of the dens and leads to non-union fracture through the upper part of the odontoid process.

Type III is a fracture that extends downwards into the cancellous portion of the body of the axis (Figure 10). The type II fracture is more prone to non-union and therefore, may need surgical fusion[13].

Figure 10. Complex type III odontoid fracture of the atlas in a 32-year-old male driver involved in a motor vehicle collision. Coronal reformatted CT image of the craniocervical junction demonstrating fracture extension into the body of the C2 vertebra (black arrows) with a further vertical fracture line extending through the right side of the body (white arrow).

Hangman's fractures

Initially it was described in human subjects, when they were executed by hanging with the knot of the noose positioned under the submental region. This fracture-type represents bilateral fractures of the pars interarticularis of the axis.

Table 1. Classification of cervical spine injury[15]

Mechanisms of spinal injury	**Stability**
Flexion	
Anterior wedge fracture	Stable
Flexion teardrop fracture	Extremely unstable
Clay shoveler's fracture	Stable
Subluxation	Potentially unstable
Bilateral facet dislocation	Always unstable
Atlanto-occipital dislocation	Unstable
Anterior atlantoaxial dislocation with or without fracture	Unstable
Odontoid fracture with lateral displacement	Unstable
Fracture of transverse process	Stable
Flexion-rotation	
Unilateral facet dislocation	Stable
Rotary atlantoaxial dislocation	Unstable
Extension	
Posterior neural arch fracture (C1)	Unstable
Hangman's fracture (C2)	Unstable
Extension teardrop fracture	Usually stable in flexion; unstable in extension
Posterior atlantoaxial dislocation with or without fracture	Unstable
Vertical compression	
Burst fracture of vertebral body	Stable
Jefferson fracture (Cl)	Extremely unstable
Isolated fractures of articular pillar and vertebral body	Stable

Injuries of the Sub-axial Cervical Spine

They account for 65% and 75% of cervical spine fractures and dislocations respectively. In 1982, Allen, Ferguson and colleagues conducted a retrospective study in 165 patients. They proposed that posture, force vectors, and magnitude of cervical spine will reproduce injury patterns, and thus, cervical spine trauma was categorized into six spectra of injury based on radiography which include flexion compression, vertical compression, flexion-distraction, extension compression, extension distraction, and lateral flexion. Each mechanism had a separate severity scale[26].

Flexion-compression injuries

Include vertebral body compression fractures and triangular, teardrop fracture or a quadrangular fracture with posterior ligamentous disruption. Posterior subluxation of the posterior vertebral body into the canal, acute kyphosis and disruption of the anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL) and other posterior ligaments are the most severe forms.

Flexion-distraction injuries (Most common)

Comprise a spectrum of injuries which result from mild posterior ligamentous sprains to bilateral facet dislocations. Facet subluxation is mildest form which can be easily missed on initial evaluation.

Unilateral facet dislocations and facet fracture-dislocations are the other patterns seen. C6-7 is the level most commonly affected. Bilateral facet dislocations are associated with increased incidence of neurologic injury[29].

Vertical compression injuries

They most commonly manifest as a cervical burst fracture and are classified as most severe pattern. Axial loading of the cervical spine causes compression of the vertebral body resulting in retropulsion of the posterior wall into the canal.

Extension injuries

Abnormal widening of the disc space which represents the disruption of the anterior longitudinal ligament and disc which corresponds to stage I lesion as per Allen and Ferguson classification. Disruption of the posterior ligaments with displaced cephalad vertebrae into the spinal canal corresponds to stage II lesion.

Central cord syndrome is also and another common pattern of injury in extension injuries (due to compression between a hypertrophied spondylotic disc-osteophyte complex and a bulging ligamentum flavum) first described by Schneider in 1954. It is characterized by greater motor impairment of the upper extremities than that of the lower extremities with concomitant bladder dysfunction and variable sensory disturbance.

This classification was further modified by Harris et al, where he included rotational components in lieu of lateral flexion[29].

Moore et al.[30], has recently proposed a classification of lower cervical spine injury which is described more so on morphologic than a mechanistic approach. Spine was divided into four columns: the anterior column, the lateral columns (lateral masses and paired facets) and the posterior column (the posterior bony arch and supporting ligaments). The scoring was based on the severity of injury and score was given to each column.

CERVICAL SPINE CLEARANCE

As per ATLS protocol, airway protection and cervical spine immobilization are the initial steps in case of blunt trauma.

Clearance refers to the excluding of unstable cervical spine injuries confidently that could otherwise result in neurologic injury or death.

There are two criteria established for cervical spine clearance.

Canadian C-spine rule study includes following factors such as injury age < 65 years, no dangerous mechanism {such as fall from height of >91 cm (>3 ft), axial loading injury, high-speed motor vehicle collision (>100 km/h), rollover, or ejection, recreational motor vehicle, motorcycle, or bicycle injury}, no paresthesia's, sitting position in emergency department, ambulatory at any time, neck rotation of 45° left and right to exclude cervical spine with sensitivity 100% in 8924 adults.

As per National Emergency X-Radiography Utilization Study (NEXUS) following factors such as no posterior midline cervical tenderness, no intoxication, no focal neurologic deficit and no painful distracting injuries are used to exclude cervical spine injury with a high negative predictive value of 99.8%[31,32].

ROENTGENOGRAPHIC EVALUATION OF A SUSPECTED CERVICAL SPINE INJURY

Interpretation of plain radiographs

Adequacy of plain radiographs is of most importance if plain radiographs are used to assess the cervical spine.

Adequacy of radiographs:

Lateral view: Entire cervical spine from the base of the occiput to the top of D1 vertebra must be clearly visible.

Odontoid view: Dens and lateral masses of atlas must be clearly visible.

Interpretation (Figure 11. a, b & c): Examine for

1. Alignment of the vertebrae;
2. Appearance
3. Position
4. Spacing between vertebrae
5. Soft tissues.

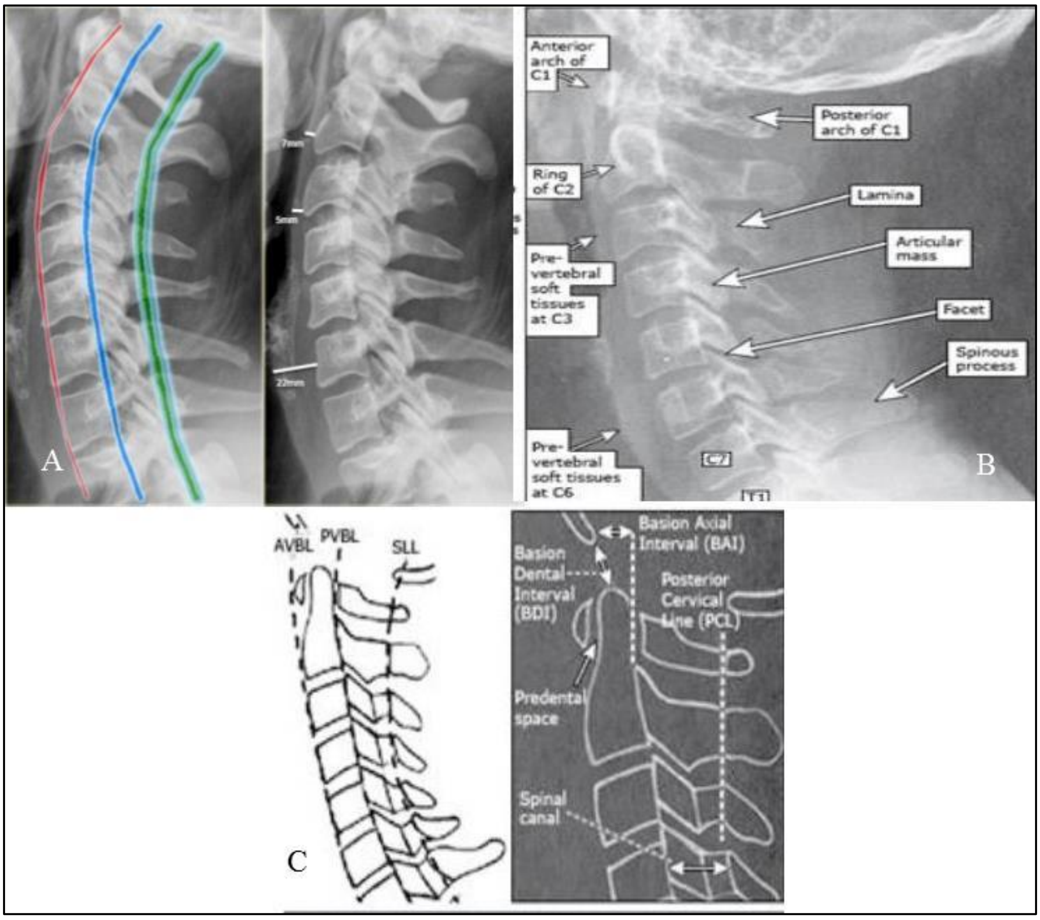

Figure 11. (a, b & c). Plain radiograph of cervical spine lateral views showing the anterior & posterior spinal line and spinolaminar line.

1. Lateral view

Is the most useful view. Approximately 85-90% of spinal injuries are evident on this view. Adequacy of radiographs: Entire cervical spine from the base of the occiput to the top of D1 vertebra must be clearly visible.

Systematic approach: Check alignment by following 3 contour lines:

- Anterior contour line connects the anterior margins of the vertebrae.
- Posterior contour line connects the posterior aspect of the vertebrae.
- Spinolaminar contour line connects the bases of the spinous processes.

Prevertebral space:

At C2 no more than 7 mm.

At C3 and C4 no more than 5 mm.

At C6 it is wider due to oesophagus and cricopharyngeal muscle, but should not exceed 22 mm in adults or 14 mm in children younger than 15 years.

In children younger than 24 months there can be physiologic widening of the prevertebral space during forceful expiration (i.e. crying).

Widening of the space between spinous processes suggests ligamentous disruption[33].

2. Odontoid view

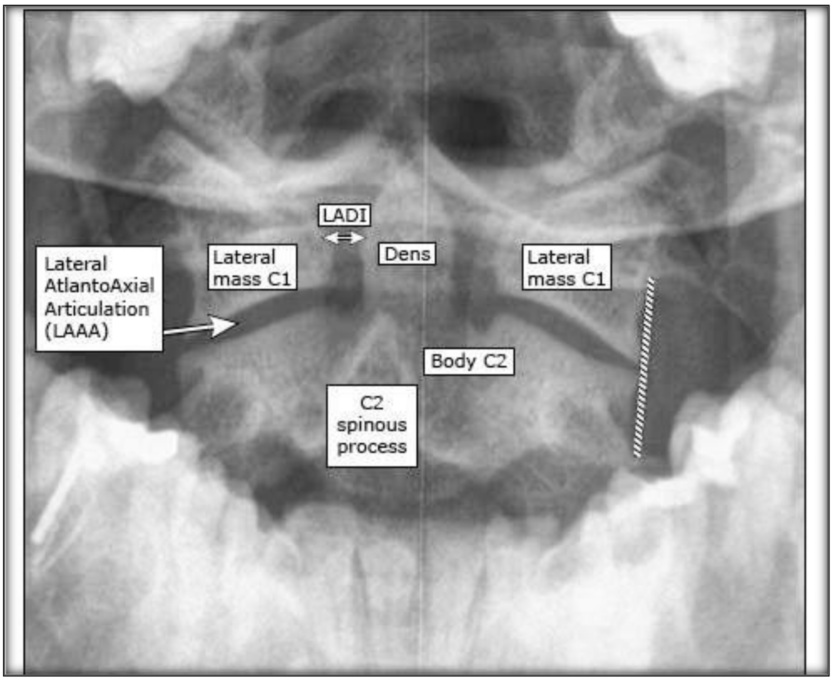

Figure 12. Plain radiograph of cervical spine in odontoid view.

Adequacy: the dens and lateral masses (C1 and C2) are visible including the entire lateral atlanto-axial articulation (LAAA). Rotation is minimised: Dens and C2 spinous process are in midline.

- Alignment: Lateral margins of the articular surfaces of C1 and C2 are aligned. About 1-2 mm symmetric overriding is allowed medially or laterally.
- Bones: lateral masses of C1, body and spinous process of C2, Peg and base of dens.
- Cartilage: The lateral atlantoaxial articulation (LAAA) of C1-C2 form parallel joint surfaces.
- Spaces: Lateral Atlanto-Dental Intervals (LADI) is similar but not necessarily equal[33].

1. Antero-posterior view

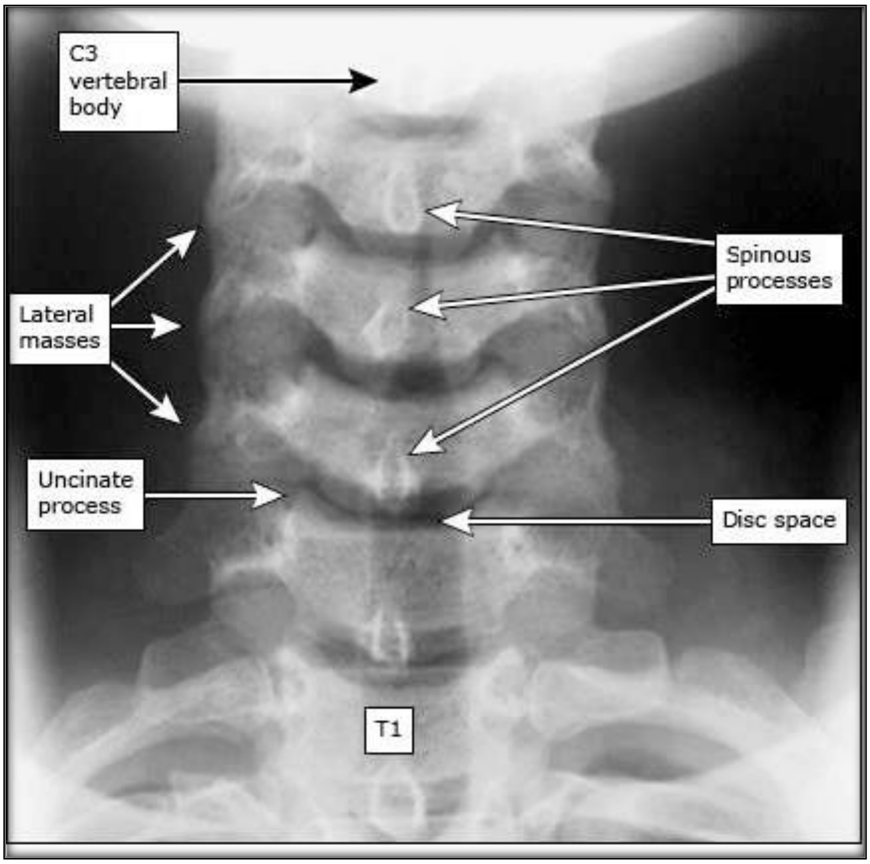

Figure 13. Plain antero-posterior radiograph of cervical spine.

- Adequacy: No tilt or rotation. The vertebral bodies of C3-T1 are visible.
- Alignment: The spinous processes are aligned in the midline. The articular masses form a smooth, undulating and continuous lateral margin.
- Bones: Identify and inspect the following structures – Vertebral bodies, uncinate processes, lateral masses and spinous processes.
- Cartilage: Disc spaces are of uniform height. Articular surfaces are parallel.
- Spaces: Spinous processes are equidistant[33].

CT FOR CERVICAL SPINE INJURY

The limitations of plain radiography of cervical spine to reliably identify or exclude fractures after blunt trauma are well documented[32].

Woodring and Lee[34] provided some of the earliest proof that plain radiography may be insufficient and insensitive to identify cervical spine fractures in trauma patients when compared with CT. Their review of 216 patients showed that 61% of fractures seen on CT scan were missed by plain x-rays.

Schenarts et al. published their validation on the use of CT to image the upper cervical spine in 2001. In 1,356 patients with altered sensorium, 70 patients had 95 injuries to the upper cervical spine (occiput to C3). They found that 45% of these fractures were not visualised X-ray. The authors concluded that their observations supported the EAST guidelines[35, 36] for the use of CT to clear the upper cervical spine in patients with altered sensorium.

Griffin reviewed 1,199 patients who had both cervical radiography and CT. There were fractures visualized in 116 patients. Only 75 of 116 (64.7%) fractures were seen on plain radiography. Cervical CT identified all injuries. The authors found no identifiable factors to predict the false negatives using cervical spine radiography (CSR) and stated that ‘there does not appear to be any role for CSR in injury exclusion in the setting of blunt trauma’[37].

Multidetector computed tomography (CT) is now therefore commonly used to evaluate the traumatic cervical spine injury. Practice guidelines from the Eastern Association for the Surgery of Trauma (EAST) recommendation stated that axial, sagittal and coronal reconstructions of CT cervical spine covering from occiput to the D1 vertebra, be used as the primary method of screening for cervical trauma[38].

Cost effectiveness

The debate to abandon plain cervical radiography in favour of complete cervical spine CT for screening after blunt trauma has strengthened, the argument over economics continues.

Blackmore and others[9]. designed a ‘decision analysis model’ to study cost-effectiveness from a societal perspective. They analysed hypothetical cohorts of patients in three separate groups: low-, moderate-, and high-risk patients for cervical spine injury. Using published sensitivities for fracture identification for plain cervical radiography and cervical CT, the authors determined that ‘CT is the preferred cervical screening modality in trauma patients at high and moderate risk for cervical spine fracture.

Tan et al[39]. published a cost-effectiveness study looking at the use of CT to image C7 to T1 when not seen on plain radiographs. In 360 patients that required CT of C7 to T1, 11 fractures were seen. The authors concluded that the cost-effectiveness for preventing negative sequel of missed injuries was $9,192 for each fracture identified and $50,557 for each unstable fracture identified.

Interestingly, because patient charges are the same for partial or complete CCT (cranio cervical CT) scans, patients who undergo plain CSR (cervical spine radiography) evaluation first, followed by segmental CCT, are billed more than patients who simply underwent only complete CCT from occiput to T1 because of charges related to obtaining and reading the plain CSR. And these patients incur this expense without the benefit of the better diagnostic sensitivity of CT scan for the mid-cervical spine (C3-6) where many fractures occur.

Later, another group developed and validated a clinical decision rule using three injury mechanisms and three clinical parameters to identify high-risk patients that warrant imaging of the cervical spine with CT.

The presence of any one of the following indicates high risk: [40]

• High-speed (≥56 kph [35 mph] combined impact) motor vehicle crash

• Death at scene of motor vehicle crash

• Fall from height (≥3 m [10 ft])

• Significant closed head injury or intracranial haemorrhage seen on CT

• Neurologic symptoms or signs referred to the cervical spine

• Pelvic or multiple extremity fractures

CT is more resourceful than plain radiographs in addition to improved sensitivity in high-risk patients. A retrospective review suggests that blunt trauma patients with a normal cervical spine CT and no neurological deficits do not require further assessment with MRI before clearing the cervical spine of bony and ligamentous injury[41].

CT has the advantage of assessing non-spinal injuries simultaneously and rapidly.

Increased radiation is the most important disadvantage. Researchers found a tenfold increase in the radiation dose to the skin (28 versus 2.89 mGy) and a 14-fold increase in the dose to the thyroid (26 versus 1.8 mGy) with CT as compared to standard radiographs[42,43].

MRI FOR CERVICAL SPINE INJURY

MRI is less sensitive than CT for the detection of fractures[44]. However; it is proven to be superior in determining spinal cord and nerve roots integrity, intervertebral discs, surrounding soft tissue, ligamentous structures, and vertebral arteries[45]. As known, MRI does not subject the patient to ionizing radiation.

Therefore, MRI is indicated in the following situations: [46]

1. To differentiate intrinsic (hemorrhage, edema, or injury to the cord itself) and extrinsic (hematoma, disc prolapse, retropulsed fractured fragment compressing the cord) causes of acute as well as causes of delayed and progressive neurologic deterioration in spinal injury.
2. Detecting and predicting the outcome of "Spinal Cord Injury Without Radiographic Abnormalities" (SCIWORA).
3. Determining the acuity of bony injuries.
4. Along with MR angiography, it helps in detecting associated vascular injury of the neck (e.g., vertebral artery injury).

The following conditions increase the risk for vascular injury of the neck: [47,48]

• Severe blunt force to the neck

• Significant hyperextension or hyperflexion injuries of the neck

• Unexplained neurologic deficits

• Fractures of the skull base

• Fractures of cervical vertebra adjacent to or involving vascular foramina

• Penetrating injuries adjacent to vascular structures

• Severe facial fractures

Disadvantages of MRI however in the trauma setting are: [49]

• Risk of transport and the critical support required for sick patients.

• Restless patients giving undiagnostic images.

• Delay in clearing the cervical spine of injury.

Evaluation of ligamentous injury and SCIWORA

Spinal cord injury without radiographic abnormality (SCIWORA) is often defined as the presence of neurologic deficits in the absence of evidence of bony injury on a complete, technically adequate, plain radiograph series or a CT scan. True SCIWORA is seldom associated with permanent neurologic injury in adults[50]. However, cervical spinal subluxation without an associated bony injury can occur when the ligamentous complexes rupture, posteriorly to anterior starting with the nuchal ligament progressing to involve other ligaments.

Degenerative changes of the spinal column and spinal stenosis predispose to ligamentous injury.[57] Findings to suspect SCIWORA like widening of both the interspinous and intervertebral spaces posteriorly are very subtle in a CT scan or a plain lateral radiograph and can completely missed.

Epidemiology — SCIWORA once thought to occur primarily in children, has been seen in adults too, considering the wide use of MRI[51,52,53].

Two retrospective reviews found that of 818 and 166 patients with cervical spine injury respectively, 3.3 and 4.2 percent had SCIWORA[51,53,54].

Another retrospective review found the prevalence of SCIWORA to be 32.2 percent among adults with a cervical spinal cord injury. Most SCIWORA injuries occurred either in older patients involved in minor mechanisms or younger patients involved in high-energy mechanisms. The reasons for the discrepancies in the reported rates of SCIWORA among adults remain may reflect a true increase in incidence or an increase in reporting[55,56].

GENERAL AND MEDICAL MANAGEMENT.

Primary Survey: Assessment and stabilization of the trauma victim follow the ABCDE pattern: Airway, Breathing, Circulation, Disability (Neurologic status), and Exposure.

The first vital thing is to secure the patient's airway. If it is not secure, immediate basic airway management should be done. Once the airway and breathing are secure, management of uncontrolled hemorrhage using direct pressure should be carried out. Immobilization of cervical spine is done to prevent injury. Placement of a hard cervical collar, barriers to lateral head movement (eg, foam pads, rolled towels), and a long backboard to be performed for proper spinal immobilization. Vitals are to be recorded.

Obtain vital signs as part of their assessment of patient circulation. Ideally, blood pressure measurements are obtained in each arm. Studies suggest that prehospital hypotension is associated with an increased need for emergent surgery and with increased mortality[57,58].

Basic measures to control severe pain and hemodynamic instability are done by giving IV analgesics and IV fluid bolus.

Secondary Survey: After completion of the initial assessment and stabilizing treatments, performing a quick thorough review of the entire body to note and manage any injuries, if missed during the initial survey. Not thoroughly inspecting the back, the axillae, the gluteal region, and pannicular folds are the common pitfalls to be excluded.

Endotracheal intubation (ETI) if necessary must include protocols and equipment (eg, End-tidal CO2 monitor) for confirmation of proper tracheal tube placement, and a rescue device for failed airway management[59].

CLINICAL ASSESMENT & PHYSICAL EXAMINATION

With the patient in supine position, a general physical examination is performed. The head should be examined for lacerations and contusions and facial fractures should be ruled out by palpation. The ear canals should be inspected to rule out leakage of spinal fluid or blood behind the tympanic membrane, suggestive of a skull fracture. The spinous processes should be palpated from the upper cervical to the lumbosacral region. A painful spinous process may indicate a spinal injury. Careful and gentle rotation of the head may elicit pain; however, excessive flexion and extension of the neck should be avoided.

SURGICAL TREATMENT

Surgical treatment involves reduction, decompression and external / internal fixation or both. This can be grouped into operative and non-operative methods[28,60,61].

Indications for surgical intervention include:

1. Progression of neurological deficit.

2. In patients who have partial neurologic deficit but show no improvement,

3. Open injury from stabs or gunshot injuries.

4. Evidence of spinal instability.

Non-operative treatment

After initial medical stabilization and documentation of neurological function, spinal alignment can be obtained by:

Skull traction; this is through skull calipers, which come in many forms and types. Crutchfield 1938 is the oldest, as it is clumsy to insert and falls out easily. The most widely used and accepted is the spring-loaded Gardner-Wells tongs. This is despite the disadvantage of protruding widely from the side of the head and interfering with nursing. Once calipers are inserted, patient should be pain free. If pain persists, then slipping of the tongs on the scalp or infection should be ruled out. Weight to a maximum of 2.25 kg per each level below the occiput i.e. 13.6 kgs at C6 level is normally practiced.

Halo vest immobilization; the halo orthosis was first used by Perry and Nickels in 1959 for stabilization after cervical spine fusion in patients with poliomyelitis. Use of the halo vest has expanded considerably since then, and it is used in the treatment of many cervical spine injuries.

The halo is constructed of graphite or metal and is secured to the frontal and parietal areas of the skull with metal pins. The halo is the most common device applied for treatment of unstable cervical and upper thoracic fractures and dislocations as low as T3[62].

Operative treatment.

Decompression is done where bony fragments protrude into the spinal canal and thus resulting in narrowing and compression. It is also indicated in conditions where there is compression of a nerve root at the level of the neural canal.

Unstable injuries of the cervical spine, with or without neurological deficit, generally require operative treatment. In most patients early open reduction and internal fixation are indicated to maintain stability and allow a better functional rehabilitation. Cervical spine fractures may be stabilized by various approaches which include an anterior, a posterior, or a combined approach. This allows rapid mobilization of the patient in a cervical orthosis, and healing usually occurs within 8 to 12 weeks.

APPROACHES

There are three approaches: Anterior, posterior and combined both.

Anterior decompression and fusion, with or without internal fixation, are most often indicated for burst fractures of the cervical spine with documented compression of the neural elements by retropulsed bone or disc fragments and an incomplete neurological deficit[61].

For posterior ligamentous or bony instability, posterior stabilization with internal fixation and bone grafting are indicated.

Laminectomy as a posterior approach has a limited role in the treatment of cervical fractures or dislocations and may contribute to further clinical instability and neurological deficit.

Treatment of spinal cord injury

Patients with spinal cord injury are given glucocorticoids in acute settings and however, will require a long-term therapy using various important aspects such as nursing, psychotherapy, physiotherapy, occupational therapy, with the duration depending on the severity of the cord injury and therefore the prognosis of neurological recovery.

OUTCOMES

Prognostic indicators of outcome are based upon clinical symptoms, associated injuries, and radiographic findings, all of which help in outlining whether a spinal column injury is stable or unstable[63].

X-ray imaging background

Wilhelm Conrad Roentgen from Wurzburg in Germany, professor of physics coincidentally discovered the X-ray also known as the ‘new light ‘on 8 November 1895 while conducting experiments focusing on light phenomena and other emissions which was generated by discharging an electrical current in a highly-evacuated glass tube called *Crookes tube,* named after William Crookes, the British investigator[64].

To Roentgen’s wonder and he noticed that an object across the room began to glow when his cardboard-shrouded tube was charged. This object turned out to be a barium platinocyanide-coated screen, and whilst holding various materials between the tube and screen to test the new rays, Roentgen saw the bones of his hand clearly displayed in an outline of flesh[64].

Roentgen gave his preliminary report (‘Über eine neue Art von Strahlen’) to the Würzburg Physical–Medical Society, accompanied by experimental radiographs and by the image of his wife’s hand (bearing a ring on the right ring-finger). By New Year’s Day he had sent the printed report to physicists across Europe[64].

By the January of 1896, Roentgen was acclaimed as the discoverer of a medical miracle and was later awarded the first nobel prize in physics in 1901, upon which he donated the prize money to his university, declined to seek patents or proprietary claims on his discovery of the ‘new light’ with having many descriptions of his discovery and its applications[64].

By early 1896 the first angiography carried out with injection of mercury compounds at post-mortem by moving-picture X-rays and military radiology images were obtained[64].

The necessary apparatus was easily acquired. An evacuated glass tube (with anode and cathode), and a generator (coil or static machine), combined with photographic materials, could set anyone up in as a ‘‘skiagrapher’. Approximately 1 month later of Roentgens discovery, Hoffmans (physicist and high school director) and van Kleef (medical doctor) used this new technology to acquire images of human anatomy in Maastricht, the Netherlands[65].

Table 2. X-ray imaging evolution describing differences between 1986 and 2010 model[65].

January 1896	December 2010
Tube	
Evacuated glass bulb with some residual gas	High vacuum
Gas discharge generates free electrons and ions	Electrons come from heated filament
X-rays from glass wall surrounding anode	Anode is tungsten disk
X-ray focus is 10–100 cm^2	X-ray focus is approximately 1 mm^2
Permissible load of the order of watts	Permissible load of the order of kilowatts
No filtering of x-rays, except by glass wall	Typically ≥2.5-mm-thick aluminum filter
Exposure time of minutes to hours	Exposure time of milliseconds to seconds
High-Voltage Generator	
Battery and Ruhmkorff inductor	Main and medium-frequency generator
High voltage in the form of short spikes	High voltage that is nearly constant
Power consumption of 20 W	Power consumption up to 100 kW
High voltage estimated from spark length	High voltage measured electronically
Detector	
Screenless photographic plate	Flat panel detector/storage phosphor plate

Nikola Tesla (1856–1943) began his investigation of x-rays describing features of transmitted and reflected rays by teaching the practical purpose of the reflected x-rays was to improve the quality of the shadowgraph by increasing the object-film distance and decreasing exposure time. Tesla explained changes in x-ray characteristics as being caused by variations in x-ray tubes and electrical generators[66].

He correctly realized that strong shadows can be produced only at great object-film distances and with short exposure times. Moreover, he perceived that bulbs with thick walls produced rays with greater penetrating power, which was later explained by the longer deceleration of electrons on the thicker barrier[66].

Tesla was also among the first to comment on the biologic hazards of working with unipolar X-ray tubes, attributing the harmful effects on the skin to the ozone and the nitrous acid generated by the rays, rather than to the ionizing effects (at that time still unknown and unnamed) in 1894[66].

CT IMAGING: BACKGROUND

There has been a significant improvement in the field of medical imaging in both the technologic and clinical areas following the discovery of X-ray in 1895 by Wilhelm Conrad Roentgen, a German Physicist. Innovations in technology are a norm in the Radiology Department, with introduction of new ideas and methods and refinements in existing techniques happening continuously. One such evolution is the invention of computed tomography (CT).

The first idea of a computed tomography machine was conceived by Sir Godfrey Hounsfield in 1967 and the first patient was scanned for brain cyst in 1971[67].

Sir Godfrey Hounsfield, an electronic engineer working at the Central Research Laboratories of EMI in England commenced work on image reconstruction in 1968. His original apparatus consisted of a collimated isotope source mounted on a lathe bed. The objects examined were phantoms contained within a ten-inch water. The scan took nine days to complete because of the low intensity of the X-ray radiation source, and a further two and half hours to process the reading through a computer. The resulting image though of poor quality proved that the system worked. To provide sufficient intensity the equipment was modified by replacing the isotope with an industrial X-ray tube[67].

A prototype scanner was then developed and installed in Atkinson Morley Hospital in Wimbledon, England on 1st October 1971. The first patient scan was a 41 year old female with suspected frontal lobe tumor, the tumor was clearly demonstrated on the scan[68].

Hounsfield and Ambrose presented their paper on CT to the annual congress of the British Institute of Radiology on 20th April 1972 to great acclaim. The first CT papers, by these authors appeared in British Journal of Radiology in 1973. The invention of this technique resulted in the award of 1979 Nobel Prize in physiology and medicine to Sir G. N. Hounsfield, Central Research Lab., England (EMI), and A. N. Cormack of Physics Department, Tufts University, Massachusetts, U.S.A. Advanced Technological Developments.

Over the last ten years, four different generations of CT scan equipment were produced. The most important improvements have been in the reduction in the single image generation time from five minutes to 2.5 seconds in the third and fourth generations scanners and an increase in spatial resolution and contrast[67]. The introduction of second generation CT scanners further reduced the scan time from about six minutes to about two minutes. Late second generation CT scanners with $\geq$ 20 detectors further reduced scanning time to about $\leq$ 20 seconds. This dramatically improved quality of body scans, which could not be performed previously within a breath hold. The third generation scanners further reduced the scan time to 5 seconds or less, which has now further improved to about 0.33 seconds[68.]

Slip Ring Scanners

There was no significant improvement in CT technology following 4th generation CT scanners in late 1980’s. The only limitation at that time was interscan delays. Following one 3600 rotation, the cables connecting rotating components (x-ray tube and detectors) to the rest of the gantry required rotation to be stopped and reversed for next slice, all of which added time of scan.

All this changed with application of low-voltage slip rings. Slip rings provide electricity to the rotating components without fixed connections (Figure 11). Slip rings made it possible for continuous rotation, thereby reducing scan time. This technology also paved the way for introduction of spiral/helical CT scans[68].

In the mid-1980s, another high speed CT scanner was introduced, which was referred to as the Electron Beam CT (EBCT) scanner used for imaging cardiovascular system. In 1989, Dr. Willi Kalender introduced volume scanning by using spiral / helical CT scanners. In spiral/helical CT Scanners, a thin X-ray beam traces a path around the patient and scans a volume of the tissue. Recently, dual slice spiral /helical CT scanner and multislice CT scanners were introduced which mainly increase the speed and volume of scan. Volume CT scanning has resulted in a wide range of applications such as CT fluoroscopy, CT angiography, 3D Imaging and virtual reality imaging[67].

Figure 14. Slip-ring technology in Siemens Somatom Emotion CT scanner.

RADIATION DOSE OPTIMIZATION

All CT scanners have a gantry, an x-ray source, and an array of detectors. On passage through the body part, the incident beam is attenuated in a manner dependent on the local tissue composition (greater attenuation for bones, lesser for soft tissues)[69].

Principle of ALARA

As low as reasonably achievable (ALARA) is a concept designated for ensuring that any radiological investigation should use optimal radiation dose to provide images, which are adequate for diagnosis and treatment. This is possible by identifying imaging parameters and protocols, which can provide clinically required information while maintaining radiation doses as low as possible[70].

FACTORS THAT INFLUENCE RADIATION DOSE FROM CT

In general, there are some factors that have a direct influence on radiation dose, such as the x-ray beam energy (kilovolt peak), tube current (in milliampere), rotation or exposure time, section thickness, object thickness or attenuation, pitch and/or spacing, dose reduction techniques such as tube current variation or modulation, and distance from the x-ray tube to isocenter[69]. The principles of ALARA suggest that the right radiation dose should be given to the right patient and a one-size-fits-all approach should be abandoned. The various techniques through dose-optimization can be achieved is by using tube current modulation a.k.a. automated exposure control (AEC), use of lower tube potential and use of advanced reconstructive techniques such as iterative reconstruction methods[70].

Beam Energy

Tube potential (peak voltage) determines the incident x-ray beam energy, and therefore variation in tube potential substantially changes CT radiation dose. However, the effect of tube voltage on image quality is more complex as it affects both image noise and tissue contrast. It is important to note that decreased tube voltage is associated with a notable increase in image noise. Specially, this occurs if the patient is too large or the tube current is not appropriately increased to compensate for the lower tube voltage. The dose variation is approximately proportional to the square of the tube voltage change (i.e., square of the ratio of final and initial peak voltage), and the noise change is approximately inversely proportional to the tube voltage change [71].

However, it is essential that the relationship between reduction in tube voltage and reduction in radiation exposure be carefully evaluated owing to the complex relationship between tissue contrast, image noise and radiation dose depending on patient size. For example by reducing kVp from 140 kV to 120 kV in an abdominal CT a 20 to 40% reduction in radiation dose can be obtained. However, there is need for further research into this area so as to assess the feasibility of reduction in kV as part of dose reduction measures[69].

ESTIMATING EFFECTIVE DOSE FROM CT

The definition of effective dose was given earlier as the weighted sum of organ doses resulting from the examination, where the radiosensitive organs were defined along with their tissue-weighting factors. The effective doses for AP and lateral cervical radiographs are 0.12 and 0.02 mSv, respectively. Although it appears straightforward to estimate effective dose, it is actually difficult to accurately estimate the dose to an individual organ from a CT scan. This is even more difficult when attempting to estimate the effective dose for each patient when each one has unique characteristics of height, weight, age, gender, and composition. Many methods are in practice for calculating the effective dose[63].

One of the widely used methods to estimate the effective dose involves conversion factors for a general anatomic region as described by the European Guidelines on Quality Criteria for Computed Tomography, which are based on the work of Jessen et al. In this approach, the $CTDI_{vol}$ and distance are used to estimate the dose length product (DLP), which is then multiplied by a region-specific conversion factor to estimate the effective dose. These conversion factors range from 0.0059 mSv/mGy X cm for the neck region to 0.014 mSv/ mGy X cm for the chest region and 0.0021 mSv/ mGy X cm for the head. This approach obviously does not take into account any patient-specific or even examination-specific factors but provides an easily estimated value of effective dose[68]. The conversion factor for CT abdomen and pelvis is 0.0021 mSv/mGy cm[70].

The effective dose is calculated as product of DLP X f (conversion)[72].

RADIATION DOSES WITH CURRENT PROCEDURES

The concern with any studies evaluating efficacy of CT for evaluation of cervical spine injury is the risk of additional radiation. In fact one might argue for the need of additional radiation dose. To address this question, it is important to review the additional risk of radiation and how it fares with current CT studies and recommendations on limitations of radiation dose.

Additionally, the American Association of Physicists in Medicine (AAPM), a scientific body that ensures safety and quality in use of radiation in medical procedures has stated that "Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be non-existent. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged. These predictions are harmful because they lead to sensationalistic articles in the public media that cause some patients and parents to refuse medical imaging procedures, placing them at substantial risk by not receiving the clinical benefits of the prescribed procedures"[73].

Table 3. Average Radiation Exposure for Different Radiological Techniques

For this procedure:	*** Your approximate effective radiation dose is:**	**Comparable to natural background radiation for:**	****Additional lifetime risk of fatal cancer from examination:**
ABDOMINAL REGION:			
Computed Tomography (CT)-Abdomen and Pelvis	10 mSv	3 years	Low
Computed Tomography (CT)-Abdomen and Pelvis, repeated with and without contrast material	20 mSv	7 years	Moderate
Computed Tomography (CT)-Colonography	10 mSv	3 years	Low
Intravenous Pyelogram (IVP)	3 mSv	1 year	Low
Radiography (X-ray)-Lower GI Tract	8 mSv	3 years	Low
Radiography (X-ray)-Upper GI Tract	6 mSv	2 years	Low
BONE:			
Radiography (X-ray)-Spine	1.5 mSv	6 months	Very Low
Radiography (X-ray)-Extremity	0.001 mSv	3 hours	Negligible
CENTRAL NERVOUS SYSTEM:			
Computed Tomography (CT)-Head	2 mSv	8 months	Very Low
Computed Tomography (CT)-Head. repeated with and without contrast material	4 mSv	16 months	Low
Computed Tomography (CT)-Spine	6 mSv	2 years	Low
CHEST:			
Computed Tomography (CT)-Chest	7 mSv	2 years	Low
Computed Tomography (CT)-Chest Low Dose	1.5 mSv	6 months	Very Low
Radiography-Chest	0.1 mSv	10 days	Minimal
HEART:			
Coronary Computed Tomography Angiography (CTA)	12 mSv	4 years	Low
Cardiac CT for Calcium Scoring	3 mSv	1 year	Low
NUCLEAR MEDICINE:			
Positron Emission Tomography - Computed Tomography (PET/CT)	25 mSv	8 years	Moderate
*The effective doses are typical values for an average-sized adult. The actual dose can vary substantially, depending on a person's size as well as on differences in imaging practices.			
**Legend			

Risk Level	Approximate additional risk of fatal cancer for an adult from examination:
Negligible:	less than 1 in 1,000,000
Minimal:	1 in 1,000,000 to 1 in 100,000
Very Low:	1 in 100,000 to 1 in 10,000
Low:	1 in 10,000 to 1 in 1000
Moderate:	1 in 1000 to 1 in 500
Note: These risk levels represent very small additions to the 1 in 5 chance we all have of dying from cancer.	

CLINICAL STUDIES

Head injuries with concurrent cervical spine fractures

In a single centre study including 228 significant blunt head trauma patients, 1.7 % of the patients with a significant blunt head trauma had CSI[24]. In a large study conducted by Fujii et al[7], National trauma databank 550,313 trauma cases, the incidence of CSI in TBI patients was 8.6%.

In a retrospective study of 406 patients in a trauma centre with head injuries, CSI occurred in only 1.2% of head injury patients. They also concluded that, in management of head trauma, cervical spine radiography was not efficacious and may not provide additional information in emergency conditions[74].

A study was conducted by Hasler et al., incidence of CSI in all trauma patients was 3.5%. They also stated that, patients having lowered GCS or systolic blood pressure, severe facial fractures, dangerous injury mechanism, male gender and/or \ age $\geq$35 years have an increased risk for CSI. The study concluded that head injury was not an independent predictor of CSI[75].

A study was conducted by Hills et al in blunt trauma patients, CSI occurred in 4.5% of HI patients. It was concluded from the study that, patients with clinically significant head injury were at a higher risk for CSI. In patients with a GCS $\leq$ 8 were at even higher risk (7.8%) of sustaining CSI[76].

In a retrospective study conducted by Holly et al[22]. including 447 moderate-severe head injury patients, incidence of CSI in head trauma patients was 5.4%. GCS ≤ 8 or patients who sustain injury from motor vehicle accidents were included as the risk factors for CSI.

Michael et al.[77] conducted a study in 359 patients with head injury, CSI was seen in 6% of head injured patients. Coincidence of head injury and CSI in comatose patients was found to be 2.4%. They concluded that all severely head injured patients should be treated as having concomitant CSI until proven otherwise.

In a review article by Milby et al[78]. including 281,864 trauma patients, cervical spine injury was seen in 3.7% of all trauma patients and in 7.7% of unevaluable patients (those include, distracting painful injury, intoxication or associated HI).

In a. prospective study conducted by Soicher et al[79] in 260 patients who had significant head injury, CSI was seen in 3.5% of patients.

Mulligan et al.[80] conducted a study in 1.3 million trauma patients and found that CSI occurred in 7.0 % of head injuries.

In a prospective study conducted by Tian et al[23]. in 1,026 comatose TBI patients, CSI incidence in comatose TBI patients was 6.9%. They concluded that patients with a lower GCS, motorcycle accident as the mechanism of injury and patients with a skull base fracture had a raised risk for CSI.

A study was conducted by Vahldiek et al[81]. in 3 centres with 1,342 minor blunt trauma patients. He found that there was no significant association between HI and CSI. However, one patient had combined significant craniocervical injury.

Williams et al[82]. conducted a retrospective study; he found that CSI occurred in 4.8% of head injury patients.

Plain radiographs versus CT

A retrospective study was conducted including the NEXUS cohort comprised of 34,069 blunt trauma patients aged 1 month to 101 years from 21 United States centres. This trial reviewed this database to determine the frequency and types of cervical injuries missed by plain radiography. Of the total 34,069 patients enrolled, 818 (2.4%) patients had at least one cervical spine injury. Sensitivity of plain radiographs in identifying at least one injury was (60.1%) 498 patients. CT or magnetic resonance imaging (MRI) was used to diagnose missed injuries by plain radiographs[33].

In a prospective observational study including 1511 consecutive trauma patients done in 2005, Patients with average age and Glasgow Coma Scale score (GCS) of 35.4 years and 13.2, respectively were included; C-spine injuries were seen in 9% (60 injuries). They reported that CT was 100% sensitive and 99.5% specific. Whereas, plain radiographs had a sensitivity of 45.0% and specificity of 97.4%[20].

In a study of 1199 blunt trauma patients who failed the NEXUS criteria, had subsequent three view C-spine radiographs and CT. The mean GCS was 13 and 116 (9.5%) patients had C-spine injury. CT identified all 116 injuries with 100% sensitivity and radiographs identified 75 injuries with 65% sensitivity. Surgical management was needed in thirteen of the 41 injuries, which were missed by radiography[37].

In 1505 included patients, the average age of the patient was 37 years, and most were victims of motor vehicle accidents (40%). 5.2% patients sustained C-spine injuries. C-spine CT had sensitivity of 100% in detecting all clinically significant injuries, whereas C-spine radiographs had a sensitivity of 36% in detecting clinically significant injuries. They also classified that sensitivity of radiographs for cervical spine injuries in high-, moderate-, and low-risk patients was 46%, 37%, and 25% (1/4 injuries), respectively[83].

MATERIALS AND METHODS

Source of data:

Patients with TBI referred for CT to the Department of Radio-Diagnosis at R. L. Jalappa Hospital and Research Centre attached to SDUMC, Kolar were taken up for the study.

An informed consent was taken from individuals/ attenders for their willingness to participate in the study.

Study design: Prospective cross sectional study.

They were included in the study if they meet the inclusion/exclusion criteria.

The study was conducted over a period of 18 months from January 2016 to June 2017.

Inclusion Criteria:

1. All patients with moderate to severe traumatic brain injury (GCS <12).

Exclusion Criteria:

1. Cervical spine pathologies
2. Previous history of cervical spine injury/ surgery.
3. Age less than 18 yrs.
4. Pregnancy

Method of data collection

This study was approved by the institutional review board and informed consent was taken from all the individuals prior to inclusion in the study.

Details of the mode of injury and time of head injury were recorded. Demographic indices such as age and sex were noted. Note of evidence of intoxication if any was also noted. Severity of the head injury using the Glasgow coma scale on arrival at the casualty department was noted.

Any traumatic brain injury with GCS score of 9–12 was considered moderate head injury and traumatic brain injury with GCS score of ≤8 was classified as severe head injury. Neurological status was noted and physical neck examination where feasible was undertaken.

A total of 1845 patients with age > 18 years had TBI. Out of these, 1368 patients had a GCS score of ≥ 12 and were therefore excluded from the study. Of the remaining 477 patients, 367 patients (pregnancy, technically unsatisfactory images, having previous history of cervical spine injury, cervical spine pathology and history of surgery) were excluded. 28 patients did not give consent to the study. Fifteen patients died before investigations were completed.

A total of 67 patients with blunt head trauma were evaluated.

All 67 patients satisfying the inclusion criteria underwent the cervical spine X-rays which include two views: anteroposterior view revealing the spinous processes of the second cervical through the first thoracic vertebra and the lateral view revealing the base of the occiput to the upper border of the first thoracic vertebrae.

Followed by NCCT scan (SIEMENS® SOMATOM EMOTION® 16) from occiput to T1 vertebra as an extension of the head CT scan as a combined screening and diagnostic imaging modality for cervical trauma.

MRI of cervical spine was performed in patients whose plain radiographs and CT scans were poorly visualized or when they were normal, but the patient had a neurologic deficit that might have been caused by spinal cord or nerve root injury.

CT Protocol

The following were the parameters for CT brain and CT CS protocol. CT scan was performed using 16-slice Siemens® machine using the following parameters

CT parameters used are:-

- Axial sections of 3 mm thickness.
- Kilovolt peak: 130 kV
- Tube current: Calculated by the CT machine based on the CARE4D® protocol
- Pitch: 1.0
- Collimation: 3 mm
- Tube tilt: 15 degrees.

Volume rendering and reconstructions (sagittal and coronal reconstructions with post study reconstructions done at 0.75 mm) using bone algorithms were used when necessary. All patients were assessed for the presence or absence of fractures, type of cervical trauma and associated findings. The radiation dose was noted based on DLP and CTDI for all the CT scans.

Figure 15. SIEMENS® SOMATOM EMOTION 16® CT scanner used in the study.

Calculation of Effective Dose from CT:

The effective dose was calculated as product of DLP X f (conversion factor). The CT scanner provided the DLP data. The conversion factor for CT head is 0.0021 mSv/mGy cm. Hence the effective dose was calculated using Microsoft Excel® based on the following formula:

Effective dose (in mSv) = DLP (in mGy cm) X* 0.0021 *mSv/mGy cm.

The risk of performing additional sequences for CT CS is the increased radiation dose. This theoretical risk has been addressed by the American Association of Physicists in Medicine (AAPM) statement[10], which states "Risks of medical imaging at effective doses below 50 mSV (milli Sievert) for single procedures or 100 mSV for multiple procedures over short time periods are too low to be detectable and may be non-existent."

Based on the current evidence it can be stated with reasonable confidence that the current study design involving additional radiation exposure with CT CS procedure is 1.74 mSv which would not cause any additional health risk to study participants. Currently the CT brain protocol includes the upper two cervical vertebrae. Thus, CT CS when combined with CT brain would mean scanning of five more vertebrae. Hence, our study does not pose any significant increased radiation risk to the patient.

Image Assessment

Two experienced radiologists reviewed the X-ray and CT scan. The radiologists were blinded to the other investigation modality and they assessed the studies independently. Each study was evaluated by both the radiologists in random order and the results were compared. The radiologists evaluated the studies with respect to number of fractures, the cervical level involved and stability of the fractures independently in each datasets.

Statistical Analysis

Data was recorded into Microsoft® Excel® and was analyzed using OpenEpi® software. All the data were presented as mean ± SD. Sensitivity and specificity for each modality was compared with results obtained. A *P* value of <.05 was considered as statistically significant.

RESULTS

A total of 1845 patients of age > 18 years with TBI referred for CT brain. Out of these, 1368 patients had a GCS score of ≥ 12 and were therefore excluded from the study. Of the remaining 477 patients, 28 patients did not give consent for the study. Therefore 449 patients were considered for the study. Among these patients, 367 patients either one or more of following: history of pregnancy (n=33), history of cervical spine pathology {arthritis, spondylosis, spondylolysis, malignancy, metastases)} (n = 195), past history of penetrating neck trauma, cervical spine fractures/ surgery (n = 139) were excluded. Fifteen patients died before the investigation was complete. Finally, a total of 67 patients with blunt trauma head trauma were evaluated.

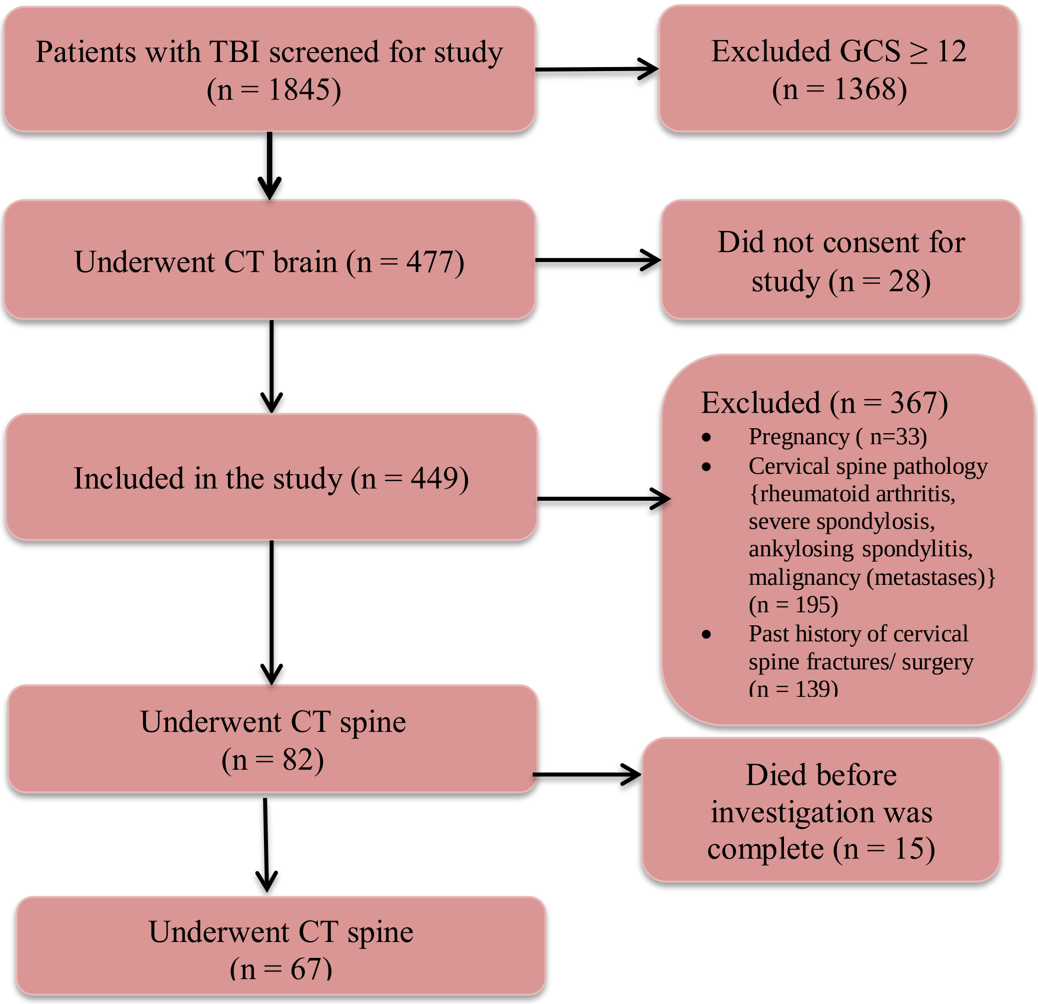

Figure 16. Study design.

Age distribution of patients with TBI

The age range for head injuries was 18 years to 72 years with a mean age of 39 years. A higher incidence of 35.8 % was noted in age groups 18-30 and 31-45 each. The older age group ≥ 46 had a lower incidence of 28.4 %(Figure 17).

Table 4. Age distribution of patients with TBI

Age group	No of patients	Percentage
18-30	24	35.8
31-45	24	35.8
46-70	19	28.4
Total	67	100.0

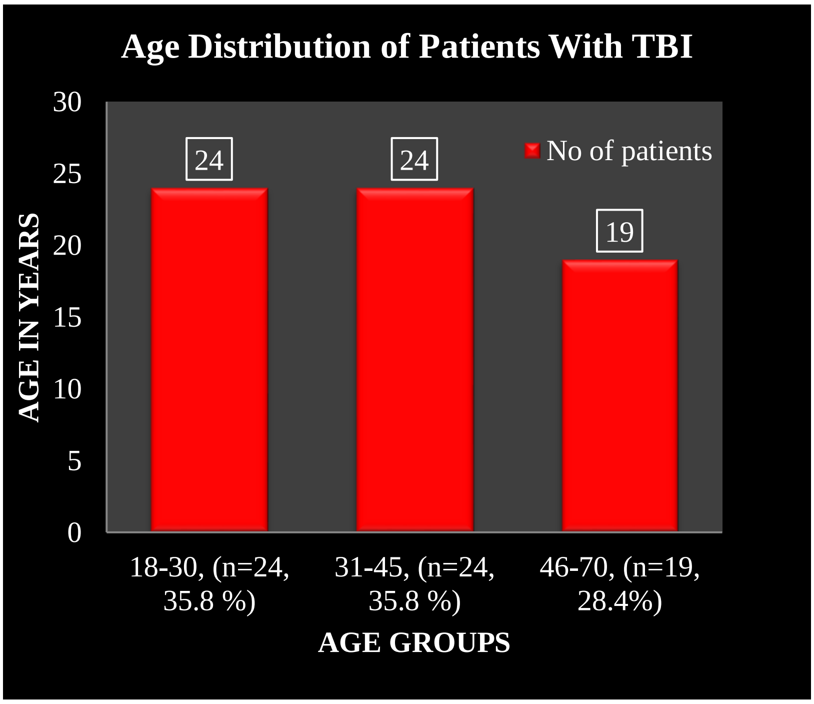

Figure 17. Age distribution of patients with TBI.

Gender distribution of patients with TBI

Of the sixty seven patients with head injuries, fifty five patients (82.1 %) were male (Figure 18).

Table 5. Gender distribution of patients with TBI

Gender	No of patients	Percentage
Males, (n=55)	55	82.09
Females, (n=12)	12	17.9
Total	67	100

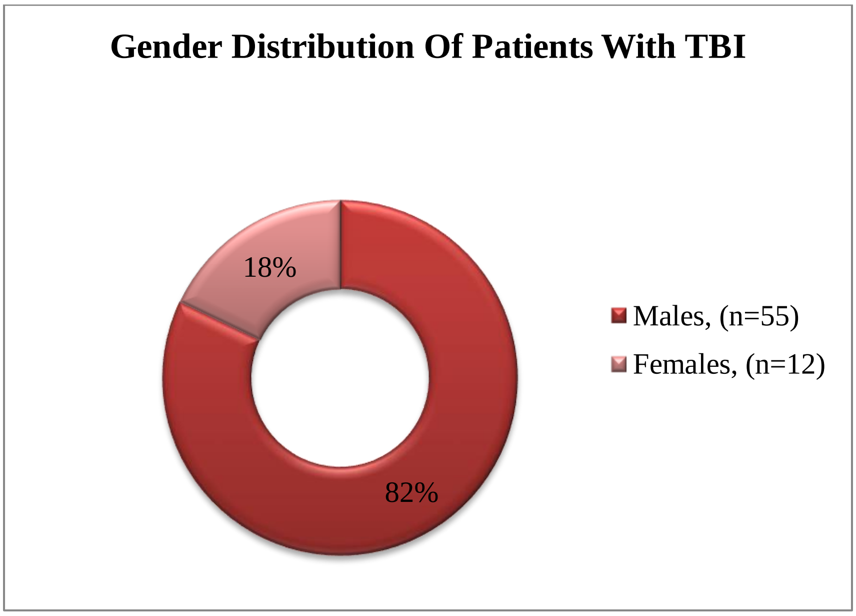

Figure 18. Gender distribution of patients with TBI.

Mode of head injury

Of the sixty seven patients, fifty seven patients (85%) with head injury were secondary to road traffic injury and of the remaining ten patients (15%) were secondary to self-fall (Figure 19).

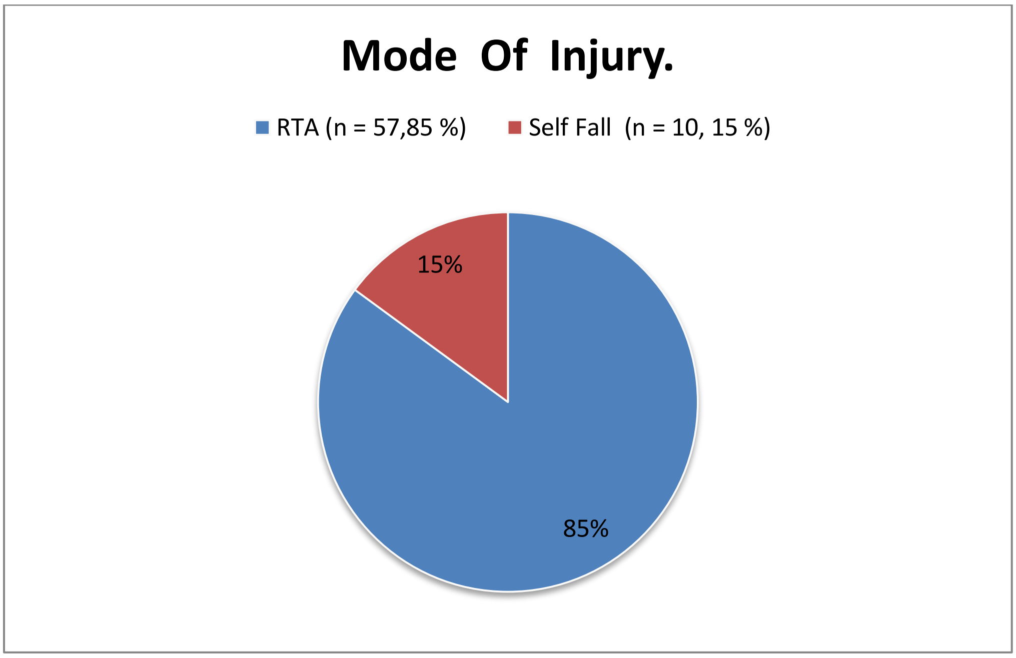

Figure 19. Distribution of patients based on mode of head injury.

Frequency of cervical spine injury in patients with TBI

The total number of patients with head injury patients was 67. Of these twenty (29.9 %) were found to have cervical spine injury.

Table 6. Frequency of cervical spine injury in patients with TBI

Incidence of cervical spine injury	No patients	Percentage
Cervical spine fracture present (n = 20)	20	29.9
No cervical spine fracture (n = 47)	47	70.1

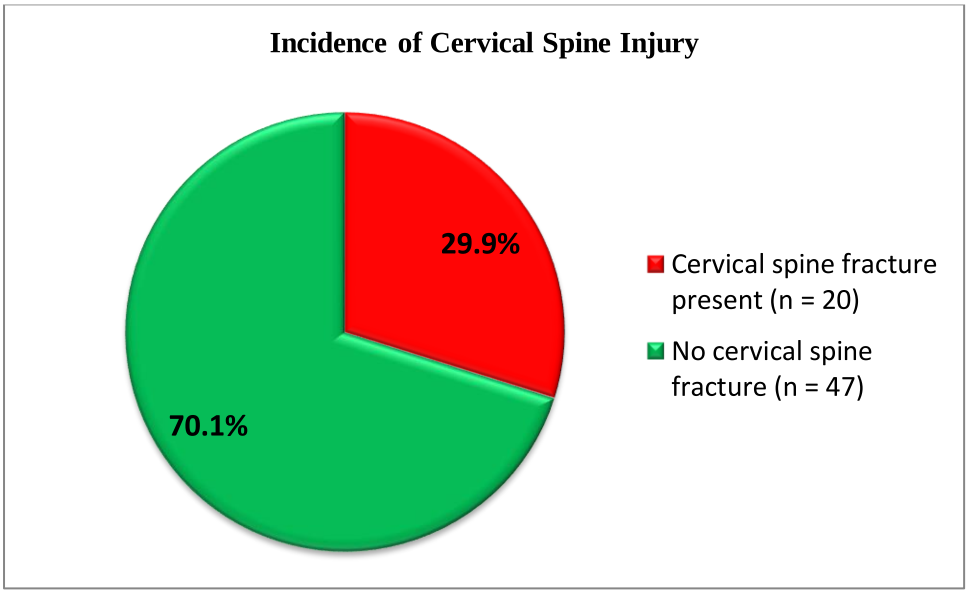

Figure 20. Frequency of cervical spine injury in patients with TBI.

Age & gender distribution of patients with cervical spine injuries.

Of the twenty patients with cervical spine injury, seventeen (85 %) were male and five (15 %) were female.

Both younger 18-30 and middle 30-45(40 %) age had equal higher incidence compared to older 45-70(20 %) age group.

Table 7. Age & gender distribution of patients with cervical spine injuries.

Age group	Total	Male (n =17); 85%	Female (n =3); 15%
18-30 (40 %)	8	6	2
30-45(40 %)	8	7	1
45-70(20 %)	3	3	0

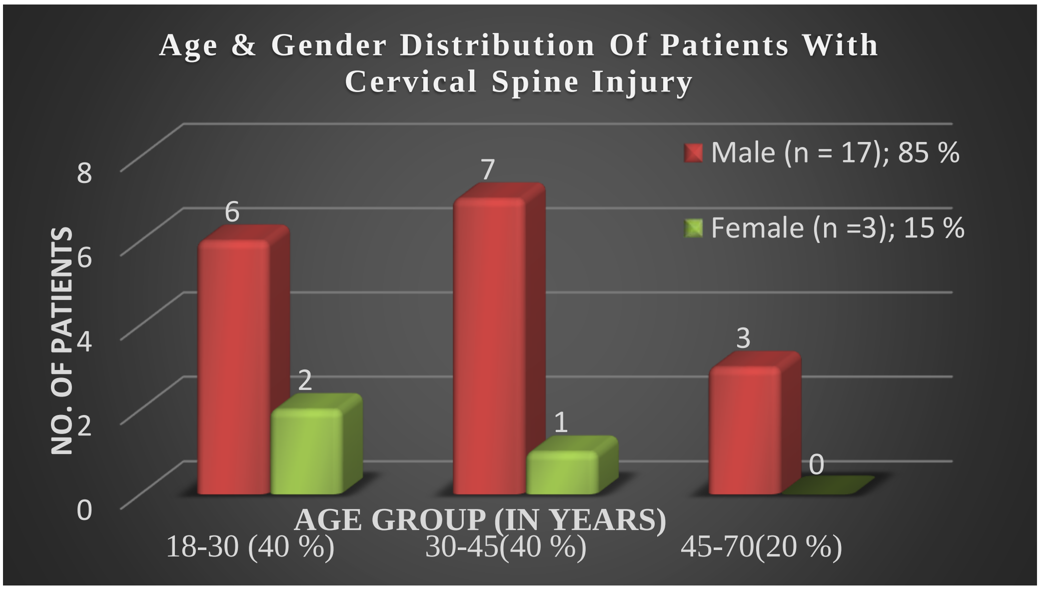

Figure 21. Age & gender distribution of patients with cervical spine injuries.

Severity of head injury (GCS score) and cervical spine injury

Of the sixty seven patients with head injury, 26 (38 %) had moderate head injury and 41 (61 %) had severe head injury.

The risk of cervical spine fracture in patients with moderate TBI was 26.9% (7 of 26 patients) and in patients with severe TBI was 31.7% (13 of 41 patients), which was not statistically significant (P = .35; NS). This suggests that irrespective of moderate or severe head injury, the risk of cervical spine fracture remains high.

It is therefore important that cervical spine evaluation should be performed in both moderate and severe head injury.

Table 8. Severity of head injury (GCS score) and cervical spine injury

		Cervical spine injury		
		Present	Absent	Total
GCS SCORE	MODERATE	7	19	26
	SEVERE	13	28	41
	TOTAL	20	47	

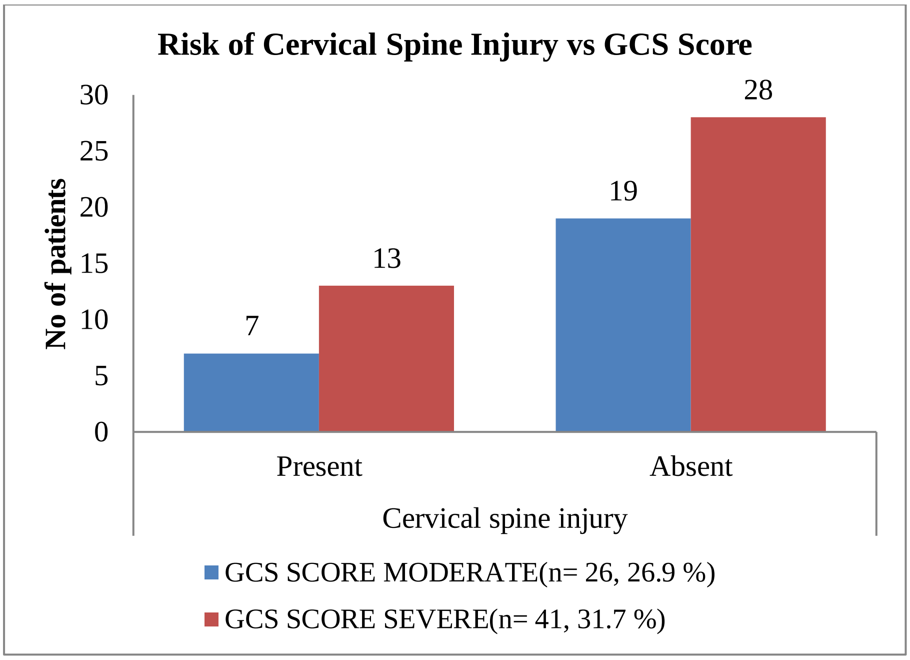

Figure 22. Severity of head injury (GCS score) and cervical spine injury

Patients with fractures detected on CT and x-ray

Out of 67 patients, 20 patients sustained cervical spine injury.

Fractures were detected in twenty patients by CT, of which 6 (30%) patients with fractures were detected by X-ray.

Table 9. Patients with fractures detected on CT and x-ray

Study	Patients	Percentage
Fractures seen on CT (n = 20; 100%)	20	100
Fractures seen on X-ray (n = 6; 30%)	6	30

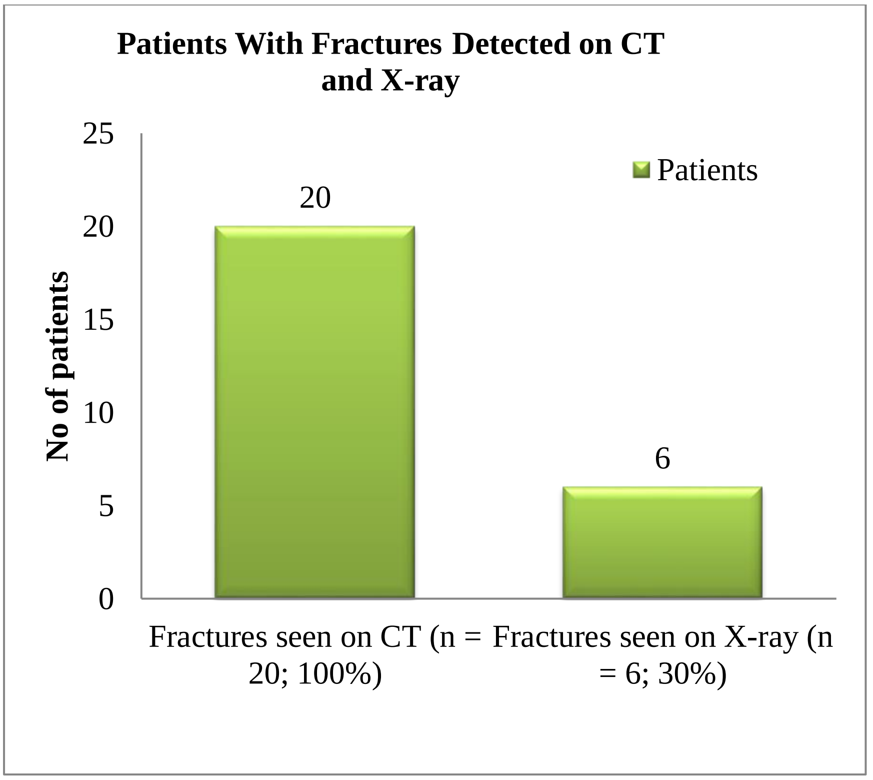

Figure 23. Patients with fractures detected on CT and x-ray

Correlation between X-ray and CT findings

Of the 67 patients with head injury, 50 patients (74.6 %) had same findings on X-ray and CT. CT detected findings in seventeen patients (25.4 %) which X- ray could not detect, X-ray did not detect any additional finding which was missed by CT.

Table 10. Correlation between X-ray and CT findings

X-ray and CT correlation	Number of patients	Percentage
Findings same on X-ray and CT	50	74.6
Findings seen on CT, not seen in X-ray	17	25.4
Findings seen on X-ray, not seen in CT	0	0.0

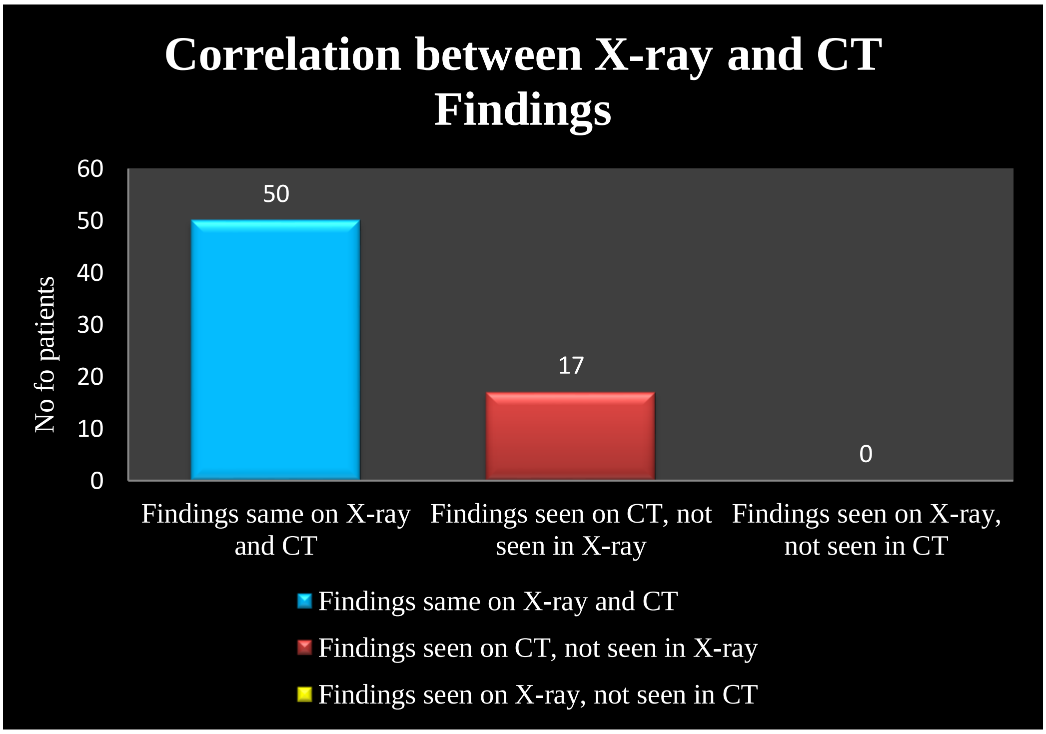

Figure 24. Correlation between X-ray and CT findings

Percentage correlation of X-ray findings with CT findings at each cervical level.

Table 11. Distribution of fractures at each cervical level which as seen on X-rays and CT.

Cervical level	X-rays	CT	Seen on CT; missed on X-rays	Seen on X-ray; missed on CT	Correlation
C1	1	3	2	0	33.3
C2	2	5	3	0	40.0
C3	1	2	1	0	50.0
C4	0	2	2	0	0.0
C5	1	4	3	0	25.0
C6	2	8	6	0	25.0
C7	0	13	13	0	0.0
Total	7	37	30	0	18.9

As seen in column 3, there were 30 fractures additionally documented in CT cervical spine, but were not visualized on X-rays. None of the X-ray finding was missed on CT. At C1, only 1/3rd of fractures were detected on X-rays. Similarly at C2, 40% of cases were detected, at C3 it was 50% and at C5 and C6 levels only 25% of fractures were detected in X-rays.

At C4 and C7 levels, none of the fractures were detected on X-ray. Overall, the correlation of X-ray findings with respect to CT for detection of cervical spine fractures remained abysmally low at 18.9%.

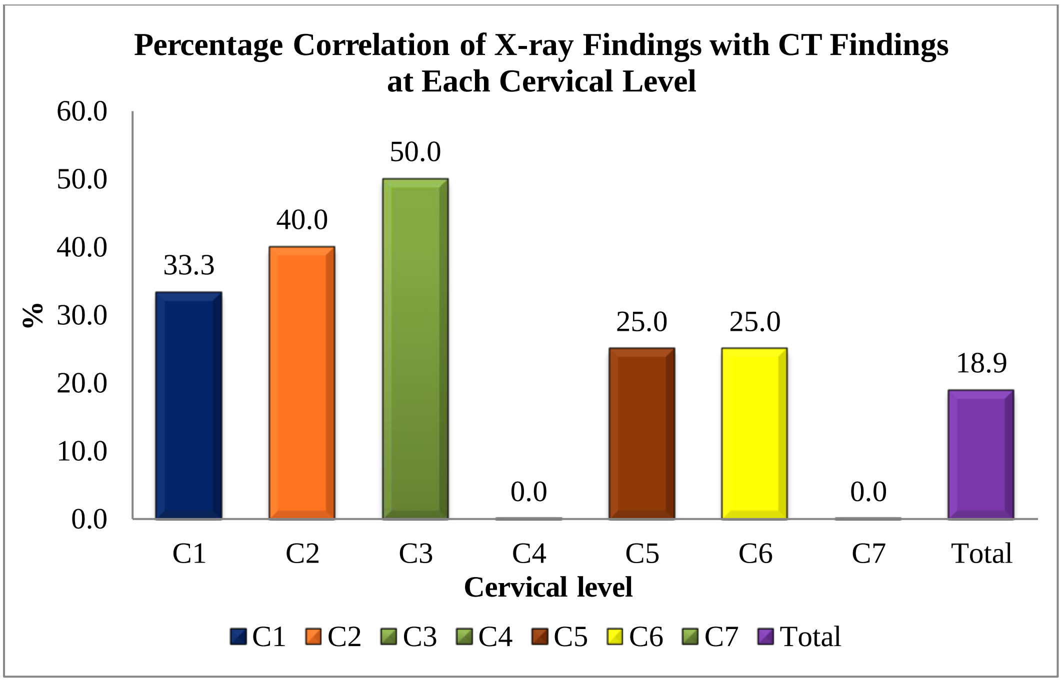

Figure 25. Percentage correlation of X-ray findings with CT findings at each cervical level.

Vertebral level of injury seen on CT and X-rays

Majority of the injuries were at seven cervical vertebra (C7), followed by sixth (C6) and second (C2) vertebrae. Four patients out of the nineteen had injury at C5; three had injury at C1, two each at level C3 and C4.

Nine patients had injuries at more than one level.

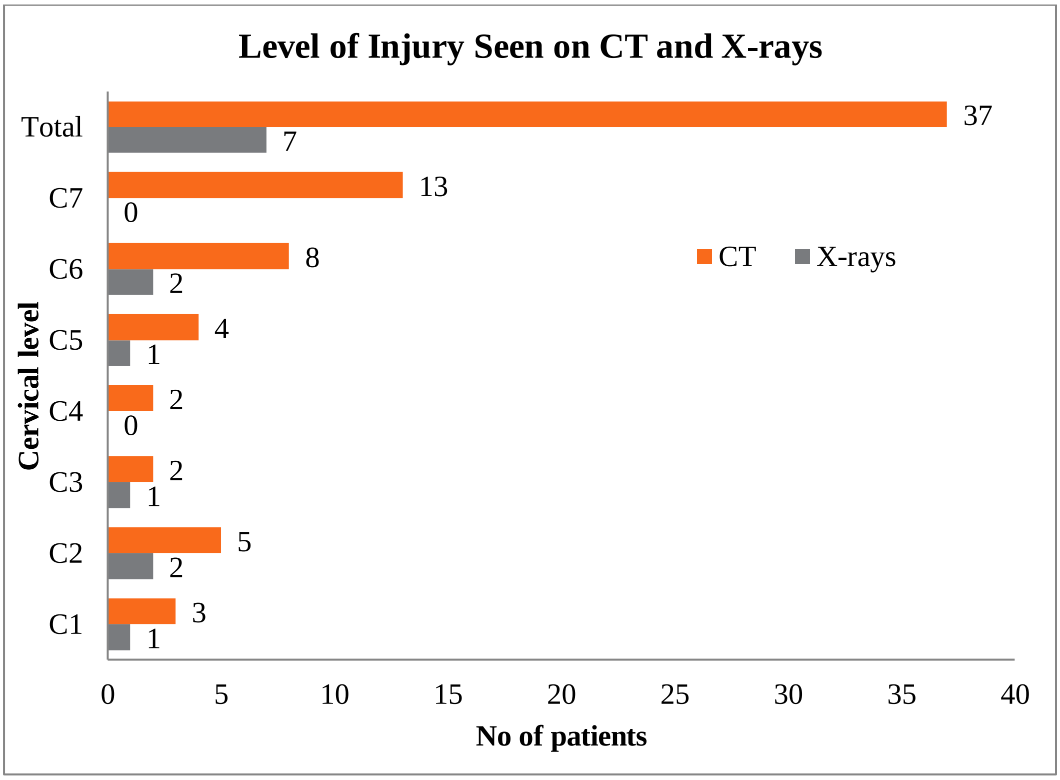

Figure 26. Vertebral level of injury seen on CT and X-rays.

Stable fracture versus unstable fracture

Of 20 patients, 10 patients had stable (50%) and unstable (50%) fractures each detected on CT, whereas X-ray could detect 4 stable, 2 unstable fractures and misdiagnosed 8 unstable fractures as stable which require management.

Table 12. Distribution of patients with stable fracture and unstable fracture.

Type of fracture	X-ray	CT
Stable fracture	4	10
Unstable fracture	2	10

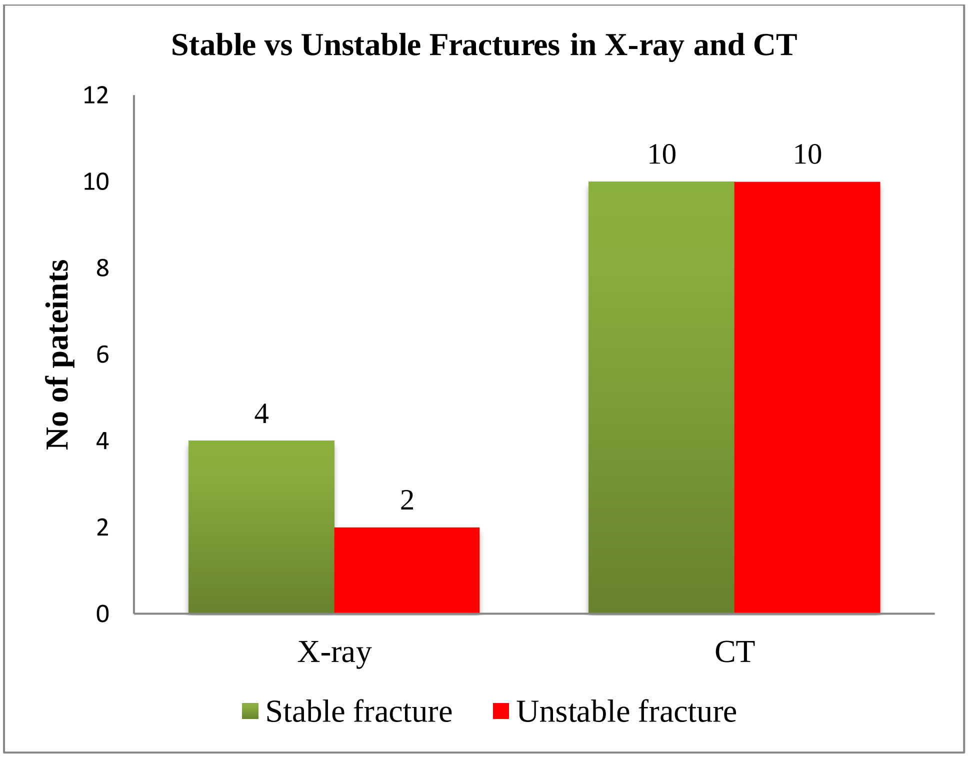

Figure 27. Distribution of patients with stable fracture and unstable fracture.

Diagnostic accuracy of plain X-ray in diagnosis of cervical spine fracture, keeping CT as gold standard.

Table 13. Diagnostic accuracy of plain X-ray in diagnosis of cervical spine fracture, keeping CT as gold standard.

Estimated value (95% CI)	X-RAY
Sensitivity	23.07 %
Specificity	95.12%
Positive predictive value	75 %
Negative predictive value	66 %

Although X-ray has a good specificity but had lower sensitivity, positive and negative predictive value. This shows limited utility of X-rays over CT.

MRI findings in patients with cervical spine injury

Out of 20 patients with cervical spine injury, 4 patients had neurological deficit attributable to cord injury and underwent MRI has the further investigation modality suspecting spinal cord / nerve root abnormality. MRI revealed cord compression in one patient and cord/nerve injury in three patients. Of the three patients, two patients had preganglionic and one patient had post-ganglionic brachial plexus injury.

Treatment offered for cervical spine injury.

Of the twenty patients, 12 patients (60 %) received hard cervical collars as definitive management and 8 patients (40%) had operative management which includes pedicle screw fixation followed by cervical collar for 4-6 weeks.

Table 14. Management of patients with cervical spine injury.

Management	No of patients	Percentage
Non-operative (n = 12)	12	60
Operative (n = 8)	8	40.0
Total	20	100

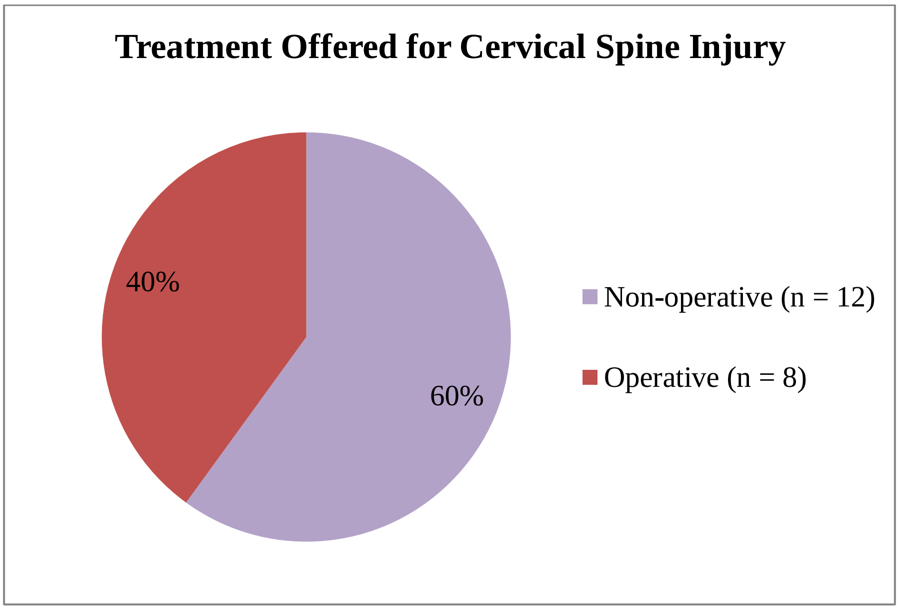

Figure 28. Treatment offered for cervical spine injury.

Average CT dose calculated.

Table 15. Total CT dose calculation.

CT study	Dose received (mSv)	
	Mean	SD
Brain	2.10	0.28309
C-spine	1.74	0.27921
Combined	3.84	0.39805

The average dose received for brain CT is 2.10 ± 0.28 mSv (mean± SD). Performing CT cervical spine would result in an additional dose of 1.74 ±0.27 mSv (mean± SD). Therefore performing CT brain and cervical spine would result in a combined dose of 3.84 ± 0.398 mSv (mean± SD), which is less than the threshold suggested by AAPM.

IMAGES

Figure 29. X-ray AP view of cervical spine of a 40 year old man with history of TBI following RTA, fracture of transverse process of C7 on right side is seen.

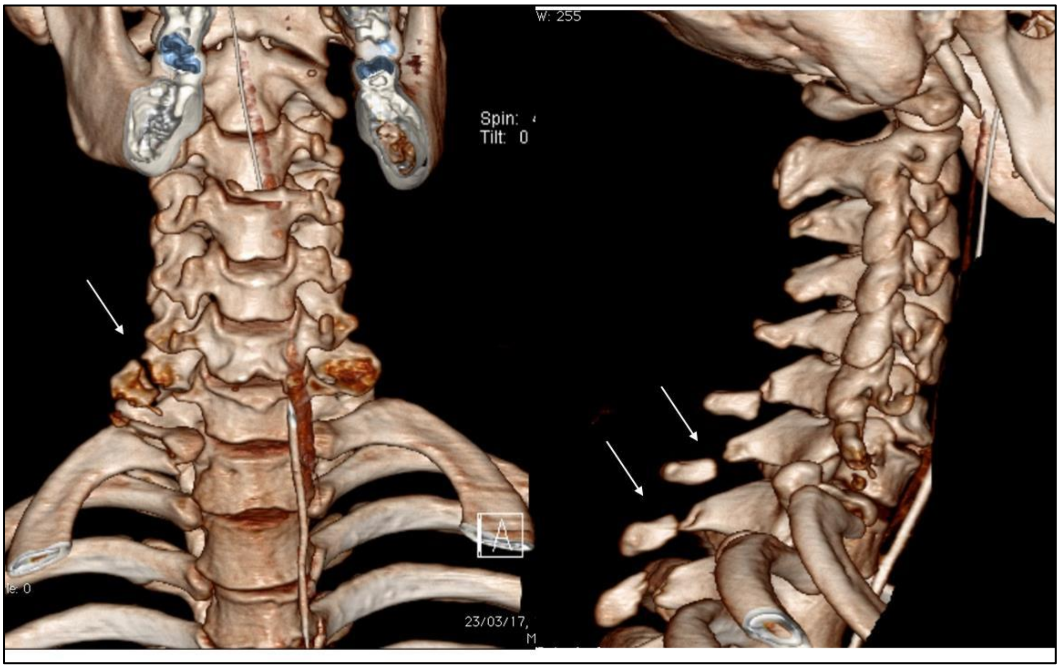

Figure 30. Volume rendered image of same image in coronal and sagittal reconstruction shows fracture of right transverse process and fracture of spinous process of C6, C7, T1 & T2. On follow up this patient had right sided upper limb weakness which he underwent MRI, which revealed post ganglionic injury of brachial plexus.

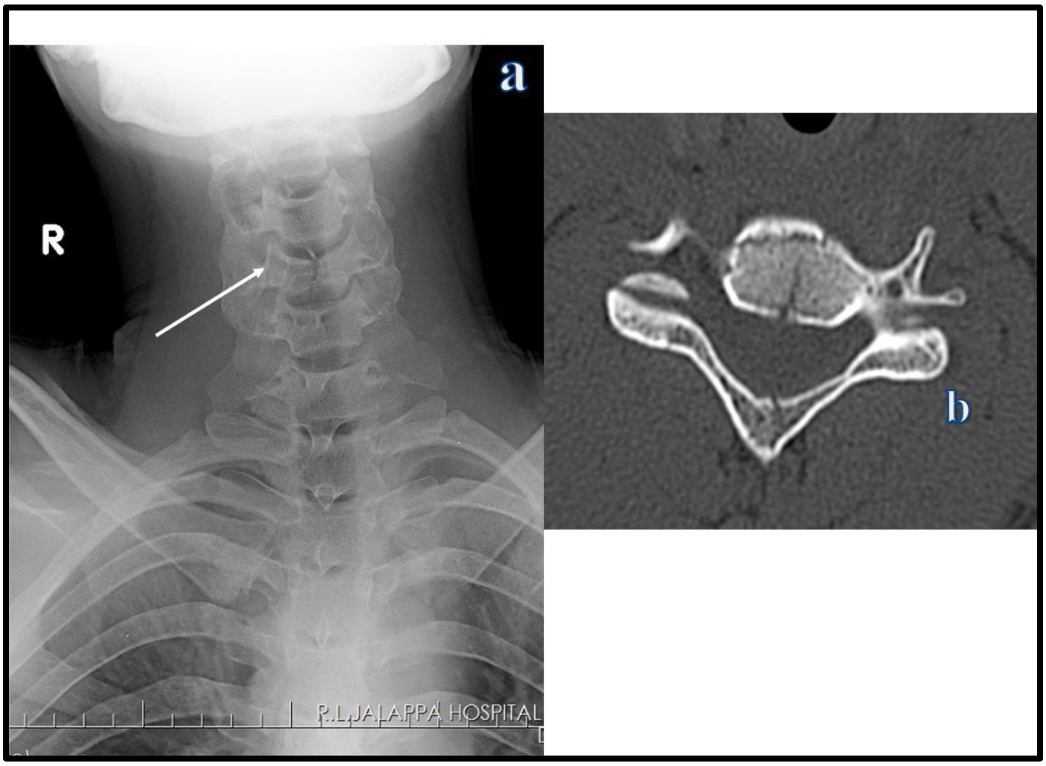

Figure 31 (a & b). X-ray AP view and CT axial section of cervical spine of a 20 year old male patient who sustained head injury following a RTA. X-ray showed reduced vertebral height and fracture involving body of C5 vertebra. CT showed fracture involving anterior and posterior elements making it an unstable fracture.

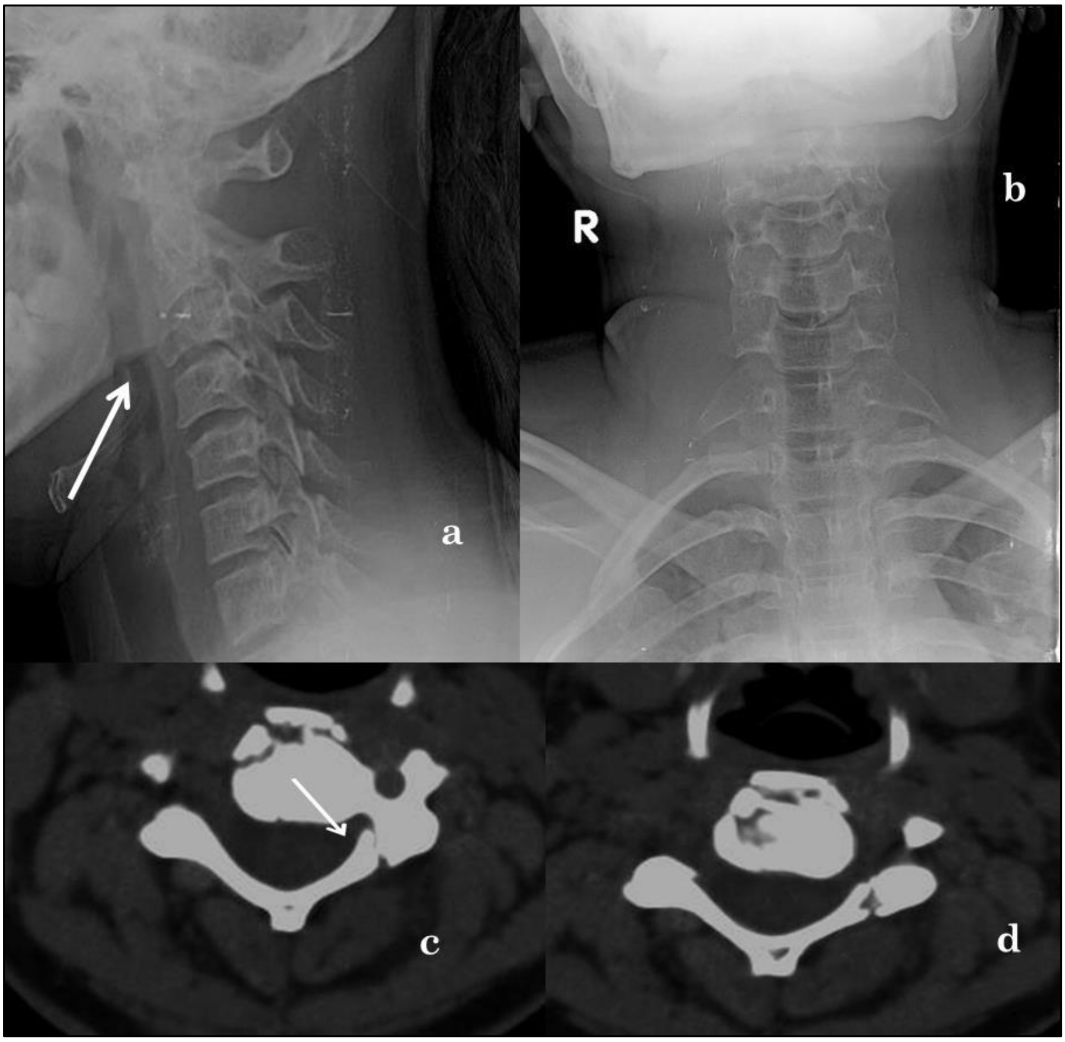

Figure 32 (a & b), X-ray AP and lateral view of 19 year old female who had come with history of RTA, X-ray lateral view reveals cervical straightening and reduced vertebral height suggestive of a wedge compression fracture of body of C3 vertebra and subtle findings on AP view. c & d, CT axial section of cervical spine showing fracture of anterior body and posterior left pedicle fracture with mild displacement.

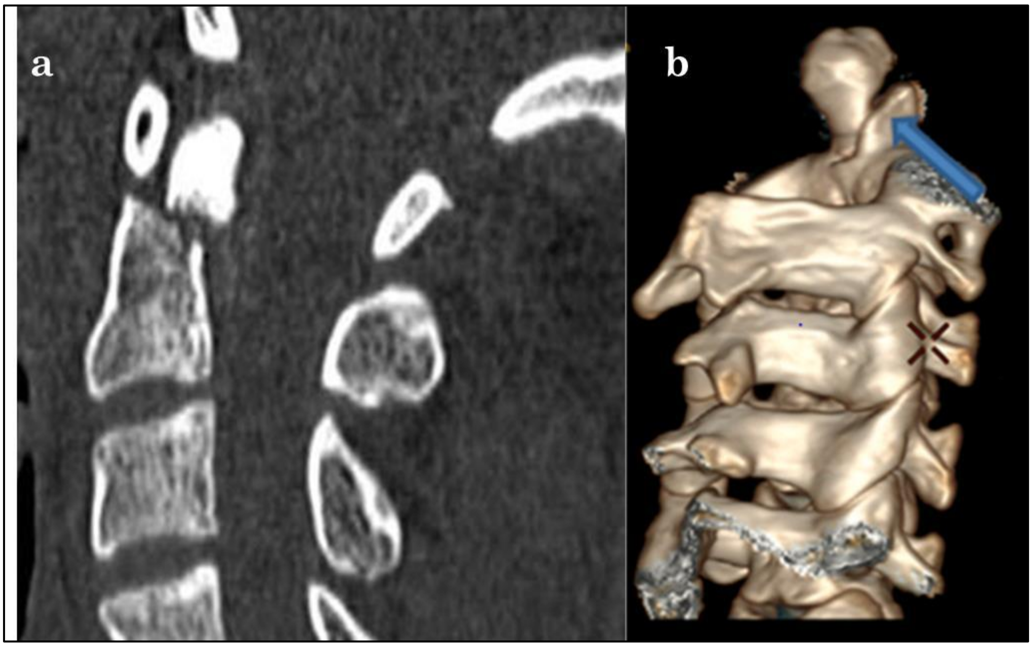

Figure 33. CT sagittal reformatted image of cervical spine bone window and volume rendered oblique image of a 28 year old male patient who had GCS score of 2 after sustaining TBI in RTA showed type II fracture of odontoid process of C2 vertebra (Anderson & Alonso classification) with backward displacement of fracture fragment. This patient on follow up underwent operative management of pedicle screw fixation and later with cervical collar for 4-5 weeks.

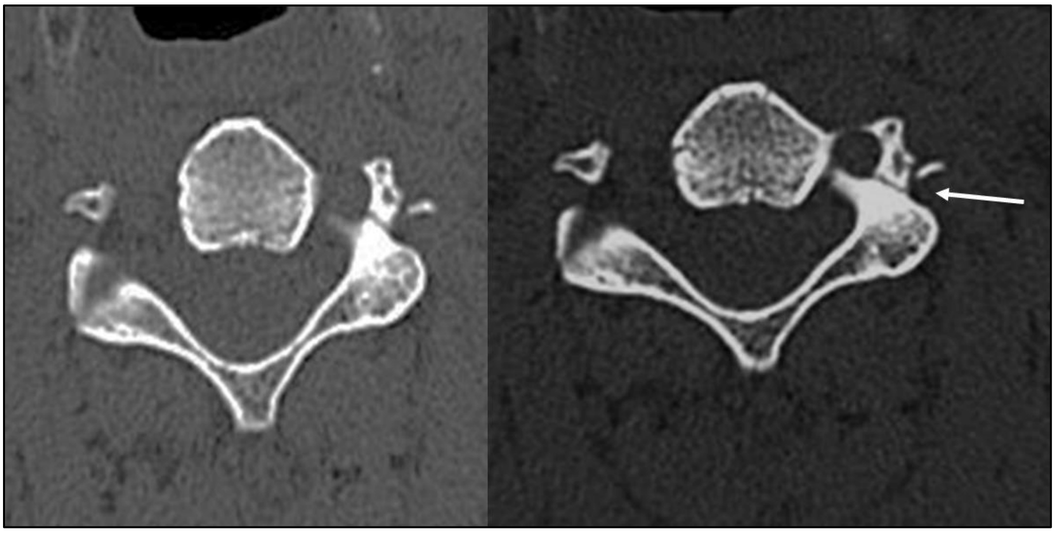

Figure 34. CT axial sections at the level of C6 cervical vertebra bone window, showing linear fracture of left transverse process (white arrow) and also mild extension into foramen transversarium which may result in vertebral artery injury. This fracture was missed on X-ray.

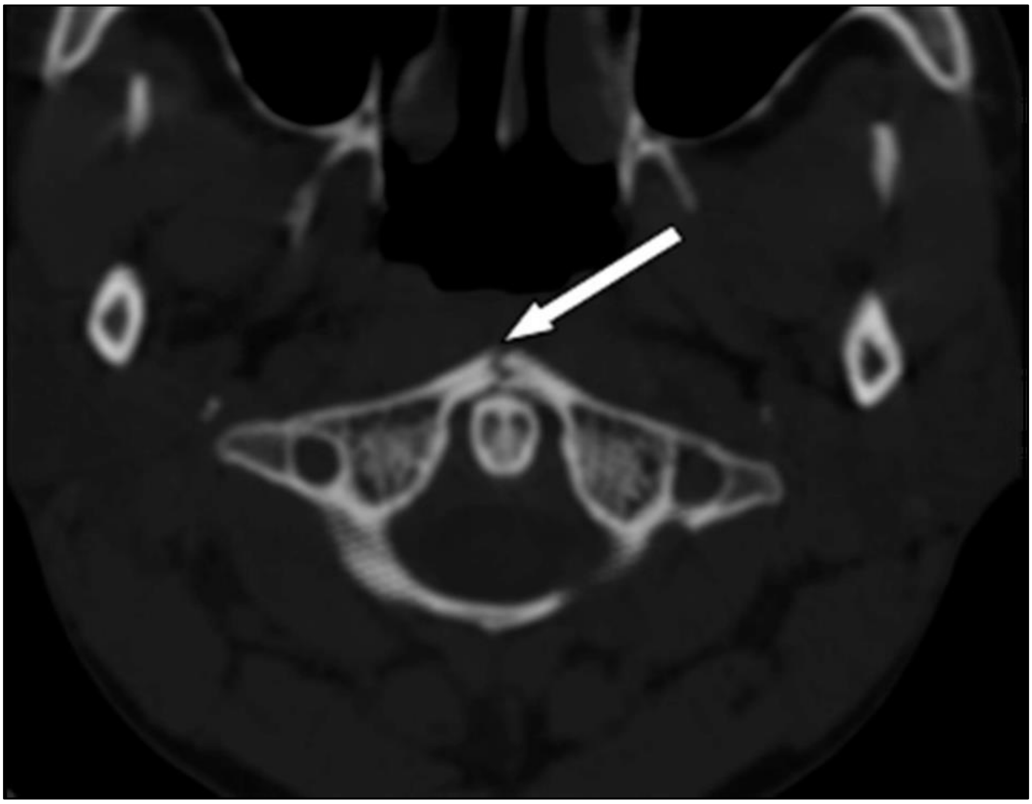

Figure 35. CT scan axial section bone window of 30 year old male who fell from a height and presented to our hospital in a state of altered consciousness. CT showed a linear undisplaced fracture involving anterior arch of the Atlas vertebra (white arrow).

DISCUSSION

Initially X-rays were considered the investigational method of choice for cervical spine clearance in setting of trauma. After the advent of computed tomography scans with improved quality and availability, it is started to replace cervical spine radiography[84].

In our study of 67 patients, 20 patients sustained cervical spine injury. Thirty seven fractures (100%) were detected in twenty patients by CT, of which only six (30%) patients with fractures were detected by X-ray. Most of the fractures missed by X-rays were in lower cervical spine.

It is known that X-rays may not be optimal in evaluating injuries at crucial levels such as the occipitocervical and cervicothoracic junctions due to obvious anatomic considerations and it may not be possible to obtain an appropriate image in the emergency setting[36,85,86].

Diagnostic accuracy of plain X-ray in diagnosis of cervical spine fracture, keeping CT as gold standard

In our study we correlated findings between X-ray and CT. Of 67 patients with head injury, 50 patients (74.6 %) had same findings on X-ray and CT.

CT detected findings in seventeen patients (25.4 %) which X- ray could not detect, X-ray did not detect any additional finding which was missed by CT.

In our study of 67 patients with TBI, the sensitivity, specificity, positive predictive value and negative predictive value of X-ray with CT as gold standard was 23.07 %, 95.12%, 75 % and 66 % respectively. This showed that although X-ray has a good specificity but had lower sensitivity, positive and negative predictive value indicating limited utility of X-rays over CT. Our results are also similar to findings reported in other studies.

A retrospective study was conducted including the NEXUS cohort comprised of 34,069 blunt trauma patients which showed that sensitivity of plain radiographs in identifying at least one injury was 60.1% (n = 498)[33]. However, an another study including 1505 patients, C-spine radiographs had a sensitivity of 36% in detecting clinically significant injuries. The sensitivity of radiographs for cervical spine injuries in high-, moderate-, and low-risk patients was 46%, 37%, and 25% (1/4 injuries), respectively[83].

A prospective observational study including 1511 trauma patients with average age and Glasgow coma scale score (GCS) of 35.4 years and 13.2 showed that when compared to CT, plain radiographs had a sensitivity of 45.0% and specificity of 97.4%[20].

In a recent study, of the 19 fractures seen on CT, only 6 were identified on plain radiography. In almost all of these patients, CCT was done only to achieve anatomic completion, not to look for possible fractures. As a result of a combination of anatomic inadequacy, fracture subtlety, or radiographic misinterpretation, 68.4% of fractures from C3 to T1 were missed on plain radiography. However the specificity and negative predictive value of plain CSR were 99.2% and 96.7%, respectively, these impressive percentages were not because by the accuracy of the modality but due to the low incidence of cervical spine fractures in the study population. The authors concluded that low sensitivity of 31.6% of plain radiographs to identify such clinically important injuries is unacceptable[85].

Similarly, Woodring and Lee in their study of 216 patients showed that 61% of fractures seen on CT scan were missed by plain x-rays. They concluded that plain radiography may be insufficient and insensitive to identify cervical spine fractures in trauma patients when compared with CT[34].

Epidemiology

Road traffic accidents contribute to 2.1% of global mortality, of which India accounts for 10% of road traffic accidents deaths. Road traffic death rate in India is estimated to be 16.8/100000 population[87,88]. Acute head injury is a common cause of admissions in emergency department, and failure to detect CSI, especially in patients with a decreased level of consciousness can lead to catastrophic consequences[89]. The prevalence of cervical spine injuries is increasing which may be due to increasing awareness and modifications in diagnostic tools[90]. Cervical spine injury can be a cause of lifelong disability[91,92].

CSI is one of the major causes of morbidity and mortality following blunt trauma. Clearance for CSI constitutes a vital part of management of acute trauma[86]. However, contradiction in past literature makes it very confusing for health care professional to choose the most appropriate clearance plan in managing these injuries[93]. Inadequate evaluation can result in late diagnosis and treatment in a third of CSI patients. Early identification of injuries can reduce neurological damage and facilitate functional recovery[94].

Patients with blunt injury often do not present with cervical spine injury due to associated distracting injuries. These make cervical cord injury clearance difficult in an emergency setting. Although failure to diagnose CSI may result in complications such as paralysis, death or pain, there are no clear recommendations regarding the radiological evaluation of cervical spine[95].

Incidence of CSI in moderate to severe TBI

In our study the incidence of CSI in patients with moderate-to-severe brain injury was found to be 29.8 % (n = 20). The incidence of CSI in western hemisphere is variable ranging from 2 to 10%; however, there is inadequate data on incidence of CSI in India[83,85,96,97].

Michael et al. conducted a study in 359 patients with head injury, where CSI was seen in 6% of head injured patients. Coincidence of head injury and CSI in comatose patients was found to be 2.4%.

They concluded that all severely head injured patients should be treated as having concomitant CSI until proven otherwise[77].

In a review by Milby et al. involving 281,864 trauma patients, cervical spine injury was seen in 3.7% of all trauma patients and in 7.7% of unevaluable patients (those include, distracting painful injury, intoxication or associated head injury)[78].

Severity of head trauma

In the present study the incidence of cervical spine injury was 26.9 % in moderate head injury and 31.7 % in severe head injury. Although there was a numerical increase in incidence of CSI with severe head injury the difference did not reach statistical significance (Chi-square analysis P = 0.35). This suggests that patients with moderate head injury as almost as likely as patients with severe head injury to undergo CSI.

Our study results are similar to data from literature; however, in other studies, severe TBI was found to be significant indicator for TBI. In a study by Holly LT et al. in 447 patients with moderate to severe head injury, they found that patients with Glasgow coma scale less than 8 were more likely to be associated with cervical spine injury[22]. A similar association was also reported by Hills et al. in a four year prospective study in 1269 patients with head injury[76].

A study was conducted by Hasler et al., incidence of CSI in all trauma patients was 3.5%. They also stated that, patients having lowered GCS or systolic blood pressure, severe facial fractures, dangerous injury mechanism, male gender and/or age ≥35 years have an increased risk for CSI[75].

In a prospective study conducted by Tian et al. in 1,026 comatose TBI patients, CSI incidence in comatose TBI patients was 6.9% with a raised risk for CSI in patients with a lower GCS, motorcycle accident as the mechanism of injury and patients with a skull base fracture[23].

Gender distribution

In our study males constituted 82% of population (n = 55) and 18% were females. Of the 20 patients with head injury 85 % (n = 17) were males and remaining 15 % (n = 3) were female, with a male: female ratio of 5.6:1. There was a slightly higher incidence of CSI among males when compared with females (30.9% and 25% respectively).

Our results are similar to those by reported by Hills et al who reported a similar male preponderance of CSI (78%) in their study[76].

Age distribution

In the present study most cervical spine injuries occurred in the age group of 18-30 years and 31-45 years (35.8 %) with a mean age of 39 years. Our results are comparable to findings reported by other authors[1,75].

Mode of injury

In our study road traffic accidents constituted a majority of cases of trauma (85 %; n = 57) and remaining 15% was due to self-fall (n = 10). This suggests a higher incidence in road traffic accidents as a cause of cervical spine injury compared to falls. However, when the incidence of CSI was observed, 15 patients with RTA had CSI (26.3%) and 50% of patients with self-fall (n = 5 of 10) had CSI. These findings were also seen in other studies with a similar distribution.

For example, in a study done in Kenya, 57% were secondary to road traffic accidents, 31% secondary to assaults, 5% from falls from height. This showed a little variance with our study as our study did not contain assault cases[98].

The cause of TBI may be affected by the areas where the studies are conducted. Our study was performed at a place which is in close proximity to a highway and therefore has a high burden of RTAs. However, in few studies, which were conducted near hilly regions, fall was the common mode of injury[4,89].

Thesleff et al in their study reported falls as commonest cause of injury in about half of patients (47.8%; n = 521) followed by car accidents 22.4% (n = 244) [89]. A similar observation was made by Nazir et al, who also reported that falls were the cause of TBI in half of their patients (51%) followed by RTAs (21%), assault 14%and other minor causes are 14%. It was also observed that RTA is a predominant cause of head injury in adults, whereas fall is the commonest cause among children less than 10 years[4].

Level of injury

There were a total of 37 cervical spine fractures detected. 30 fractures were additionally documented in CT cervical spine, but were not visualized on X-rays. None of the X-ray finding was missed on CT. At C1, only 1/3rd of fractures were detected on X-rays. Similarly at C2, 40% of cases were detected, at C3 it was 50% and at C5 and C6 levels only 25% of fractures were detected in X-rays.

At C4 and C7 levels, none of the fractures were detected on X-ray. Overall, the correlation of X-ray findings with respect to CT for detection of cervical spine fractures remained abysmally low at 18.9%.

This indicated that majority of the cervical spine injuries in the present study occurred in the lower cervical spine and were poorly visualized on X-ray due to improper positioning as patient were intoxicated and associated with polytrauma.

This was in concordance with findings reported by a similar study in Kenya by Njoroge PK, who observed the most of the cervical spine fractures were seen in lower cervical spine (78%) between the 4^{th} to 6^{th} cervical vertebrae with the majority (42% of the total) at fifth cervical vertebrae. Only 21% occurred in the upper cervical spine (occiput to second cervical vertebrae) with the majority at the second cervical vertebrae (15% of the total)[98].

In a study by Shrago et al including 50 patients with cervical spine injury found that 56% of patients with head trauma had injury at upper cervical level and 44% lower cervical level[28].

Number of fractures detected.

In our study of 67 patients with moderate to severe TBI, 20 patients sustained cervical spine injury and 37 fractures were detected in twenty patients by CT.

Our study results are similar to findings reported by Thesleff et al., who in their study of 72 patients with cervical spine injury, reported 101 fractured vertebrae. Furthermore, he concluded that head trauma patients with acute intracranial lesions on CT have a higher risk for cervical spine fractures in comparison to patients with a CT-negative head injury, a finding which suggests that patients with moderate-to-severe TBI are more likely to have cervical spine injury[89].

MRI & Neurological deficit

In our study of the twenty patients with cervical spine injury 4 patients (20%) had neurological deficit and underwent MRI to rule out spinal cord / nerve root abnormality. MRI revealed cord compression in one patient and of the remaining three patients, two patients had preganglionic and one patient had post ganglionic brachial plexus injury.

This was also noted in study in Nairobi, where of the nineteen patients with cervical injuries one male patient aged 65-year old was having neurological deficit with findings consistent with central cord injury[98].

Magnetic resonance imaging is an effective choice of imaging in patients who have neurological deficit, when ligamentous or disc injury is suspected and when other modalities do not offer a conclusive diagnosis. It has a negative predictive value nearing 100%. However, its positive predictive value is not adequate, and hence it is not indicated for initial cervical spine clearance[32,99].

Another study involving 180 obtunded blunt trauma patients with GCS<13 but no deficits where analyzed by CT followed by MRI. MRI detected acute abnormalities in 21% of CT negative results, but none were clinically significant. Therefore, unless indicated, MRI may not be initially indicated for cervical spine clearance[100].

Hogan et al compared MDCT and MRI in evaluating 366 obtunded blunt trauma patients and found the MDCT had a 98.9% negative predictive value for ligamentous injury and 100% negative predictive value for cervical instability. Only four patients with isolated ligamentous injury were identified on MRI that was CT negative[101].

Treatment

In our study of the twenty patients with CSI, 12 patients (60 %) received hard cervical collars as definitive management. And remaining 8 patients (40%) had operative management which includes pedicle screw fixation followed by cervical collar for 4-6 weeks.

Our management pattern was similar to data reported by Griffen et al., in their study in blunt trauma patients who failed the NEXUS criteria. They reported that 35.34 % were managed surgically[37].

Radiation doses with current CT procedures

The concern with any studies evaluating efficacy of CT for evaluation of cervical spine injury is the risk of additional radiation.

Additionally, the American Association of Physicists in Medicine (AAPM), a scientific body that ensures safety and quality in use of radiation in medical procedures has stated that "Risks of medical imaging at effective doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable and may be non-existent.

Based on the current evidence it can stated with reasonable confidence that the current study design involving additional radiation exposure with CT CS procedure is less than 1.74 mSv would not cause any additional health risk to study participants. Currently the CT brain protocol includes the upper two cervical vertebrae. Thus, CT CS when combined with CT brain would mean scanning of five more vertebrae. Hence, our study does not pose any significant increased radiation risk to the patient.

Limitations of the study

Our study has few limitations. In our study the sample size was limited to 67 patients, most of whom were patients with RTA and polytrauma. It is possible that the type of injury may also play a role in cervical spine injury. However, our study was not powered to evaluate this relationship due to lower incidence of other types of injury.

Similarly a close proximity to highway and higher risk of RTAs in our study may have skewed the age group and gender distribution. It is possible that these factors may also affect the risk of cervical spine injury. However, we could not assess the same.

CONCLUSION

We concluded that in patients with moderate-to-severe traumatic brain injury, there is a high risk of associated cervical spine fractures. It is prudent that when scanning for head injury in these patients, the evaluation be extended to include the cervical spine to rule out cervical spine fractures. This will help in early identification of cervical spine injury or rule out cervical spine injury and guide appropriate management. Furthermore, the lower accuracy of cervical spine radiography indicates that cervical spine radiography should be considered only if CT is unavailable.

SUMMARY

The risk of cervical spine injury in blunt cranial trauma patients is reported to be between 1% and 3% for all and up to 11.5% for high-risk patients. Delay in diagnosis or missed injuries may result in partial or full paralysis in up to 29% of injured patients. Computed tomography is an excellent method of screening trauma patients to confirm or exclude cervical spine fracture. The sensitivity of cervical spine CT is higher than that of radiography.

The study is a cross sectional prospective study was carried out on the pattern of cervical spine injury in patients with TBI. The objectives of the study are to study the incidence of cervical spine injuries in patients with moderate-to-severe TBI and to compare the sensitivity and specificity of cervical spine radiography with CT cervical spine in detecting cervical spine injury in patients with moderate-to-severe TBI.

A total of 1845 patients of age > 18 years with TBI referred for CT brain. Out of these, 1368 patients had a GCS score of ≥ 12 and were therefore excluded from the study. Of the remaining 477 patients, 28 patients did not give consent for the study. Therefore 449 patients were considered for the study. Among these patients, 367 patients either one or more of following: history of pregnancy (n=33), history of cervical spine pathology {arthritis, spondylosis, spondylolysis, malignancy, metastases)} (n = 195), past history of penetrating neck trauma, cervical spine fractures/ surgery (n = 139) were excluded.

Fifteen patients died before the investigation was complete. Finally, a total of 67 patients with blunt trauma head trauma were evaluated.

All 67 patients satisfying the inclusion criteria underwent the cervical spine X-rays including anteroposterior view and the lateral view followed by NCCT scan from occiput to T1 vertebra as an extension of the head CT scan and MRI of cervical spine was performed in patients when the patient suspecting spinal cord or nerve root injury.

The age range for head injuries was 18 years to 72 years with a mean age of 39 years. A higher incidence of 35.8 % was noted in age groups 18-30 and 31-45 each with male preponderance and RTA as the most common mode of injury. Of the 67 patients with head injury, twenty patients (29.9 %) were found to have cervical spine injury. The risk of cervical spine fracture in patients with moderate TBI was 26.9% (7 of 26 patients) and in patients with severe TBI was 31.7% (13 of 41 patients) suggesting that irrespective of moderate or severe head injury, the risk of cervical spine fracture remains high.

Fractures were detected in twenty patients by CT, of which 6 (30%) patients with fractures were detected by X-ray.

C7 is the most common site of vertebral level involved and simultaneous involvement of multiple vertebral levels was also noted.

The sensitivity, specificity, positive predictive value and negative predictive value of X-ray with CT as gold standard was 23.07 %, 95.12%, 75 % and 66 % respectively showing that although X-ray has a good specificity but had lower sensitivity, positive and negative predictive value. Of 20 patients, 10 patients had stable (50%) and unstable (50%) fractures each detected on CT, whereas X-ray could detect 4 stable, 2 unstable fractures and missed diagnosed 8 unstable fractures as stable which require management

The risk of cervical spine fracture in patients with moderate TBI was 26.9% and 31.7% in severe TBI patients, which was not statistically significant (P = .35; NS) suggesting that irrespective of moderate or severe head injury, the risk of cervical spine fracture remains high.

We concluded that patients with moderate-to-severe traumatic brain injury are at high risk of associated cervical spine fractures. The sensitivity of cervical spine CT is higher than that of radiography and by performing CT of the cervical spine at the time of head CT may allow a more rapid radiologic exclusion of cervical spine fracture than by performing conventional radiography. This will help in early identification of cervical spine injury or rule out cervical spine injury and guide appropriate management. Furthermore, the lower accuracy of cervical spine radiography indicates that cervical spine radiography should be considered only if CT is unavailable. Thus, Multidetector CT helps in initial screening for evaluating blunt C-spine trauma in patients who do not meet criteria for clinical clearance.

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ANNEXURE I

COMPUTED TOMOGRAPHIC EVALUATION OF CERVICAL SPINE IN TRAUMATIC BRAIN INJURY

PROFORMA

Demographic details:

Name:

Age:

Sex: ☐ **Male** ☐ **Female**

Mode of Injury:

RTA		
SELF FALL		

GCS: **Moderate (9-12):** ☐ **Severe (<8):** ☐

Clinical Diagnosis:

Findings:

Fracture seen:

Vertebral level	C1	C2	C3	C4	C5	C6	C7
X- ray							
CT							
STABLE							
UNSTABLE							

CT Radiation dose

Patient name	IP/OP	DLP	CTDI

Impression:

ANNEXURE II

INFORMED CONSENT FORM

Study Title: COMPUTED TOMOGRAPHIC EVALUATION OF CERVICAL SPINE IN PATIENTS WITH TRAUMATIC BRAIN INJURY.

Principal Investigator: Dr. Gowthami. M / Dr. Rachegowda. N

I, Mr/Miss/Mrs____, have been provided an opportunity to participate in research project titled "Computed tomographic evaluation of cervical spine in patients with traumatic brain injury." It has been communicated to me in my vernacular language that this study requires use of computed tomography (CT) imaging for brain and cervical spine. The standard-dose technique will be performed as per part of usual clinical care. An additional scan will be performed for cervical spine. Furthermore, I have been explained about the potential risks involved with radiation resulting from additional scans and that it is very negligible/ nonexistent.

The research investigators wish to assess the incidence of cervical spinal injuries and see if CT cervical spine has better sensitivity and specificity in detecting cervical spine injury when compared with radiograph c-spine in patients with moderate-to-severe head injury. If study results are positive, this study can help to consciously follow a CT protocol for traumatic brain injury patients.

I understand that the medical information produced by this study will become part of institutional record at Sri Devaraj Urs Medical College and will be kept confidential.

I understand that my participation is voluntary. I may refuse to participate or withdraw my consent and discontinue participation at any time without citing any reason whatsoever and without any prejudice to my present or future care at this institution.

I agree not to restrict the use of any data or results that arise from this study provided such a use is only for scientific purpose(s). I will not be paid any financial compensation for participating in this research project. I hereby give consent to participate in this research project.

Name and Signature/thumb impression.

Name and signature of third person (in case the participant is illiterate)

ANNEXURE III

PATIENT INFORMATION SHEET

Computed tomographic evaluation of cervical spine in patients with traumatic brain injury.

Principal Investigator: Dr. Gowthami.M/ Dr. Rachegowda. N

I, Dr. Gowthami.M, am a post-graduate student in Department of Radio-Diagnosis at Sri Devaraj Urs Medical College. I will be conducting a study titled "Computed tomographic evaluation of cervical spine in patients with traumatic brain injury" for my dissertation under the guidance of Dr. N. Rachegowda, Prof. and Head, Department of Radio-Diagnosis. In this study, we will assess the incidence of cervical spinal injuries and see if CT c-spine has better sensitivity and specificity in detecting cervical spine injury when compared with radiograph c-spine in patients with moderate-to-severe head injury. You would undergo CT scan of brain and an additional CT scan will be performed of CT cervical spine in the same setting for detection of traumatic brain injuries and cervical spinal injuries. There will be no additional expenses incurred by you for the additional scan as it is part of routine scan procedure. CT scan is associated with risk of x-ray exposure. Performing two scans will not cause any adverse health impact on you. If the study results are positive, it will help to reduce x-ray exposure for CT scan for patients with traumatic brain injury.

All of your personal data will be kept confidential and will be used only for research purpose by this institution. You are free to participate in the study. You can also withdraw from the study at any point of time without giving any reasons whatsoever. Your refusal to participate will not prejudice you to any present or future care at this institution

Name and Signature of the Principal Investigator   Date

ANNEXURE IV

ಮಾಹಿತಿಯುಕ್ತ ಸಮ್ಮತಿಯ ನಮೂನೆ

ನಾನು ರುಜುಮಾಡಿರುವ, ಈ ಅಧ್ಯಯನದಲ್ಲಿ ಭಾಗವಹಿಸಲು ಈ ಸಮ್ಮತಿಯ ರೂಪ ಅಂಶಗಳಂತೆ ನನ್ನ ವೈಯಕ್ತಿಕ ಮಾಹಿತಿಯ ಸಂಗ್ರಹಣೆ ಮತ್ತು ಬಹಿರಂಗಪಡಿಸುವಿಕೆಯ ಅಧಿಕೃತಗೊಳಿಸಲು ಒಪ್ಪುತ್ತೇನೆ.

ನಾನು ವಿಧಾನ ಮತ್ತು ಸಂಗ್ರಹಿಸಿ ಅಧ್ಯಯನ ಮಾಡುವ ಸಂದರ್ಭದಲ್ಲಿ ಬಹಿರಂಗಪಡಿಸಲಾಗುತ್ತದೆ ಮಾಹಿತಿಯನ್ನು ಗೌಪ್ಯ ಪ್ರಕೃತಿಯ ಅಪಾಯಗಳು ಮತ್ತು ಲಾಭಗಳ ಈ ಅಧ್ಯಯನದ ಉದ್ದೇಶ ಅರ್ಥ. ಸಂಗ್ರಹಿಸಿದ ಮಾಹಿತಿಯನ್ನು ಮಾತ್ರ ಸಂಶೋಧನೆಗೆ ಬಳಸಲಾಗುತ್ತದೆ.

ನಾನು ಈ ಅಧ್ಯಯನದಲ್ಲಿ ವಿವಿಧ ಅಂಶಗಳನ್ನು ಕುರಿತು ಪ್ರಶ್ನೆಗಳನ್ನು ಕೇಳಲು ಅವಕಾಶ ಹೊಂದಿದ್ದರು ಮತ್ತು ನನ್ನ ಪ್ರಶ್ನೆಗಳಿಗೆ ನನ್ನ ತೃಪ್ತಿ ಉತ್ತರಗಳನ್ನು ನೀಡಲಾಗಿದೆ.

ನಾನು ಯಾವುದೇ ಸಮಯದಲ್ಲಿ ಈ ಅಧ್ಯಯನದಿಂದ ಹಿಂಪಡೆಯಬಹುದು ಉಚಿತ ಉಳಿದು ಈ ನನ್ನ ಭವಿಷ್ಯದ ಕಾಳಜಿ ಬದಲಾಗುವುದಿಲ್ಲ ಎಂದು ಅರ್ಥ.

ಈ ಅಧ್ಯಯನದಲ್ಲಿ ಭಾಗವಹಿಸುವಿಕೆ ನನಗೆ ಯಾವುದೇ ಹೆಚ್ಚುವರಿ ವೆಚ್ಚವಿಲ್ಲದೆ ಒಳಗೊಳ್ಳುವುದಿಲ್ಲ.

ವಿಷಯದ ಹೆಸರು ಮತ್ತು ಅರ್ಜಿದಾರರ ಸಹಿ ದಿನಾಂಕ:

ಹೆಸರು ಮತ್ತು ಸಾಕ್ಷಿ ಸಹಿ: ದಿನಾಂಕ

ಹೆಸರು ಮತ್ತು ವ್ಯಕ್ತಿ ಪಡೆಯುವ ಒಪ್ಪಿಗೆ ಸಹಿ: ದಿನಾಂಕ

ANNEXURE V

Key to master chart

C= Conservative;

CS= Cervical Spine;

CT = Computed tomography;

F = Female;

FP= False Positive;

M = Male;

mAs = milli Ampere second;

mGy = milliGray;

mSv = milli Sievert;

N= No/ Absent;

NA= Not Applicable;

No.= Number;

O=Operative;

RTA= Road Traffic Accident;

S*= Suspicious;

S= Stable;

SF= Self Fall;

US= Unstable;

Y = Yes/Present;

sl.no	CT dose (mSv)			Age (in years)	Trial ID	Sex	GCS score	Mode of injury	X-ray										CT										Management	Follow up (in days)
	Head	CS	Total						Fracture	No involved	Vertebral level							Stable/Unstable	Fracture	No involved	Vertebral level							Stable/Unstable		
											C1	C2	C3	C4	C5	C6	C 7				C1	C2	C 3	C 4	C 5	C 6	C7			
1	2.11	1.39	3.50	19	16669	F	7	RTA	Y	1	N	N	Y	N	N	N	N	S	Y	2	N	N	Y	N	Y	N	N	US	O	5
2	2.50	1.44	3.94	29	33251	M	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	11
3	2.11	1.84	3.95	39	24324	M	10	SF	N	0	N	N	N	N	N	N	N	N	Y	1	N	Y	N	N	N	N	N	S	C	30
4	2.11	1.44	3.55	38	3342	F	3	RTA	Y	1	N	N	N	N	N	Y	N	US	Y	4	N	N	N	Y	Y	Y	Y	US	O	20
5	1.92	1.99	3.91	25	97949	M	5	SF	Y	2	Y	Y	N	N	N	N	N	US	Y	3	Y	Y	N	N	N	N	Y	US	O	3
6	2.35	1.29	3.63	25	63888	F	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	5
7	2.11	1.89	4.00	18	80600	M	8	SF	N	0	N	N	N	N	N	N	N	N	Y	1	N	N	N	N	N	N	Y	S	O	3
8	1.93	1.93	3.86	30	11789	F	9	RTA	N	1	N	N	N	N	N	Y	N	S	Y	1	N	N	N	N	N	Y	N	S	C	10
9	2.45	2.04	4.49	58	58416	M	10	RTA	S*	FP	N	N	N	N	N	N	N	N	Y	1	Y	N	N	N	N	N	N	US	C	3
10	2.11	1.71	3.82	23	13165	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	10
11	2.11	1.99	4.10	42	85461	M	7	RTA	N	0	N	N	N	N	N	N	N	N	Y	2	N	N	N	N	N	Y	Y	S	C	4
12	2.11	1.44	3.55	50	37632	M	7	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	3
13	2.11	1.25	3.36	38	94308	M	11	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	17
14	2.30	1.61	3.91	28	94156	M	2	RTA	N	FP	N	N	N	N	N	N	N	N	Y	4	N	Y	Y	Y	N	N	Y	US	O	4
15	2.30	2.11	4.41	19	3719	F	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	8
16	1.92	1.99	3.91	21	52182	M	9	RTA	N	0	N	N	N	N	N	N	N	N	Y	1	Y	N	N	N	N	N	N	S	C	3
17	2.29	1.48	3.78	23	64331	M	7	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	7
18	1.93	1.82	3.75	65	88379	M	6	RTA	N	0	N	N	N	N	N	N	N	N	Y	2	N	N	N	N	N	Y	Y	S	C	4

C= Conservative; CS= Cervical Spine; CT = Computed tomography; F = Female; FP= False Positive; M = Male; mAs = milli Ampere second; mGy = milliGray; mSv = milli Sievert; N= No/ Absent; NA= Not Applicable; No.= Number; O=Operative; RTA= Road Traffic Accident; S*= Suspicious; S= Stable; SF= Self Fall; US= Unstable; Y = Yes/Present

	CT dose (mSv)								X-ray										CT											
sl.no	Head	CS	Total	Age (in years)	Trial ID	Sex	GCS score	Mode of injury	Fracture	No involved	Vertebral level							Stable/Unstable	Fracture	No involved	Vertebral level							Stable/Unstable	Management	Follow up (in days)
											C1	C2	C3	C4	C5	C6	C 7				C1	C2	C 3	C 4	C 5	C 6	C7			
19	2.11	1.99	4.10	22	88147	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
20	1.93	2.02	3.95	58	71144	F	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
21	2.11	1.48	3.59	32	74307	M	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
22	2.49	1.70	4.19	19	11900	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
23	2.50	1.52	4.03	48	90125	F	7	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	7
24	1.92	1.30	3.22	48	3341	M	10	RTA	N	0	N	N	N	N	N	N	N	N	Y	1	N	N	N	N	N	N	Y	S	C	4
25	0.21	1.70	1.91	72	31136	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
26	2.11	2.02	4.13	54	92641	M	9	SF	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
27	2.11	1.75	3.86	42	37418	M	7	SF	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	6
28	2.11	1.71	3.82	23	94535	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	10
29	2.11	1.98	4.09	40	27068	M	3	SF	N	0	N	N	N	N	N	N	N	N	Y	4	N	Y	N	N	Y	Y	Y	US	O	8
30	2.30	2.11	4.41	21	46393	M	11	SF	N	0	N	N	N	N	N	N	N	N	Y	1	N	N	N	N	N	N	Y	S	C	5
31	2.11	2.02	4.13	55	39794	F	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
32	2.49	1.97	4.46	40	82189	M	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
33	2.11	1.88	3.99	40	98704	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	14
34	2.11	1.30	3.41	45	93625	M	8	RTA	N	0	N	N	N	N	N	N	N	N	Y	2	N	N	N	N	N	Y	Y	US	O	8
35	2.30	1.89	4.19	58	35372	M	11	RTA	N	0	N	N	N	N	N	N	N	N	Y	1	N	N	N	N	N	N	Y	S	C	4
36	2.11	1.93	4.04	45	6129	F	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4

C= Conservative; CS= Cervical Spine; CT = Computed tomography; F = Female; FP= False Positive; M = Male; mAs = milli Ampere second; mGy = milliGray; mSv = milli Sievert; N= No/ Absent; NA= Not Applicable; No.= Number; O=Operative; RTA= Road Traffic Accident; S*= Suspicious; S= Stable; SF= Self Fall; US= Unstable; Y = Yes/Present

sl.no	CT dose (mSv)			Age (in years)	Trial ID	Sex	GCS score	Mode of injury	X-ray										CT										Management	Follow up (in days)
	Head	CS	Total						Fracture	No involved	Vertebral level							Stable/Unstable	Fracture	No involved	Vertebral level							Stable/Unstable		
											C1	C2	C3	C4	C5	C6	C7				C1	C2	C3	C4	C5	C6	C7			
37	2.11	1.71	3.82	55	87155	F	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
38	1.92	2.14	4.06	55	87134	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
39	1.93	2.02	3.95	30	4590	M	4	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
40	2.11	1.39	3.50	45	69492	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
41	1.92	2.02	3.94	24	53169	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
42	2.11	1.98	4.09	45	83593	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
43	2.11	1.75	3.86	42	70524	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
44	2.11	1.96	4.07	65	72903	M	4	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	16
45	2.49	1.89	4.38	20	68993	M	6	RTA	Y	1	N	N	N	N	Y	N	N	S	Y	1	N	N	N	N	Y	N	N	US	O	3
46	2.11	1.90	4.01	20	39350	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
47	1.92	1.30	3.22	50	50542	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	5
48	2.30	1.48	3.78	24	7715	M	8	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
49	2.11	1.81	3.92	65	441	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	14
50	2.11	1.99	4.10	40	96637	M	8	RTA	Y	1	N	N	N	N	Y	N	N	N	Y	2	N	N	N	N	N	Y	Y	US	C	5
51	2.11	2.02	4.13	50	52602	M	5	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3

C= Conservative; CS= Cervical Spine; CT = Computed tomography; F = Female; FP= False Positive; M = Male; mAs = milli Ampere second; mGy = milliGray; mSv = milli Sievert; N= No/ Absent; NA= Not Applicable; No.= Number; O=Operative; RTA= Road Traffic Accident; S*= Suspicious; S= Stable; SF= Self Fall; US= Unstable; Y = Yes/Present

sl.no	CT dose (mSv)			Age (in years)	Trial ID	Sex	GCS score	Mode of injury	X-ray										CT										Management	Follow up (in days)
	Head	CS	Total						Fracture	No involved	Vertebral level							Stable/Unstable	Fracture	No involved	Vertebral level							Stable/Unstable		
											C1	C2	C3	C4	C5	C6	C7				C1	C2	C3	C4	C5	C6	C7			
52	2.11	1.25	3.36	38	31501	M	7	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	3
53	2.11	1.70	3.81	55	97932	M	4	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	6
54	2.30	1.61	3.91	30	37046	M	6	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
55	1.92	1.30	3.22	36	62553	M	5	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	6
56	2.11	1.38	3.49	40	81909	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	4
57	2.11	2.02	4.13	38	25024	M	2	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	6
58	2.11	1.37	3.49	26	13891	M	5	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	N	20
59	1.73	1.72	3.45	45	47822	M	4	RTA	N	0	N	N	N	N	N	N	N	N	Y	2	N	N	N	N	N	Y	Y	US	C	4
60	2.11	1.91	4.02	32	96193	F	10	SF	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	7
61	2.11	1.83	3.94	62	83593	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	4
62	1.92	1.53	3.45	22	62100	M	11	SF	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	2
63	2.11	2.48	4.59	35	92987	M	5	RTA	Y	1	N	Y	N	N	N	N	N	S	Y	1	N	Y	N	N	N	N	N	S	C	35
64	1.93	1.41	3.34	20	40757	M	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	4
65	2.11	1.71	3.82	45	18659	M	9	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	6
66	2.11	1.44	3.55	85	64942	F	8	SF	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	7
67	2.11	1.99	4.10	40	91472	M	10	RTA	N	0	N	N	N	N	N	N	N	N	N	0	N	N	N	N	N	N	N	N	NA	2

C= Conservative; CS= Cervical Spine; CT = Computed tomography; F = Female; FP= False Positive; M = Male; mAs = milli Ampere second; mGy = milliGray; mSv = milli Sievert; N= No/ Absent; NA= Not Applicable; No.= Number; O=Operative; RTA= Road Traffic Accident; S*= Suspicious; S= Stable; SF= Self Fall; US= Unstable; Y = Yes/Present