Detailed observation of axis ring fractures using computed tomography: a retrospective analysis of 202 cases

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Abstract

Background: There is a dearth of research observing the precise anatomical location, pattern, and frequency of the fracture lines in axis ring fractures based on large size sample database and deducing the possible injury mechanism for such fractures. The study aimed to observe the anatomical features of axis ring fractures and evaluate the probable mechanism of injury.

Methods: 202 patients with axis ring fractures were identified. According to the involvement of anatomical structures, the axis ring injuries were classified into facet joint injury and pure bony injury. The axis ring was also divided into: anterior, middle, and posterior elements. The anatomical structures involvement and fracture patterns of such fractures were observed using CT.

Result: 501 anatomical structures of the axis ring were involved in 202 patients, including 288 facet joints injuries and 213 bony injuries. For facet joints injuries, the most common injuries were superior articular facet injuries, and for pure bony injuries, the most common injuries were pediculoisthmic component fractures. In regard to different element of the axis ring, the injuries of anterior element were more common than that of middle or posterior element. Most of (76.2%) axis ring fractures were asymmetrical, with different elements of the axis ring damaged on different side.

Conclusion: In axis ring fractures, fracture lines could occur in any part of the ring. Facet joints injuries were more common than pure bony injuries, and the injuries of anterior element were more common than that of middle or posterior element. The probable mechanism of such injuries might be hyperextension and axial load, with an additional rotational load.

Introduction

Axis ring fracture, also referred to as traumatic spondylolisthesis of the axis or a “Hangman’s fracture”, is the second most common injury of the axis (C2) [1]. It is estimated that these fractures account for 20–22% of all axis injuries [2, 3].

Effendi et al. reviewed the clinical and radiological data of 131 patients with axis ring fractures [4]. They found that these fractures might occur through any part of the ring of the axis, including superior or inferior articular processes, pedicle, pars interarticularis, laminae, posterior wall of C2 vertebral body, and foramen transversarium. In addition, they also found that axis ring fracture tends to be asymmetrical [4, 5]. Some other authors regarded these injuries as pedicle or par interarticularis fractures of the axis [6, 7]. The variety of fracture lines and asymmetrical feature of such injuries, however, are confirmed in recently published researches [1, 3, 5, 8–11].

Ideally, surgical management for axis ring fractures should be tailored according to the fracture line location, fracture pattern, and even injury mechanism, instead of using the same technique [5, 11, 12]. Therefore, two questions need to be answered [5, 13]: What is the precise anatomical location, pattern,

and frequency of the fracture lines in axis ring fractures based on large size sample database? What is the possible injury mechanism for such fracture pattern?

To the best of our knowledge, no studies with a large sample so far address these issues. Therefore, the objective of this study was to observe the anatomical features of axis ring fractures, and evaluate the probable mechanism of injury by reviewing the clinical and radiological data from prospectively maintained database founded by 7 medical centers in China.

Methods And Materials

We reviewed all the medical records in our prospectively maintained database, which accumulated 367 cases with C2 vertebra or axis ring fractures from 7 tertiary referral medical centers in China with a catchment population of 63 million between December 2013 and December 2018. This study project was approved by the institutional research and ethics committee.

Patients were included if they fulfilled all the 2 criteria: (1) patients were medically confirmed of axis ring fractures with bilateral fracture lines through any part of the bony ring, including pediculoisthmic component (PIC) fractures, posterior wall of vertebral body fractures, superior or inferior articular facets, or lamina [14, 15]; (2) patients with complete imaging studies, including X-rays, axial plane computed tomography (CT) scans, sagittal and coronal plane reconstructions, and three-dimensional reconstructions of cervical spine, and all CT images were acquired using at least a 64-slice multidetector CT scanner [5]. Patients with congenital anomalies, infections, or tumors in the upper cervical spine were excluded [13, 16].

202 patients with axis ring fractures were included in this study. There were 147 male and 55 female, and the average age at injury was 49.1 years (range, 15–91 years). The most common causes of injury were falls, causing 95 (47%) injuries. Motor vehicle accidents were second common, accounting for 66 (32.7%) injuries. The less common causes of injury were low energy injuries (e.g. fallen from standing height), causing 25 (12.4%) injuries. The remaining causes of injury were others, causing 16 (7.9%) injuries.

Radiographic assessment

For the purpose of this review, only pre-treatment imaging studies were collected and analyzed. According to the involvement of anatomical structures, the axis ring injuries were classified into facet joint and pure bony injuries. Facet joint injury included superior or inferior articular facet injuries of the axis, and C2-C3 disc injuries followed by axis ring fractures, which was defined as significant angulation (> 11 degrees) and/or anterior translation (> 3 mm) of C2-C3 [3, 17]; Pure bony injury included the posterior wall of vertebral body fractures, PIC fractures, and lamina fractures of the axis.

Based on the fact that fractures often ran from one anatomical structure to the adjacent structures, we regarded the anatomical area bearing the larger part of the fracture line as the primary site [5]. The rules identifying the involvement of anatomical structures were as follows: 1. a superior articular facet fracture line extending to the posterior wall of C2 body was still considered as a superior articular facet fracture in

contrast to fractures of two anatomical structures; 2. a posterior wall of C2 body fracture line extending to the C2-C3 disc was still considered as a posterior wall of C2 body; 3. a long inferior articular facet fracture line extending to part of PIC was still considered as a inferior articular facet fracture and vice versa; 4. a lamina fracture involving some part of inferior articular facet fracture line was still considered as a lamina fracture and vice versa.

The axis ring was divided into three parts: anterior element, which included C2-C3 disc, bilateral superior articular processes, and the posterior wall of C2 vertebral body behind the odontoid process; middle element, the only component was PIC [15] ; and posterior elements, which included bilateral inferior articular processes and lamina (Fig. 1). The incidence of various anatomical structures injuries, location of fracture line, and fracture feature of the axis ring were observed.

Results

Anatomical structures involvement in axis rings fractures

501 anatomical structures of axis rings were involved in 202 patients, including 288 facet joints injuries (288/501, 57.5%) and 213 bony injuries (213/501, 42.5%), with 2.5 anatomical structures damaged for each patient.

For 288 facet joints injuries identified in 144 patients:

- –129 superior articular facet injuries in 111 patients (129/501, 25.7%)
- – 96 C2-C3 disc injuries in 96 patients (96/501, 19.2%)
- – 63 inferior articular facet injuries in 63 patients (63/501, 12.6%).

For 213 bony injuries identified in 149 patients:

- – 99 PIC injuries in 87 patients (99/501, 19.8%)
- –79 posterior wall of vertebral body fractures in 77 patients (79/501, 15.8%)
- – 35 lamina fractures in 35 patients (35/501, 7%).

In the anterior element of axis ring, 304 anatomical structures were involved in 153 patients (304/501, 60.7%), and of which 225 facet joints injuries were identified (225/304, 74%), and the remaining was 79 pure bony injuries (79/304, 26%). In the middle element of axis ring, 99 anatomical structures were involved in 87 patients (99/501, 19.8%), and all of them were pure bony injuries. In the posterior element, 98 anatomical structures were involved in 98 patients (98/501, 19.6%), and of which 63 facet joints injuries were identified (63/98, 64.3%), and the remaining was 35 pure bony injuries (35/98, 35.7%).

To sum up, facet joints injuries were more common than pure bony injuries (57.5% VS 42.5%) in our series of 202 patients. Of facet joints injuries, the incidence of superior articular facet injuries was 25.7%,

C2-C3 disc injuries 19.2%, and inferior articular facet injuries 12.6%. Of pure bony injuries, the most common injuries were PIC fractures (19.8%), followed by fractures of posterior wall of C2 vertebral body (15.8%) and lamina (7%). In regard to different element of axis ring, the injuries of anterior element (60.7%) were more common than that of middle (19.8%) or posterior (19.6%) element. In the anterior and posterior element of axis ring, facet joints injuries were more common than pure bony injuries. Because of the unique anatomical structures in the middle element of axis ring, all of them were pure bony injuries.

The different fracture patterns of axis ring fractures

Firstly, 154 (154/202, 76.2%) axis ring fractures were asymmetrical, with different elements of axis ring damaged on different sides, and only 48 axis ring fractures were with the same elements of axis ring (Fig. 2);

Secondly, when observed with the incidence of different combinations of anterior, middle, and posterior elements, the injuries of anterior element on one side were the most common (172, 85.1%), and the other side injury could be located in the anterior, middle or posterior element (Fig. 3–5 and Table 1);

Table 1
The incidence of different fracture patterns of axis ring fractures

	Fracture pattern	Subtype	N (%)
Anterior element	Anterior + anterior elements	bilateral fractures through superior articular facet and/or posterior cortex of C2 on different sides	36 /17.8%
	Anterior + middle elements	one fracture through superior articular facet and/or posterior cortex of C2 on one side and another through the C2 PIC on the other side	57 /28.2%
	Anterior + posterior elements	one fracture through superior articular facet and/or posterior cortex of C2 on one side and another through the contralateral inferior articular facet or lamina	79 /39.1%
Middle element	Middle + middle elements	bilateral fracture lines through the C2 PIC on different sides symmetrically or asymmetrically	12 /5.9%
	Middle + posterior elements	one fracture through one side of C2 PIC and another through the contralateral inferior articular facet or lamina	18 /9.0%
Note: PIC, pediculoisthmic component			

Thirdly, typical “Hangman’s fractures” described as bilateral fractures in the middle element of axis ring were rare, and the incidence of which was only 5.9% (12/202); Finally, the incidence of axis ring fractures

with middle and posterior element injuries in different sides was 9% (18/202) (Fig. 6).

Discussion

Since its first description, there was no uniform definition and precise location of axis ring fractures [5, 12]. Authors who used different terms for this injury usually reported variable sites and different anatomical locations in such fracture. Recently, Menon et al. [5] conducted a research and confirmed fracture lines could occur in any part of the ring (neural arch) of axis, e.g. the pedicles, pars interarticularis, facets, laminae, the cortex of vertebral body, or even foramen transversarium of C2 in axis ring fractures. And the anatomical information in their study may modify the surgical treatment in such injury [5]. Therefore, research with large-sample accurately describing the precise anatomical location and frequency of the fracture lines in these injuries is of importance.

To the best of our knowledge, this is the first multiple-center and large-sample study observing the anatomical features of axis ring fractures using three-dimensional CT. The result of this current study demonstrated: Firstly, most of fracture lines of axis ring fractures were asymmetrical, and typical “hangman’s fractures” described as bilateral pedicle or par interarticularis fractures of axis were rare; Secondly, facet joints injuries in axis ring fractures were more common than pure bony injuries, and superior articular facet injuries were most common; Thirdly, when axis ring was divided into anterior, middle, and posterior elements, the injuries of anterior element were more common than that of middle or posterior element.

Several authors tried to describe, classify, and correlate between different patterns of axis ring fractures and mechanism of injury or even treatment options [1–5, 17]. Levine and Edwards modified Effendi’s classification and published the most widely accepted, comprehensive, and consummate classification scheme for axis ring fracture [4, 9, 17]. However, Levine- Edwards’ classification was based on X-ray films of cervical spine, which supposed that most of such injuries were bilateral pars fractures or pedicle of C2 rather than fractures involving various anatomical structures of axis ring. The result of our study showed that typical bilateral pedicle or par fractures of axis were rare, and most of fracture lines were asymmetrical, which was consistent with previous or recently published studies [3, 4, 10, 11, 13, 18]. Therefore, our study reminded spine surgeons that three-dimensional CT was necessary for axis ring fractures, and using the precise anatomical structures to replace the general term “neural arch fracture” or “Hangman’s fractures” might be more proper to assist in planning the reasonable treatment [5, 11, 19].

The result of this current study showed not just the location, pattern, extent and symmetry in these fractures but also high prevalence of facet joints injuries. Menon et al. [5] conducted a similar study in which 32 patients with axis ring fractures were included, and they found that facet joint involvement were demonstrated in 50% of patients, which consist with that of our study. The high prevalence of facet joints injuries in axis ring fractures means that most of axis ring fractures may be involved with intra-articular injuries, and it also has the potential to plan the suitable treatment. However, literature is unclear about

the suitable treatment for axis ring fractures involving the superior facet of axis. In axis ring fractures, listhesis of C2 over C3 vertebra is common, and if superior facet of axis injury exists, C1-C2 joints and C2-C3 disc/joints are unstable [20, 21]. So stabilization of both these joints might be necessary, and anterior cervical surgery such as anterior cervical discectomy and fusion (ACDF) of C2/3 does not play any role in such a situation [20]. Geol suggested posterior fixation and fusion at C1-C3 level could be a most suitable surgical technique [20].

Based on the features of 202 axis ring fractures: 1. most of fracture tended to be asymmetrical; 2. facet joints injuries were more common than pure bony injuries; 3. the injuries of anterior element were more common than that of middle or posterior element, we postulated that the probable mechanism for most of axis ring fractures might be hyperextension and axial load, which caused anterior element fractures on one side as primary injury, and the rotational element during the extension component of the injury vector caused contralateral middle or posterior element fracture as asymmetrical secondary injury. Our hypothesis was supported by previous studies: biomechanical studies demonstrated that the extension compression force was the primary injury vector in axis ring fractures [1, 5, 17]; In regard to asymmetry of such fracture, Duggal et al. [22] suggested that this injury was almost always asymmetrical because of the rotational element during the extension component of the injury vector.

Limitations

First, although this study is multicenter studies with large sample sizes, it is still a retrospective research. Second, fractures extending into the transverse foramen were not recorded, because transverse foramen is located outside the superior facet joint and pedicle of the axis, and its damage does not cause instability; and fracture lines running into this structure were always accompanied with superior facet joint or pedicle fracture. Third, CT with axial cuts and three-dimensional reconstructions in the frontal and sagittal plane were the only tool in this study, combination plain X-rays, MRI, and CT may give more persuasive information about axis ring fractures.

Conclusion

In our series of 202 patients with axis ring fractures, fracture lines could occur in any part of the ring, facet joints injuries were more common than pure bony injuries, and the injuries of anterior element were more common than that of middle or posterior element. Most of axis ring fractures were asymmetrical, and an anterior element injury of axis ring on one side and another injury located anterior, middle, or posterior element on the other side was the most common pattern. The probable mechanism for most of axis ring fractures might be hyperextension and axial load which usually caused anterior element injuries, with an additional rotational load causing middle or posterior element injuries. These data might be helpful in describing location of axis ring fractures and planning the reasonable treatment.

Abbreviations

CT: computed tomography; PIC: Pediculoisthmic component; ACDF: Anterior cervical discectomy and fusion

Declarations

Ethics approval and consent to participate

This was a retrospective study approved by the Ethical Committee of the Affiliated Hospital of Southwest Medical University. All patients provided written informed consent prior to their inclusion in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

G.L. and S.H. worked through the whole study from designing the study, acquisition of data, analysis and interpretation of data, and drafting the manuscript. Q.W. made substantial contributions to conception to this paper and contributed in critically revising the manuscript. M.T. contributed in designing the study and revising the manuscript. Y.H., J.T., and P.L. made substantial contributions to acquisition of data, analysis and interpretation of data. C.W. and Y.H. was in charge of analyzing the data and revising the manuscript for important intellectual content.

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Figures

Figure 1

Diagram depicting anterior (marked by the red area), middle (marked by the acid blue area), and posterior element (marked by the black area) of axis ring

Figure 2

Axis ring fracture with bilateral fracture lines through the C2 PIC on different sides. Axis CT scan (a) showed bilateral fractures through C2 PIC on different sides; Sagittal plane scan (b) showed PIC fracture on right side; Three-dimensional reconstruction image (c) showed bilateral PIC fractures.

Figure 3

Axis ring fractures with anterior elements injuries on different sides. Axis CT scan (a) showed bilateral fractures through anterior elements of C2 on different sides; Sagittal image (b) showed anterior slippage of C2 vertebral body; Three-dimensional reconstruction image (c) showed left fracture line extending upward to the superior articular process and right fracture line extending posterior wall of C2.

Figure 4

Axis ring fractures with anterior and middle elements injuries on different sides. Axis CT scan (a) showed asymmetric fracture lines; Sagittal image (b) showed fracture line through posterior wall on left side; Three-dimensional reconstruction image (c) showed left fracture line through posterior wall and upper articular surface of C2, with right PIC fracture

Figure 5

Axis ring fractures with anterior and posterior elements injuries on different sides. Axis CT scan (a) showed posterior wall fracture of left vertebral body with contralateral lamina fracture; Parasagittal image (b) showed right fracture line through inferior articular process of axis. Three-dimensional reconstruction image (c) showed fracture line through of posterior wall of left vertebral body and another fracture line contralateral lamina and inferior articular process

Figure 6

Axis ring fractures with middle and posterior elements injuries on different sides. Axis CT scan (a) showed asymmetry of fracture line. Sagittal image (b) showed PIC fracture on left side; Three-dimensional reconstruction image (c) showed axis ring fracture with one fracture line through left PIC and transverse foramen and another through right lamina.