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FULL PAPER

Imaging findings of flexion type of hangman's fracture; an attempt for a more objective evaluation with newly introduced scoring system

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Objective: To identify the flexion type of hangman's fracture on imaging studies.

Methods: 38 cases of hangman's fracture were retrospectively studied and categorized into flexion and non-flexion groups. Plain radiograph, CT and MRI of these patients were evaluated; 13 radiological parameters that might define flexion injuries were measured. The data were statistically analyzed to identify good criteria and to rank them according to their importance in predicting flexion.

Results: Seven radiological criteria that have the highest correlation with flexion injury were identified. These are C2-3 lower end-plate angle, C2-3 posterior body angle, interspinous angle, disc disruption (MRI), widening of

interspinous distance, disruption of the posterior ligamentous complex (MRI) and angle at the fracture site. Scoring 1 point for each positive criterion, a total score of 4 predicts flexion injury with 100% sensitivity and 96.9% specificity. Score of 5 has 83.3% sensitivity and 100% specificity.

Conclusion: Flexion hangman's injury can be diagnosed by the presence of four out of seven radiological criteria in the newly introduced scoring system. The authors believe that this method may help spinal surgeons in their selection of therapeutic strategy.

Advances in knowledge: This study introduces fast, simple and more objective imaging criteria for the diagnosis of flexion hangman's injury and separates it from the non-flexion pattern.

INTRODUCTION

Hangman's fracture or traumatic spondylolisthesis of the axis (TSA) is an injury involving the C2 vertebra fracturing its neural arch bilaterally. It is associated with disc and posterior ligamentous complex (PLC) injury of varying degrees and often at different levels. Once diagnosed in judicial hangings, most modern day injuries are due to high-velocity road traffic accidents.^{1,2} The mechanism of injury has been commonly reported as an extension compression force, although a flexion distraction variant has also been described.³⁻⁶ Biomechanical studies have suggested the extension compression force to be the primary injury vector, while the flexion component which is present in some cases is the secondary vector. However, Effendi et al,³ Levine and Edwards,⁴ and Pepin and Hawkins⁶ believed that the numbers of the flexion variants are relatively small.³⁻⁸

Several authors have tried to classify hangman's fracture by different criteria in an attempt to guide surgeons in their management of this injury. The system proposed by Effendi et al³ and later modified by Levine and Edwards⁴ divided the fractures into three types and one more sub-type, while the assessment by Francis and Fielding³⁻⁵ divides the fracture into five types. These two methods are relatively well known; they take the appearance on lateral radiograph, degree of displacement and angulation into consideration and suggest signs for instability to assist the surgeon in choosing the optimal treatment strategy for a given case; typically, stable fractures are treated non-operatively and unstable ones surgically. In a recent study, Menon and Taif⁹ have described the fracture lines and reported a higher incidence of asymmetric fractures, frequent involvement of the foramen transversarium, facet joints and posterior vertebral body. They found the fracture pedicle on one side and pars on the other to be the

commonest injury pattern followed by bilateral symmetric pedicle and bilateral symmetric par fractures.

The present study introduces a third and new perspective in classifying hangman's injury taking into account the presence of the significant flexion component diagnosed by findings on different imaging modalities that might eventually affect the choice between various treatment options. Previous literature has not given much consideration to this issue; some authors believe that such differentiation might not be of importance and will not affect the overall management. Effendi et al,³ Levine and Edwards,⁴ and Pepin and Hawkins⁶ have all suggested that the numbers of the flexion variants were relatively small and the management strategy largely non-operative like the extension type.^{3-5,10-13} However, in the few cases where surgery is recommended, the unique pathological anatomy of tissue failure in hangman's injury needs to be considered, as surgeons generally prefer fracture fixation on the tension side. It would seem rational to restore the tension band, which is the anterior column in the extension type and the posterior column in the flexion type (keeping in mind anatomical constraints to such an approach). The anterior column failure in hangman's injury typically occurs at the C2–3 disc level, but the posterior ligamentous failure occurs at the C1–2 level (Figure 1).¹⁴⁻¹⁹

Consequently, the authors believe that such a distinction between the two biomechanically distinct injury patterns is essential and the radiologist should be able to identify and report the dominant mechanism in TSA. This study attempts to establish more objective imaging criteria for the diagnosis of flexion hangman's injury and separate it from the non-flexion pattern.

METHODS AND MATERIALS

Study design and population

This retrospective study was conducted at a tertiary-care referral facility in the Middle East. It was approved by the

research and ethics committee. The hospital information system is a computerized database that was searched to retrieve patients of hangman type of C2 fracture admitted to the Department of Orthopaedics during the period from January 2009 to May 2014. 38 cases were retrieved, of which 29 were males and 9 were females. The patient age ranged from 28 to 54 years. The mechanism of injury was road traffic accident in all cases.

Technique

Three types of imaging modalities were used in the assessment, which are lateral cervical spine radiograph, CT and MRI. CT was carried out using multislice 64 CT scanner. We used sagittal reformatted images in our evaluation. MRI was performed by either a 3.0- or a 0.9-T MR system. This study considered the T_2 and fat-suppressed T_2 weighted or short tau inversion-recovery sequence in the sagittal plane.

Imaging evaluation

Lateral cervical radiographs and CT images were reviewed first to confirm the diagnosis of hangman's fracture and to determine the alignment. Cases were analyzed by two senior spinal surgeons and a senior radiologist with over 10 years' experience in musculoskeletal imaging to determine the cases showing flexion and differentiate them from cases showing no flexion. Cases were evaluated based on the final appearance of the cervical spine as noted on the lateral view and on mid-sagittal CT scan disregarding any measurement. Decision was made depending on a consensus of the team members; otherwise, the only one case with discrepancy was placed under the non-flexion group. 13 imaging criteria that might aid diagnosis were used; these criteria were selected by the working team bearing in mind the presence of flexion as the dominant mechanism of injury and according to the observation of flexion cases and their appearance from their practice.

Figure 1. Lateral cervical spine radiographs are showing: (a) the angle formed between a line drawn along the posterior aspect of C2 and another along the posterior aspect of C3 (Angle A); (b) the angle formed between a line passing across the lower border of C2 and the lower border of C3 (Angle B); (c) the angle at the fracture site formed between the two edges of the fracture in the neural arch.

Radiological measures selected were:

(a) On lateral radiograph:

- The angle between a line drawn along the posterior aspect of C2 and another one along the posterior aspect of C3 (Angle A) (Figure 1a)
- the angle between two lines drawn along the lower borders of C2 and C3 vertebrae (Angle B) (Figure 1b)
- the angle formed between the two edges of the estimated fracture itself (Figure 1c)
- the C1–2 interspinous distance estimated between C1 and C2 spinous process, which is then compared with the C2–3 interspinous distance (Figure 2a)
- the C1–2 interspinous angle estimated on the lateral radiograph, between a line drawn along the long axis of C1 neural arch and another line along C2 spinous processes parallel to its upper border (Figure 2b)
- anterior displacement of C2 over C3: the distance between the posteroinferior corner of C2 and the posterosuperior corner of C3 vertebral bodies (Figure 3a)
- widening of the C2–3 disc space compared with the C3–4 disc space (Figure 3b).

(b) CT scan:

- Posterior displacement of C2 spinous process relative to C1 and C3 spinous processes estimated on mid-sagittal reformatted CT (or mid-sagittal MRI) as the distance between the base of C2 spinous process and a line joining the bases of C1 and C3 spinous processes (Figure 3c)

- fractures in the vertebral body that may denote the mechanism of injury like how anterior or posterior chip fractures were noted (Figure 4).

(c) On MRI, the following structures were assessed:

- PLC at C1–2
- C2–3 intervertebral disc
- anterior longitudinal ligament (ALL)
- posterior longitudinal ligament (PLL).

A high T_2 signal replacing the normal low signal of these structures was taken as indicative of disruption (Figure 5).

Statistical analysis

The flexion injury group (test group) and the control group (showing no flexion) were statistically analyzed to determine the imaging features that are most useful to predict flexion injury. The following statistical tools were used for data analysis.

Receiver-operating characteristic

Receiver-operating characteristic (ROC) was used to rank the tested measurements according to their importance in predicting significant flexion injury.

The area under the curve gives an idea about the usefulness of the test and helps in comparing it with other tests. The larger the area under the curve (closer to one, ideal test), the more the validity of it.

Sensitivity, specificity, positive-predictive value (PPV) and negative-predictive value (NPV) were assessed.

Figure 2. Lateral cervical spine radiographs are showing: (a) widening of the C1–2 interspinous distance greater than double that of distance at the level of C2–3; (b) the interspinous angle formed between a line drawn along the long axis of C1 spinous process/posterior arch and another line drawn along C2 spinous processes along its superior border.

Figure 3. Three patients with hangman's fracture: (a) a lateral cervical spine radiograph is showing measurement of the displacement of C2 over C3; (b) a sagittal reformatted CT image is showing significant widening of the C2-3 disc space; (c) reformatted CT in the mid-sagittal plane is showing measurement of displacement of the C2 spinous process base relative to a line passing between bases of C1 and C3 spinous processes.

A test with high PPV is useful in establishing the diagnosis, while a high NPV is useful in excluding a diagnosis.

Summation score (univariate model)

Depending on the previous results, this method can be used to predict the presence of flexion injury. This score is calculated by summing the count of the positive criteria. The optimum cut-off value for each criterion is used to define it as positive for predicting significant flexion injury and therefore, a score of 1 is given.

Ethical approval

The study was approved by the research and ethics committee.

RESULTS

Of the 38 patients enrolled in this study, 6 patients were considered as definitely having flexion injury by the expert team. The remaining cases were considered as control group. [Tables 1](#) and [2](#) compare the 2 groups with respect to the selected 13 imaging criteria:

- Angles A and B, interspinous angle and the angle at the fracture are significantly higher in the flexion group (18.7, 18.8, 19.8 and 20.7°) compared with the non-flexion cases (4.3, 4.8, 5.5 and 8.2°).
- C2 displacement over C3 and posterior displacement of C2 spinous process is also higher among flexion cases (3.7 and

Figure 4. Sagittal reformatted cervical spine CT in two patients with hangman's fracture is showing: (a) an anterior chip fracture located anteroinferior to the C2 vertebral body; (b) a small posterior chip fracture located in the posterior aspect of the C2-3 disc.

Figure 5. T_2 weighted sagittal MR images of the cervical spine in three patients with hangman's fracture are showing: (a) disruption of the disc (white arrow) and the posterior ligamentous complex (black arrow), as manifested by an abnormal hyperintense signal replacing its normal hypointense signal; (b) disruption of the anterior longitudinal ligament seen as interruption and loss of integrity of the linear hypointense ligament (black arrow); (c) disruption of the posterior longitudinal ligament (white arrow).

- 5.2 mm) compared with controls (2 and 3.3 mm), but the difference is not statistically significant.
- 100% of flexion cases show widening of the C1–2 interspinous distance by more than double the subjacent space (significantly higher than the controls 25%).
- Significant disc disruption is more frequent among flexion cases (75%) compared with controls (20%).
- Significant disruption of the PLC at C1–2 is more among flexion cases (75%) compared with controls (20%); but, the difference failed to reach statistical significance.
- Disc space widening is observed in larger proportion of flexion cases (33.3%) compared with controls (6.3%), but the difference is not statistically significant.
- The presence of a chip fracture and disrupted ALL was more frequent among cases with flexion injury (33.3 and 50%) compared with controls (12.5 and 20%); but, this difference was not significant.
- A disrupted PLL was not different between test cases and controls.

Predicting good criteria

ROC analysis (Figure 6) revealed that the best 7 variables (which have an ROC area of ≥ 0.7 , which qualifies them as good predictors for flexion-type injury) are Angle B, Angle A, interspinous angle, disc disruption, widening of interspinous distance, disruption of the PLC and the angle at the fracture site. In Table 3, these variables are sorted in order of validity from the best predictor (Angle B) to the least (angle at fracture site).

The remaining six criteria were associated with a failure test (ROC area is ≤ 0.65) (Table 3).

Cut-off values

The optimum cut-off value for the best seven predictors was measured (Table 4).

Angle B $> 16^\circ$, Angle A $> 15^\circ$ and interspinous angle $> 28^\circ$ were 100% specific. The same angles < 13 , 11 and 12° , respectively, were associated with 100% sensitivity. The widened C1–2 interspace was 100% sensitive but 75% specific.

Significant disc disruption (rather than focal) has 100% sensitivity and NPV.

Significant disruption of the PLC (rather than focal) had 75% sensitivity, 80% specificity and 96.6% NPV.

Fracture angle with a cut-off of 24° had 66.7% sensitivity and 96.8% specificity.

The summation score

Score was tested by ROC method for its validity in diagnosing flexion-type injury (Figure 7).

Maximum score of positive criteria = 7. This score was associated with an almost perfect test (area under ROC curve is 0.997; p -value < 0.001).

A score of 4 is 100% sensitive (0% false-positive rate) and 96.9% specific, while a score of 5 is 100% specific (0% false-negative rate) (Table 5).

DISCUSSION

The force vectors responsible for the various patterns of hangman's injuries are largely hypothetical. Levine and Edwards,⁴ in their widely used classification system, proposed three possible variations with a flexion component: flexion compression resulting in the rare Type III injury with C2–3 facet subluxation, flexion distraction causing Type IIa injury pattern (characterized by the presence of angulation and disruption at the C2–3 disc) and hyperextension compression with rebound flexion resulting

Table 1. The difference in the mean of selected measurements between cases with significant flexion and those with minimal or no flexion

Imaging feature	Cases with minimal or no flexion	Cases showing significant flexion	<i>p</i> -value
Angle A			
Range	0–13	11–29	<0.001
Mean ± SE	4.3 ± 0.7	18.7 ± 2.93	
N	32	6	
Angle B			
Range	0–14	14–24	<0.001
Mean ± SE	4.8 ± 0.7	18.8 ± 1.76	
N	32	6	
Interspinous angle			
Range	(−1 to 20)	(13–36)	<0.001
Mean ± SE	5.5 ± 1.13	19.8 ± 3.38	
N	31	6	
Angle at fracture			
Range	(0–38)	(0–38)	0.012
Mean ± SE	8.2 ± 1.64	20.7 ± 6.71	
N	32	6	
Displacement—C2 over C3 (mm)			
Range	0–9	0–9	0.15 [NS]
Mean ± SE	2 ± 0.41	3.7 ± 1.41	
N	32	6	
Posterior displacement C2 spinous process			
Range	(0–8)	(2–12)	0.06 [NS]
Mean ± SE	3.3 ± 0.33	5.2 ± 1.52	
N	28	6	

NS, not significant; SE, standard error.

in a Type II injury (showing displacement rather than angulation at the C2–3 disc space).⁴

Irrespective of the precise sequence of injuries, the key to the stability of the craniocervical junction in this injury complex is the status of the C2–3 disc and the PLC, besides the C2–3 facet capsule. It is important to recognize that the disc injury typically occurs at the C2–3 level, while the PLC injury at the C1–2 level. It has also been postulated that embryonic and developmental reasons render the cervicocranium distinct from the subjacent subaxial cervical spine and the junction between the two lies at the pars interarticularis of axis.²⁰ In contrast to the subaxial cervical spine, the cranium–C2 segment does not have a typical PLC (interspinous and supraspinous ligaments). The ligamentum nuchae sends a vertical lamina from the external occipital protuberance to the C2 spinous process, which in turn serves as the midline tension band.^{21,22} Disruption of the midline ligamentous band between C1 and C2 is noted in some cases of hangman's injury and hence, it might be worth considering this while

planning treatment. Consequently, irrespective of the injury mechanics that lead to the flexion force vector, identifying it irrefutably becomes crucial.

In this study, we selected a number of imaging criteria and assessed them in both flexion cases and control groups. These imaging findings were chosen, as they were expected to be useful in determining flexion cases based on observation of the appearance of fracture on lateral cervical radiograph and the mechanism of injury.

Statistical analysis has shown the following criteria to be good in predicting flexion cases from the best one to the least useful one:

- Angle B
- Angle A
- interspinous angle
- disc disruption (MRI)
- C1–2 interspinous distance widening
- disruption of the PLC (MRI)
- Angle at fracture site.

Table 2. The positivity rate of selected features between cases with significant flexion and those with minimal or no flexion

Imaging feature	Cases with minimal or no flexion		Cases showing significant flexion		<i>p</i> -value
	<i>N</i>	%	<i>N</i>	%	
Interspinous distance					
Not widened	11	34.4	0	0.0	0.002
≤2	13	40.6	0	0.0	
>2	8	25.0	6	100.0	
Disc disruption (MRI)					
Intact	6	60.0	0	0.0	0.034
Focal disruption	2	20.0	1	25.0	
Significant disruption	2	20.0	3	75.0	
PLC					
Focal disruption	8	80.0	1	25.0	0.1 [NS]
Significant disruption	2	20.0	3	75.0	
Disc space widening					
Not widened	30	93.8	4	66.7	0.11 [NS]
Widened	2	6.3	2	33.3	
Chip fractures (CT)					
No chip fracture	28	87.5	4	66.7	0.23 [NS]
Positive (anterior or posterior)	4	12.5	2	33.3	
ALL					
Intact	8	80.0	2	50.0	0.52 [NS]
Disrupted	2	20.0	2	50.0	
PLL					
Intact	5	50.0	2	50.0	1 [NS]
Disrupted	5	50.0	2	50.0	

ALL, anterior longitudinal ligament; NS, not significant; PLC, posterior ligament complex; PLL, posterior longitudinal ligament.

Other criteria, namely displacement of C2 over C3, ALL disruption, posterior displacement of C2 spinous process, disc space widening, chip fractures and PLL disruption, were not shown to be good predictors of flexion cases.

The results also show that angle measurements, particularly Angles A and B and interspinous angle, are among the best criteria for diagnosing flexion cases and are associated with the most significant results compared with other features. This is easily understood, as these angles are influenced by the flexion angulation resulting from movement of the two separated cervical spine segments.

Angles B and A and interspinous angle equal or above cut-off values (16, 15 and 28°) have 100% specificity for positive diagnosis, while measurements <13, 11 and 12° would exclude flexion injury with 100% confidence.

Widening of the interspinous distance at C1–2 by twice the subjacent level was found to be 100% sensitive, but only 75%

specific; consequently, its absence is more significant, since it excludes the flexion injury.

The angle at the fracture site, which points to the separated segments at the region of pars fracture, is another good predictor with a significant difference between flexion and controls. It has an optimum cut-off value of 24° and is associated with very high specificity; therefore, angles above this value will establish a flexion injury with 95.4% confidence.

MRI with its excellent soft-tissue delineation and high contrast resolution is a potential tool that can be helpful in the management of hangman cases and aid in differentiating between flexion and non-flexion types. In general, ligamentous disruption is best appreciated on fat-suppressed sequences like T_2 and short tau inversion-recovery owing to suppression of the background fatty signal, rendering the abnormal high fluid signal more obvious.²³ Disruption of the PLC was found to be one of the good criteria for

Figure 6. Receiver-operating characteristic curves are showing the trade-off between sensitivity (rate of true positive) and specificity (rate of false positive) for selected parameters when used as a test to predict flexion-type injury.

predicting flexion; however, some non-flexion cases in this series also showed a degree of PLC disruption, a finding which may be related to two factors. Firstly, cases showing

no flexion on lateral radiographs may originally have had a flexion vector of injury and come to rest in a neutral position. Secondly, as reported in previous studies by Rihn

Table 3. Receiver-operating characteristic (ROC) area for selected variables when used as test to predict flexion-type injury

Imaging feature	Area under ROC curve	<i>p</i> -value
Angle B	0.997	<0.001
Angle A	0.981	<0.001
Interspinous angle	0.933	<0.001
Interspinous distance	0.875	0.004
Disc disruption (MRI)	0.850	0.048
PLC	0.775	0.12 [NS]
Angle at fracture	0.723	0.09 [NS]
Displacement—C2 over C3 (mm)	0.653	0.24 [NS]
ALL	0.650	0.4 [NS]
Posterior displacement C2 spinous process	0.643	0.28 [NS]
Disc space widening	0.635	0.3 [NS]
Chip fractures (CT)	0.604	0.42 [NS]
PLL	0.500	1 [NS]

ALL, anterior longitudinal ligament; NS, not significant; PLC, posterior ligament complex; PLL, posterior longitudinal ligament.

Table 4. Validity parameters for selected variables when used as test to predict flexion-type injury

Positive if $\geq$ cut-off value	Sensitivity	Specificity	Accuracy	PPV at pre-test probability		NPV at pre-test probability = 10%
				50%	90%	
Angle B						
≥ 13 (optimum and highest sensitivity cut-off value)	100.0	96.8	97.3	96.9	99.6	100.0
≥ 16 (highest specificity)	66.7	100.0	94.6	100.0	100.0	96.4
Angle A						
≥ 11 (optimum and highest sensitivity cut-off value)	100.0	93.5	94.6	93.9	99.3	100.0
≥ 15 (highest specificity)	66.7	100.0	94.6	100.0	100.0	96.4
Interspinous angle						
≥ 12 (optimum and highest sensitivity cut-off value)	100.0	83.9	86.5	86.1	98.2	100.0
≥ 28 (highest specificity)	16.7	100.0	86.5	100.0	100.0	91.5
Interspinous distance						
Widened (>double) (optimum cut-off value)	100.0	75.0	78.9	80.0	97.3	100.0
Disc disruption (MRI)						
Focal disruption (highest sensitivity)	100.0	60.0	71.4	71.4	95.7	100.0
Significant disruption (optimum and highest specificity cut-off value)	75.0	80.0	78.6	78.9	97.1	96.6
PLC						
Significant disruption	75.0	80.0	78.6	78.9	97.1	96.6
Angle at fracture						
≥ 7 (highest sensitivity)	66.7	51.6	54.1	57.9	92.5	93.3
≥ 24 (optimum cut-off value)	66.7	96.8	91.9	95.4	99.5	96.3
≥ 34 (highest specificity)	16.7	96.8	83.8	83.8	97.9	91.3

NPV, negative-predictive value; PLC, posterior ligament complex; PPV, positive-predictive value.

et al²⁴ and Goradia et al,²⁵ MRI has a high sensitivity and relatively low specificity for PLC disruption; therefore, it may overdiagnose PLC injury.

Another MRI feature that was assessed is disruption of the C2–3 disc. In addition to being a good predictor of flexion cases, the presence of disc injury was found to be 100% sensitive with 100% NPV, although its specificity is much lower; hence, MR findings of a normal disc can rule out flexion injury.

Previous literature have suggested that MRI is sensitive but not highly specific for diagnosing disc injury and specific but not sensitive to ALL and PLL disruption.^{25,26} Disruption of the ALL and PLL on MRI were not found to be good

predictors of flexion cases in the present study and they occurred with no significant difference between the flexion and control groups.

Previous literature found that the use of 3.0-T MRI improves the visualization of anatomic structures in the spine over 1.5-T MRI.²⁷ In our series, both 3.0- and 0.9-T MR scanners were used in the assessment. Although all the required soft-tissue structures could be clearly identified in our cases, there is still a theoretical possibility that higher magnetic field MRI has better soft-tissue delineation. However, the two MRI criteria that were found to be useful, namely disc disruption and PLC disruption, involve significant degree rather than focal degree of disruption, which is expected to be obvious even in low-field MRI.

Figure 7. A receiver-operating characteristic curve is showing the trade-off between sensitivity (rate of true positive) and specificity (rate of false positive) for score of positive criteria when used as a test to predict flexion-type injury (green line).

Displacement of C2 spinous process posterior to a line joining the bases of C1 and C3 spinous processes and chip fractures were included in the study, as they were thought to be related to the process of separation of the two C2 segments and injury mechanism; however, they were not shown to be good predictors.

As explained earlier, some of the good predictive features which carry a high PPV or NVP can be used to either confirm or exclude the diagnosis of flexion injury; however, using multiple criteria is always regarded more convenient. Based on our results, we are presenting a method of identifying flexion hangman's fracture depending on a score of 7 imaging variables. It is easily applicable in clinical practice, since it involves simple counting of the positive important criteria: Angle A, Angle B, interspinous angle, widening of C1–2 interspinous distance and angle at fracture site, which are X-ray features, as well as PLC and disc disruption, which are MRI features.

Scoring 1 point for each positive criterion, a total score of 4 was found to be 100% sensitive and 96.9% specific; thus, it can be considered the optimum cut-off value providing the best distinction between cases with flexion injury and those with no flexion injury. Having <4 positive criteria would exclude a possible flexion injury with 100% confidence and having 5 positive criteria or more can establish the flexion-type injury with 100% confidence. An example of flexion TSA is illustrated in Figure 8.

This scoring method involves more than one imaging modality for assessment (plain radiograph and MRI). Lateral radiograph is still considered very important in the initial assessment, even with the new emerging cross-sectional modality. Five out of the seven good criteria are in fact determined from plain radiographs alone and two criteria are determined solely from MRI. However, MRI can reveal the soft-tissue component to great advantage and can maximize the positivity of diagnosing flexion cases. Two important features, namely the disc and PLC disruption, can be identified and added to the score. In centres where MRI is not readily available, the conventional technique can still be utilized to correctly identify flexion cases, as five important criteria can be promptly measured. CT importance lies within the anatomical confirmation of hangman's injury by observing the pars fracture and seeing the involvement of different vertebral elements;⁹ however, we believe that its role in diagnosing flexion cases can be overcome by plain radiograph and MRI. To sum up, imaging studies can be tailored according to availability in different centres and taking into consideration each individual case.

Limitations

It is a retrospective study performed in a single centre with relatively small number of cases. Images are static representations of the injury mechanism and do not convey the actual sequence of forces in real time. So, the depiction of a flexion or extension type of hangman's fracture represents only the final position in which the injured spine has come to rest.

The assignment to test and control groups was made based on expert consensus; however, such an assessment is initially required to establish more objective criteria for future evaluation. Interoperator variability in measurements is inevitable in such radiographic studies.

Table 5. Validity parameters for the score of positive criteria when used as test to predict flexion-type injury

Positive if $\geq$ cut-off value	Sensitivity	Specificity	Accuracy	PPV at pre-test probability		NPV at pre-test probability = 10%
				50%	90%	
Score of positive criteria (maximum = 7)						
4 (highest sensitivity and optimum cut-off value)	100.0	96.9	97.4	97.0	99.7	100.0
5 (highest specificity)	83.3	100.0	97.4	100.0	100.0	98.2

NPV, negative-predictive value; PPV, positive-predictive value.

Figure 8. A patient with flexion hangman's fracture: (a) lateral radiography, (b) sagittal reformatted CT image and (c) sagittal T_2 weighted MR images of the cervical spine are showing flexion angulation of the C2 body. Angles A and B, interspinous angle and angle at fracture site are above the cut-off values. There is also widening of the interspinous distance greater than double as well as the interspinous angle. MRI is showing disruption of the posterior ligamentous complex and the disc. Total score is 7.

CONCLUSION

This study demonstrates that the presence of four of the seven imaging criteria can identify flexion hangman's fracture:

- C2–3 lower end-plate angle $>16^\circ$
- C2–3 posterior vertebral wall angle $>15^\circ$
- C1–2 interspinous angle $>28^\circ$
- C1–2 interspinous distance more than double that of C2–3
- C2–3 disc disruption

- C1–2 PLC disruption
- Fracture site angle $>24^\circ$.

This scoring system is based on a single-centre observation and it needs to be supported by further research. The authors suggest future studies on larger number of patients from multiple centres taking into consideration assessment of intraobserver and interobserver variability, which was not assessed in the present study.

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