Radiological features of traumatic vertebral endplate fracture: an analysis of 194 cases with 263 vertebral fractures

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Abstract
Background: The importance of identifying osteoporotic vertebral endplate or and cortex fracture (ECF), which primarily includes endplate fracture (EPF) and vertebral anterior cortex buckling, has been recognized. However, some old traumatic ECFs with healing process in the elderly may be mistaken as osteoporotic. This study analyzes the radiological features of traumatic EPF.

Methods: This was a retrospective analysis of 194 spine trauma patients with 263 vertebral fractures (mean age: 42.11 ± 9.82 years, 118 males and 76 females). All patients had traumatic EPF identified by X-ray/CT/MRI.

Results: The involved vertebra was mostly L1 (29.7%), followed by T12 and L2. Except EPFs involved both superior and inferior endplates (12.6%), only 1.9% involved inferior endplate alone, with the majority involved superior endplate. If each endplate was divided into five segments of equal length (from anterior to posterior: a1, a2, m, p2, p1), the most depressed point of superior EPFs was mostly at segment-a2 (approximately 45%), followed by segment-a1 (approximately 20%) or segment-m (approximately 20%), and very rarely at segment-p1. The upper 1/3 of anterior vertebral wall was more likely to fracture, followed by middle 1/3 of anterior wall. For posterior vertebral wall fracture, 68.5% broke the bony wall surrounding the basivertebral vain. 58.6%, 30.0%, and 11.4% of vertebral fractures had <1/3, 1/3–1/3, and >1/3 vertebral body height loss. As the extent of vertebral height loss increased, the chance of having both superior and inferior EPFs also increased; however, the chance of having inferior EPF alone did not increase.

Conclusion: Traumatic EPF features are characterized, which may help the differentiation of traumatic and osteoporotic EPFs.

Keywords: Spine; Vertebral fracture; Endplate; Traumatic; Vertebral cortex

Introduction
In patients with osteoporosis, a moderate force generated from daily activity may induce vertebral fracture (VF). VF is the most common osteoporotic fracture, and associated with poor life quality, impaired bending and rising, difficulties in the activities of daily living, fragility, higher risk of hospitalization, and higher mortality.[7] Prevalent VFs increase the risk of future osteoporotic fracture independent of bone mineral density (BMD). On spine radiograph, the semi-quantitative (SQ) criteria proposed by Genant et al[8] is commonly used for identifying and grading osteoporotic vertebral deformity. In vertebral osteoporosis, the endplate (EP) becomes weakened due to the loss of support from trabecular bone, and due to thinning of the EP itself. Genant et al[8] described the importance of loss of EP integrity as a characteristic of osteoporotic VF but did not make diagnosis contingent on this sign. Recently, many authors emphasize the importance of identifying osteoporotic vertebral endplate or and cortex fracture (ECF), which primarily include endplate fracture (EPF) and vertebral anterior cortex buckling.[9–13] It has been shown that mild vertebral deformity identified by ECF, but not by Genant’s SQ criteria, are associated with low BMD.[10,13] Lentle et al[11] showed ECF positive grade-1 vertebral deformity was associated with higher risk of VFs as well as nonvertebral major osteoporotic fracture, while grade-1 SQ defined vertebral deformity was not associated with higher non-vertebral fracture. In elderly females, Wang et al[16] showed, within the same mild/moderate osteoporotic vertebral deformity grades, compared with the subjects without ECF, the subjects with...
ECF are associated with a higher short-term future risk of osteoporotic vertebral deformity progression and new incident osteoporotic vertebral deformity; compared with vertebrae without SQ vertebral deformity, ECF negative mild and moderate osteoporotic vertebral deformities did not have a higher short term future risk for new incident vertebral deformity. Thus, ECF is a distinct sign of VF and should be recognized.

However, evaluation of osteoporotic ECF can be difficult. A VF identified in an elderly person might be due to a traumatic event that occurred many years earlier when the vertebra was under a high impact force, even though bone strength was then normal. Some old traumatic VFs in the elderly may be mistaken as osteoporotic. The radiographic appearance of osteoporotic ECFs has been recently described by us[13,14,18-21] and others.[9,22] The current study aims to analyze the radiological features of traumatic EPF. It is expected that the traumatic EPF features characterized in this study will help the more difficult diagnosis of osteoporotic EPF.

Materials and methods

This was a retrospective study with patients all treated for acute spine trauma during the period of January 2017 and December 2018. The institutional ethics committees approved this study and informed consent from patients was waivered. The inclusion criteria were consecutive trauma patients had EPF identified by X-ray, and/or CT, and/or MRI, with all male subjects less than 56 years old and female subjects less than 51 years old. The spine site for imaging was selected according to the trauma location. Patients’ medical records were checked to validate that none of the included cases had malignant, infectious disease of spine, and underlying causes of osteoporosis such as cortisol medication, menopause, and hyperthyroidism. Spine and/or hip BMD was performed in 18 female cases, who were aged close to 50 years, and were confirmed to be normal. We excluded those had insufficient imaging quality and those with previous spine trauma history. The total study cohort had 118 males and 76 females (mean: 42.11 ± 9.82 years; range: 13–55 years). The causes of the trauma included 134 cases (69.1%) of traffic accident, 32 cases (16.5%) with fall from >2 meters height. Other causes included sports injury and heavy subject contusion. There were a total of 263 VFs, including 149 patients with one VF, 28 patients with two VFs, 13 patients with three VFs, two patients with four VFs, and the remaining two cases had five and six VFs, respectively. Twenty EPFs were confirmed by X-ray alone, 191 EPFs were confirmed by CT, 52 EPFs were confirmed by MRI.

Table 1: The distribution of traumatic endplate fractures in superior and inferior end plates, n (%).

| Gender  | sEP (%) | IEP (%) | Both sEP & IEP (%) |
|---------|---------|---------|--------------------|
| Males   | 134 (84.8) | 3 (1.9)  | 21 (13.3)         |
| Females | 91 (86.7)  | 2 (1.9)  | 12 (11.4)         |
| Total   | 225 (85.6) | 5 (1.9)  | 33 (12.6)         |

iEP: inferior endplate; sEP: superior endplate.

Results

The most involved vertebra was L1 (29.7%, 25.3% for males and 36.5% for females), followed by T12 (18.3%, 17.7% for males and 19.2% for females), and then by L2 (12.9%, 14.6% for males and 10.6% for females) [Figure 2]. The proportion of EPF involving sEP (superior endplate) or iEP (inferior endplate) is shown in Table 1. Except EPFs involved both sEP and iEP (12.6%), only approximately 1.9% involved iEP alone, with the vast majority singular EPF involved sEP. The in-plane AP distribution of traumatic EPFs is shown in Table 2. For both males and females and both sEP and iEP, the most depressed point of fractures occurred mostly at segment-a2, followed by segment-a1 or segment-m; while infrequently at segment-p2, and rarely at segment-p1.

According to the Denis’ spine fracture classification, 152 vertebrae (57.8%) showed compression VF, 62 vertebrae...
(23.6%) showed burst VF, 32 vertebrae (12.1%) showed flexion-distraction VF, and 17 vertebrae (6.5%) showed fracture-dislocation VF. The distribution of most depressed point of EPF in different Denis’ classification VFs is shown in Table 3. In the compression VF and burst VF, the most depressed point of the superior EPFs were mostly in the segment-a2, and followed by segment-a1; while flexion-distraction VF and fracture-dislocation VF had more diverse distribution for the most depressed point.

With anterior and posterior vertebral walls divided into upper, middle and lower parts, in all type of EPFs the upper
1/3 of anterior wall was more likely to have associated fracture, followed by middle 1/3 of anterior wall [Table 4]. For posterior wall associated fracture, the middle 1/3 was more likely to involve. Moreover, 68.5% (67.2% for males and 70.5% for females) broke the bony wall surrounding the basivertebral vein [Figure 3]. Burst, Flexion-distraction, Fracture-dislocation VF commonly involved both anterior and posterior walls.

According to vertebral height loss, 154 (58.6%) VFs had <1/5 height loss, 79 (30.0%) VFs had 1/5–1/3 height loss, and 30 (11.4%) had >1/3 height loss. Table 5 shows less than 1/5 height loss was more likely to have compression VF and less likely to have flexion-distraction or fracture-dislocation VFs. On the other hand, more than 1/3 height loss is less likely to have only compression VF, and more likely to have flexion-distraction or fracture-dislocation VFs. As vertebral height loss increased, the chance of having both sEPF and iEPF also increased; however, the chance of singular inferior EPF remained low.

Discussion

In the aged population, approximately 86% of the fractures are due to low energy trauma followed by moderate or no trauma in conditions of general fragility of bone, mainly in osteoporotic patients. [27] EPF is a distinct sign of VF and should be recognized. [19-22] The differentiating between old traumatic VF and osteoporotic VF

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### Table 2: Anterior-posterior distribution of the most depressed point of endplate fractures.

| Fracture type         | Number of endplate fractures at five anterior-posterior segments |
|-----------------------|------------------------------------------------------------------|
|                       | a1 | a2 | m   | p2 | p1 | Total |
| Compression sEPF      | 34 | 69 | 34  | 13 | 0  | 150   |
| iEPF                  | 0  | 4  | 1   | 0  | 0  | 5     |
| Burst sEPF            | 15 | 32 | 6   | 8  | 1  | 62    |
| iEPF                  | 3  | 2  | 3   | 0  | 1  | 9     |
| Flexion-distraction sEPF | 8 | 7  | 9   | 5  | 0  | 29    |
| iEPF                  | 0  | 1  | 3   | 2  | 4  | 10    |
| Fracture-dislocation sEPF | 4 | 7  | 2   | 4  | 0  | 17    |
| iEPF                  | 2  | 6  | 6   | 0  | 0  | 14    |
| Total sEPF            | 61 | 115| 51  | 30 | 1  | 258   |
| iEPF                  | 5  | 13 | 13  | 2  | 5  | 38    |

iEP: inferior endplate; sEP: superior endplate.

### Table 3: The distribution of the lowest point of end plate fracture according to Denis’ spine fracture classification, n.

| Fracture type       | Number of endplate fractures, n |
|---------------------|---------------------------------|
| Compression         | 152                             |
| Burst               | 62                              |
| Flexion-distraction | 32                              |
| Fracture-dislocation| 17                              |
| Total (n = 263)     | 152                             |

### Table 4: Denis’ spine fracture classification and vertebral anterior/posterior wall involvement, n.

| Fracture type       | Anterior wall | Posterior wall |
|---------------------|---------------|----------------|
|                     | No frac | Up 1/3 | Mid 1/3 | low 1/3 | Total segments | No frac | Up 1/3 | Mid 1/3 | low 1/3 | Total segments | Both A&P frac |
| Compression (n = 152) | 15  | 123  | 28  | 7  | 173 | 152 | 0  | 0  | 0  | 152 | 0  |
| Burst (n = 62)       | 3   | 49   | 27  | 4  | 83  | 0   | 43 | 38 | 3  | 84  | 59  |
| Flexion-distraction (n = 32) | 1  | 24   | 22  | 9  | 56  | 0   | 16 | 24 | 5  | 45  | 31  |
| Fracture-dislocation (n = 17) | 1  | 14   | 16  | 0  | 31  | 0   | 14 | 17 | 5  | 36  | 16  |
| Total (n = 263)      | 20  | 210  | 93  | 20 | 343 | 152 | 73 | 79 | 13 | 317 | 106 |

*Note fracture can involve one or more segments of anterior wall and posterior wall. frac: fracture; A&P: anterior and posterior wall.
radiologically may be challenging, as they may have some similarites in appearance, such as EP depression.\cite{28} In clinical practice, there is a tendency sometimes to attribute prevalent VFs in elderly patients to osteoporosis, only to discover on close questioning of the patient that it may be the result of a traumatic fracture sustained during young adulthood. For the purpose of further clarification, this study analyzed the radiological features of traumatic EPF/ECF. Traumatic EPF features are then compared with the features of osteoporotic EPF as recently detailed by us.\cite{13,14,16,18,19}

A comparison Figure 1 of this paper and Figure 3 of Deng et al.\cite{13} shows traumatic VF and osteoporotic VF have similar distribution for vertebral level. For all cases, thoracolumbar junction had the highest prevalence of VF with L1 most commonly involved (males 25.3%/females 36.5% for traumatic VF and males 26.4%/females 24.1% for osteoporotic VF), and notably L2 and L3 vertebrae were also frequently involved. The thoracolumbar junction being most vulnerable for trauma has long been recognized.\cite{29,30}

It has been known that sEP is injured more often than iEP, as sEP is thinner and less supported by trabecular bone.\cite{13,33} In an ex vivo biomechanical testing, Zhao et al.\cite{31} reported compressive loading resulted in sEP damaged in 55 out of 57 specimens and the iEP damaged in only two (2/57; 48% females, age: 81 ± 9 years for 17 females and 76 ± 10 years for 18 males). These results from biomechanical testing are rather similar to the results of the current study. We showed that except traumatic EPF involved both sEP and iEP, only approximately 1.9% involved iEP alone. This results contrast with osteoporotic EPF results,\cite{19} where for singular EPF (only one EP in a vertebra), the ratio of superior EPF occurrence to inferior EPF occurrence was 9.63 (9.8% involved iEP) for males and 4.3 (17.4% involved iEP) for females. Thus iEP is more weakened during osteoporosis such that inferior EPF is relatively more common in osteoporotic VF than traumatic VF. This would also suggest that a standalone inferior EPF is more likely to be osteoporotic than traumatic.

Jiang et al.\cite{9} described osteoporotic EPF most commonly occurs at the center of EP, that is, segment-m. This has been confirmed by our study.\cite{19} There is in-plane regional variation in thickness of EP, being greater adjacent to the annulus than the nucleus.\cite{33} In addition, the central endplate has a greater concentration of marrow contact channels in the region which is known to be most porous.\cite{36} We have previously showed osteoporotic EPF most commonly occurred at segment-m (approximately 70%), followed by segment-a2 (approximately 25%), and then segment-p2 (approximately 5%–10%).\cite{19} Osteoporotic EPF did not occur at the most anterior and most posterior 1/5 segments of EP (segment-a1 or p1).\cite{19}

The current study shows different distribution pattern. For sEPF, 44.6% (115/258) occurred in segment-a2,
followed by 23.6% (61/258) of segment-t1, and then by 19.8% (51/258) of segment-m. Therefore, traumatic EPFs are more evenly distributed as opposed to osteoporotic EPF which more focuses on segment-m. Traumatic EPF can also occasionally occur in a segment-p1, and an EPF with focus on segment-a1 would unlikely be osteoporotic.

Based on radiographic studies, it has been generally considered that while osteoporotic ECF may involve anterior wall of the vertebra, it does not involve the posterior wall.[9,13,18,19] Our study shows, for the anterior wall of the vertebra, the co-existing fractures most commonly involve upper 1/3, and followed by middle 1/3, while the lower 1/3 fracture is less common. Of note is that for the posterior wall involvement, 68.5% broke the bony wall surrounding the basivertebral vain. Understandably, this is a biomechanically weak location, and its association with traumatic fracture has been previously reported.[37]

According to vertebral height loss classification,[26] 58.55% VFs had <1/5 height loss, 30.04% VFs had 1/5–1/3 height loss, and 11.41% had >1/3 height loss. This vertebral height loss distribution also differs from that of osteoporotic VF case.[13] Deng et al.[13] noted that, for 71.5% of the males and 82.3% of females, the VFs with ECF had vertebral loss >1/4. For osteoporotic VF, the extent of vertebral height loss is known to be positively associated with prevalence of EPF.[16,19] Che-Nordin et al.[19] reported that for VF <25% height loss, 25% to 40% height loss, and >40% height loss, the involvement of both sEP and iEP was 6.8%, 36.1%, and 76.4% respectively. Therefore, traumatic VFs are more likely to have EPF even when the extent of vertebral height loss is mild [Table 5].

Another point worthy noting is that this study of young and middle-age subjects showed there was no difference in traumatic VFs feature among males and females [Tables 1 and 2]; while osteoporotic VFs have different features for males and females.[13,14,19,26,38] In our Mr & Ms OS (Hong Kong) baseline studies,[13] it was shown that while the overall Genant SQ defined vertebral deformity prevalence is only slightly lower in men than women (ie, 13.2% vs. 16.1%), ECF prevalence is substantially lower in men than women (ie, 5.88% vs. 11.93%). Moreover, 63.2% of the vertebral deformities in men were Genant SQ grade-1, while only 30.5% of the Genant SQ vertebral deformities in women were grade-1.[13] SQ defined vertebral deformities in males with 25% to 34% height loss rarely simultaneously demonstrate ECF, while it is common for vertebral deformities in females with 25% to 34% height loss to be associated with ECF.[14] In proportion, iEP in elderly males is much less likely to have osteoporotic ECF than in elderly females.[19]

This study has a few limitations. This study was primarily focused on EPF characterization, so the vertebral anterior/posterior wall fractures might not have been fully characterized unless they co-exist with EPF. Furthermore, to allow comparison with radiographic ECF features, this study only studied vertebral anterior wall and posterior wall fractures, thus the left/right lateral wall fracture was not analyzed. The ECF features described in this study were primarily from CT and MRI examinations, while the described osteoporotic ECF features were based on radiograph. Currently, radiograph is the recommended technique for osteoporotic VF assessment. Findings on CT and MRI and radiograph may not be totally comparable. On the other hand, it can be assumed that even CT may miss ECF evident on microscopy.[13,38] This study only described acute VFs. In clinical practice, traumatic VF’s radiological healing process is often not systematically followed-up. The mean age of traumatic VF study subjects (42.1 years) is younger than that of comparison subjects of osteoporotic VF (72.5 years).[13,19] Finally, the same size of this study was only modest (194 patients with 263 vertebral fractures, collected over the course of 2 years). A larger sample size collected from multi-centers may offer even fuller features of traumatic ECF/EPF. However, we expect these limitations would not affect the overall conclusions of this study.

In conclusion, the same as osteoporotic EPFs, traumatic EPFs had the highest prevalence at thoracolumbar junction. Unlike osteoporotic EPFs, traumatic EPF’s features did not show gender differences. Except traumatic EPFs involved both sEP and iEP, the vast majority of singular EPFs involved sEP, with only approximately 1.5% involved iEP alone; while 9.8% and 17.4% of osteoporotic EPFs involve iEP alone for males and females respectively. Approximately 45% of traumatic superior EPFs had the most depressed point at segment-t1, followed by approximately 20% at segment-a1 and approximately 20% at segment-m. Traumatic superior EPFs only rarely had the most depressed point at segment-p1. While osteoporotic EPF most commonly occur at segment-m (approximately 70%), and do not occur at the most anterior and most posterior 1/5 segments of EP (segment-t1 or p1). For the associated posterior vertebral wall fractures, 68.5% broke the bony wall surrounding the basivertebral vain; while osteoporotic ECFs generally do not involve posterior vertebral wall. Compared with osteoporotic VF, traumatic VFs are more likely to have EPF even when the extent of vertebral height loss is mild. Features characterized in this study may help the differentiation of osteoporotic EPF and traumatic EPF.

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Conflicts of interest
None.

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