Bone 47 (2010) 111–116

Contents lists available at ScienceDirect

Bone

journal homepage: www.elsevier.com/locate/bone

Vertebral fractures in the elderly may not always be “osteoporotic”

G. Jiang [a], J. Luo [b], P. Pollintine [c], P. Dolan [b], M.A. Adams [b],*, R. Eastell [a]

[a] Academic Unit of Bone Metabolism, Department of Human Metabolism, University of Sheffield, UK
[b] Department of Anatomy, University of Bristol, UK
[c] Department of Mechanical Engineering, University of Bath, UK

ARTICLE INFO

Article history:
Received 1 February 2010
Revised 11 March 2010
Accepted 25 March 2010
Available online 31 March 2010

Edited by: Thomas Einhorn

Keywords:
Vertebral fracture
Osteoporosis
Trauma
Radiographs
ABQ method

ABSTRACT

Introduction: Vertebral fractures in the elderly are often assumed to be “osteoporotic” and require anti-osteoporosis therapy. However, some of these fractures may represent traumatic injuries to vertebrae that have comparatively normal bone mineral density (BMD). We hypothesize that radiographic appearances can be used to differentiate between “osteoporotic” fractures of vertebrae with low BMD and strength, and “traumatic” fractures of vertebrae with normal BMD and strength.

Methods: 73 cadaveric specimens (each comprising two vertebrae with the intervening intervertebral disc and ligaments) were obtained from donors aged 42 to 91 (mean 74) years. Areal BMD was measured in the lateral projection for each vertebral body, using DXA. Each specimen was secured in metal cups containing dental plaster, and compressed to failure at 3 mm/s on a computer-controlled materials testing machine. Mechanical failure was detected by a reduction in the gradient of the load-deformation curve. Compressive deformation for each specimen was limited to 4 mm in order to prevent gross destruction of the vertebra. Radiographs, obtained before and after mechanical loading, were assessed by an experienced radiologist (GJ) who was blinded to BMD and mechanical data. The algorithm-based qualitative method (ABQ) was used to assign each specimen to two possible outcomes: no discernible fracture of either vertebra, or fracture. The latter were further classified into specimens with osteoporotic fracture and those with traumatic fracture, by applying additional criteria for differential diagnosis. The relationship of failure load to BMD was tested using correlation. BMD and failure load for the three diagnostic outcomes were compared using one-way analysis of variance (ANOVA).

Results: Failure load was proportional to BMD ($R = 0.63$, $p < 0.001$). “Osteoporotic,” “traumatic” and “no discernible” fractures were reported in 16, 26 and 31 specimens respectively. “Traumatic” fracture specimens had higher BMD and failed at higher loads than “osteoporotic” fracture specimens ($p < 0.05$).

Conclusions: Some vertebral fractures in the elderly may be traumatic rather than osteoporotic in origin. Our radiological criteria help to differentiate between them.

Introduction

Vertebral body fracture is the most common type of osteoporotic fracture [1]. In vertebral osteoporosis, the endplate becomes weakened due to the loss of support from trabecular bone, and due to thinning of the endplate itself [2–4]. Therefore, in patients with osteoporosis, a moderate force generated from daily activity may be sufficient to induce vertebral fracture. However, a vertebral fracture identified in an elderly person might be due to a traumatic event that occurred recently, or many years previously when the vertebra was under a high impact force, even though bone density was normal.

Traumatic vertebral fractures are commonly seen in young adults, and may persist as permanent deformities. Accurate medical history can be difficult to ascertain due to poor recall in the elderly, and previous radiographs are often unavailable for comparison. Traumatic vertebral fractures could possibly have produced minimal symptoms at the time of injury, or symptoms may have been ignored or interpreted inaccurately, perhaps due to the presence of other injuries [5,6]. For these reasons, some traumatic vertebral fractures in the elderly may be mistakenly treated as osteoporotic.

The first author has developed clinical radiographic methods to distinguish between these different types of vertebral fracture in vivo. However, the clinical criteria (Table 1) have not previously been validated against precise quantitative data concerning the force required to cause fracture. Mechanical loading tests on cadaveric spines can produce experimental vertebral fractures similar to those seen in vivo, using accurately controlled forces. Therefore, we investigated whether the failure load and BMD of cadaveric vertebral specimens that were induced to fracture by mechanical testing varied according to whether the fracture appearances on radiographs were classified as “osteoporotic” or “traumatic.”

---

* Corresponding author. Reader in Spine Biomechanics, Department of Anatomy, University of Bristol, Southwell St., Bristol BS2 8EJ, UK. Fax: +44 117 9254794.
E-mail address: M.A.Adams@bristol.ac.uk (M.A. Adams).

8756-3282/$ – see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.bone.2010.03.019

Methods

Mechanical loading tests were performed on cadaveric spines at the University of Bristol, in experiments that aimed to investigate the mechanical effects of vertebroplasty. Radiographs from this study were analysed at the University of Sheffield and subsequently compared with data concerning failure load and BMD.

Cadaveric specimens

Seventy-three specimens were obtained from the thoracolumbar spine of 27 donors aged 42 to 91 years (mean 74 years). Each specimen was a complete spinal "motion segment" comprising two vertebrae with an intervertebral disc, two posterior articulations, and intervertebral ligaments. None of the donors had experienced prolonged bed-rest prior to death, or suffered from any disease known to influence bone metabolism. Half of the donors were aged 80–90 years. Twelve were men (31 specimens) and 15 were women (42 specimens), and the number of specimens per donor ranged from one to five (Table 2). Procedures for collecting and storing cadaveric material were in accordance with the Human Tissue Act (U.K.). Ethical committee approval was obtained for the experimental procedures from the Frenchay (Bristol) "NRes" ethics committee. Specimens were from all vertebral levels between T7 and L5, with most from the region T11–L3, which are most commonly fractured in elderly patients. We included different levels and both genders to increase the generalisability of results. Specimens with large osteophytes (which interfere with other tests performed by the Bristol group) and certain other pathologic conditions were excluded. Specimens were stored at −20 °C in sealed bags for up to 3 months until required for testing, and subsequently thawed at 3 °C. There is no evidence to suggest that minor variations in the duration of frozen storage could have a major influence on spinal strength.

BMD measurement

Prior to mechanical loading, BMD was measured in the lateral projection using a PIXImus dual-energy x-ray absorptiometer (DXA) (Lunar Corporation, Madison, WI, USA). The average areal BMD (g/cm^2) of the two vertebral bodies was recorded for each specimen, with a precision error of less than 5%. Values of BMD were generally low in this study in comparison to those commonly found in clinical practice, because bone density was measured for vertebral bodies only, without the relatively-dense neural arches. Because of large variations in vertebral BMD in vertebrae from the same cadaver, we compared BMD in each specimen rather than on a per-cadaver basis. For example, in 13 donors, BMD measurements for different vertebrae differed by more than 0.300 g/cm^2. Therefore it was appropriate to analyse BMD on a per-specimen basis, even though BMD values were not all independent.

Mechanical loading experiments

Each motion segment was secured in metal cups containing dental plaster (Ultrahard Die Stone Iso-Type IV, Kerr S.p.A., Italy) and tested on a computer-controlled hydraulic materials testing machine (Dartec-Zwick-Roell, Leominster, UK) [7]. Initially each specimen was subjected to a constant compressive load of 1 kN for 2 h in order to expel some water from the intervertebral disc, and ensure that its water content and internal pressure were within the physiological range [8]. Then, each specimen was positioned in 6–10° of flexion to simulate a stooped forward-leaning posture [9], and compressed to failure at 3 mm/s. Mechanical failure is defined as a permanently-impaired resistance to load, and is revealed by the first reduction in the gradient of the load-deformation graph, which was plotted for each specimen in real-time. The force at failure was recorded as the compressive strength of the fractured vertebra. Because of the subjective interpretation involved, test-retest differences in strength values range between 2% and 8%. Compressive deformation for each specimen was limited to 4 mm in order to prevent gross destruction of the vertebra. Full details of the mechanical testing have been described previously [7]. Earlier work has shown that, when specimens are compressed to failure in this way, fracture is confined to one of the two vertebral bodies, and damage is normally greatest in the region adjacent to the intervertebral disc, which is loaded in a physiological manner by the disc.

Radiography

Lateral radiographs of each specimen (in dental plaster and metal cups as shown in Fig. 1) were obtained, before and after mechanical loading. The superior and inferior surfaces of the vertebrae were obscured by the cups, but subsequent dissection showed that, in all cases, vertebral fracture occurred adjacent to the disc.

Radiological assessment of vertebral fracture

Radiographs were assessed for the identification of incident vertebral fracture using the algorithm-based qualitative (ABQ) method, which is based on endplate depression, as described by Jiang [10]. A vertebra with short height but no endplate depression is not identified as fractured, and this is what distinguishes the ABQ method from other established methods [10,11]. A vertebra identified as fractured is described as osteoporotic if traumatic and pathologic causes can be ruled out, although the ABQ method does not include guidance for recognizing fractures of traumatic origin. Additional criteria for traumatic fracture are shown in Table 1. These criteria were developed through examining the radiological characteristics of vertebral fracture in patients with confirmed history of trauma and in cases from the medical literature [5,12–20]

Assessment was by an experienced radiologist (GJ) blinded to the BMD and mechanical testing results. Vertebral fractures were further evaluated using the additional criteria (Table 1) for differentiating between osteoporotic and traumatic fracture. After mechanical loading, each specimen was classified as having one of three outcomes: (1) osteoporotic vertebral fracture; (2) traumatic vertebral fracture (angular or focal endplate depression, or fracture mainly at the vertebral ring) or (3) no discernible fracture in either vertebra.

Assessment of disc degeneration

Disc degeneration was assessed after loading (by JL) through visual inspection of the dissected disc in horizontal cross-section.

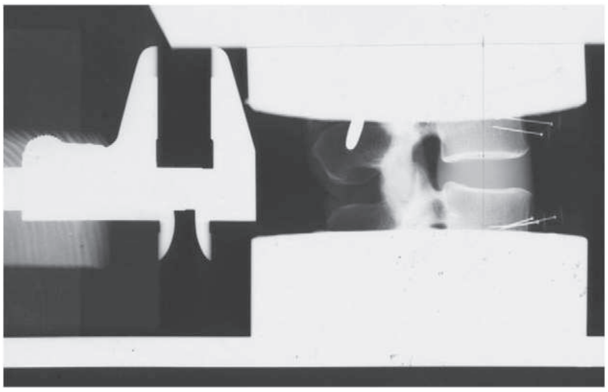

Fig. 1. Radiograph of a vertebral specimen embedded in two metal cups containing dental plaster. Pins inserted into the vertebrae were used to detect vertebral movements.

Table 1
Criteria for the radiological differential diagnosis of traumatic and osteoporotic vertebral fracture, as used in this study.

	Traumatic vertebral fracture	Osteoporotic vertebral fracture
Vertebral body	One or more of the following: 1. Angulated endplate 2. Focal endplate fracture 3. Fracture mainly at vertebral ring 4. Sign of vertical split 5. Bone fragmentation 6. Neural arch fracture 7. Impingement of adjacent vertebra 8. Bridging osteophytes 9. Sclerosis at the fractured endplate	Endplate depression with or without cortex fracture
Disc space	Decreased, increased, or unchanged	Increased
Kyphosis	Yes, when there is fracture of the anterior cortex or damage to the anterior disc	Yes for wedge or crush fracture when the anterior cortex is more severely fractured than the posterior cortex
Height loss	Yes, when there is cortical fracture or disc damage	Yes, for wedge and crush fracture

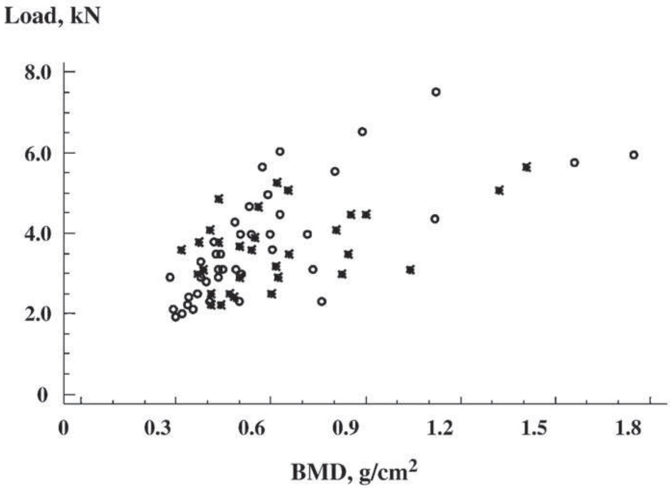

Fig. 2. Relationship between BMD and failure load for 73 specimens (1 kN = 102 kg). Correlation coefficient (R) = 0.63, p<0.001. ∗: Specimens from male donors (R = 0.50, p<0.005);○: Specimens from female donors (R = 0.70, p<0.001).

Degeneration was graded on a scale of 1 (normal) to 4 (severely degenerated) [21].

Statistical analysis

The relationship between BMD and failure load was tested using Pearson's correlation. BMD and failure load for the three diagnostic outcomes were compared using one-way analysis of variance (ANOVA) followed by post-hoc (LSD) tests. $p<0.05$ was considered statistically significant. Analyses were performed using Statgraphic Plus for Windows version 5.0 (Statistical Graphics Corporation, Rockville, MD, USA).

Results

Failure load and BMD

Failure load ranged from 1.1 kN to 6.8 kN (mean 2.9 kN), and areal BMD of the vertebral bodies ranged from 0.268 to 1.794 g/cm^2 (mean 0.601 g/cm^2). Failure load and BMD both increased at lower spinal levels (i.e. were greater at lumbar than thoracic levels: $p<0.001$). However, there was little dependence on age in the present (mostly old) sample: for example, there was no significant correlation between vertebral BMD and age ($R = 0.18$, $p = 0.15$). Fig. 2 shows a strong linear relationship between BMD and failure load ($R = 0.63$, $p<0.001$) and the relationship remains highly significant if male and female specimens are analysed separately. If the analysis is restricted to vertebral levels T11–L5 (the most common levels for vertebral fracture), the correlation coefficient for both genders combined is 0.64 ($p<0.005$).

Radiological appearances

Fig. 3 shows examples of radiographs classified as having osteoporotic fracture, traumatic fracture and no discernible fracture, according to the ABQ method and the additional criteria. More than half of the specimens sustained visible fracture (42/73); these all occurred at a single endplate only, and all fractures were mild because mechanical loading had been terminated at a maximum reduction in specimen height of 4 mm, and many fractured specimens lost less than 2 mm in height. More specimens exhibited the appearance of “traumatic” (26/42) than “osteoporotic” (16/42) fracture. The “traumatic” fractures occurred almost exclusively at the superior endplate of the lower vertebra (25/26 specimens), while the “osteoporotic” fractures occurred with similar frequency at the superior (9/16) and inferior endplates (7/16) always adjacent to the disc. Among specimens with “traumatic” fracture, 9 exhibited an abrupt or angulated fracture at the endplate, 10 a focal fracture of the endplate, and 7 a fracture mainly at the vertebral ring. Where two or more vertebral specimens originated from a single donor, the incident fractures were of the same type (either “osteoporotic” or “traumatic”) in all but four cases. However in three of these four, the traumatic appearances were too subtle to interpret with confidence.

Relationships between radiological appearances, BMD and failure load

Failure load differed significantly between the three fracture groups ($p<0.001$) whereas BMD showed marginal differences ($p = 0.08$). Post-hoc comparisons showed that specimens with “traumatic” fracture or “no discernible” fracture failed at higher load than those with “osteoporotic” fracture, as shown in Table 3. Furthermore, specimens with “traumatic” fracture had higher BMD than those with “osteoporotic” fracture. Similar results were obtained if the analysis was restricted to those 45 specimens aged over 70 years, indicating that age had little influence on the findings.

All specimens exhibited some degree of disc degeneration. Disc degeneration grade 2, 3 or 4 was observed in 32, 31 and 10 specimens, respectively, but disc degeneration grade was not a significant predictor of fracture outcome.

Discussion

Differentiating between traumatic and osteoporotic vertebral fractures radiologically can be challenging, because they may have some similarities in appearance, such as depression of the endplate. To our knowledge, this issue has not previously been addressed in the research literature. Our study is the first in which mechanically induced vertebral fracture has been evaluated radiologically using the ABQ method and additional criteria. The results support our hypothesis because they show that fractures distinguished radiologically as being “osteoporotic” occurred at lower forces and in specimens with lower mean BMD compared to “traumatic” fractures. However, some individual specimens with low BMD also exhibited traumatic appearance.

These results are consistent with the recent finding that high-trauma non-vertebral fractures are more common in those with low

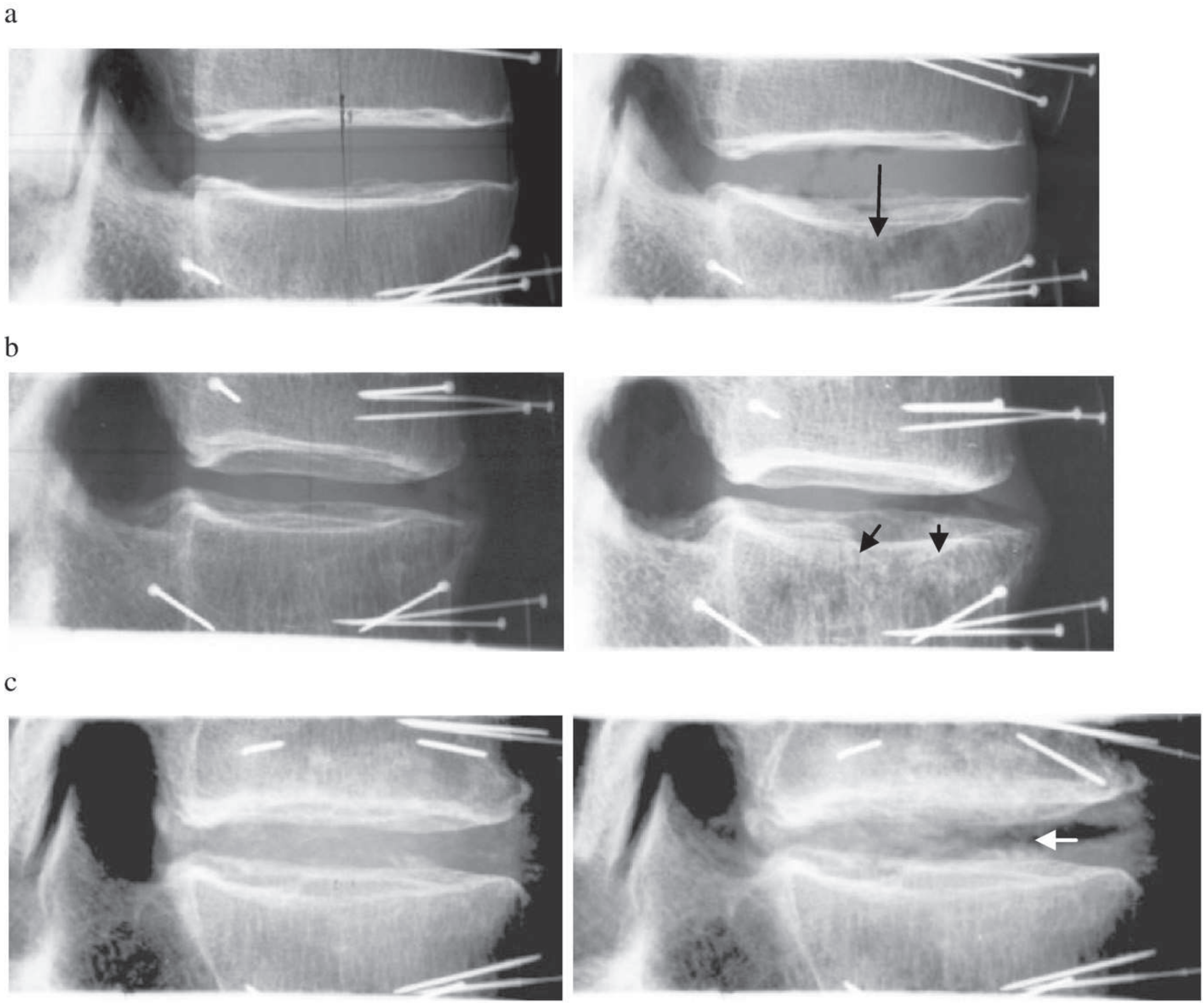

Fig. 3. Radiographs of T11–12 motion segments obtained pre-fracture (left) and post-fracture (right). Post-fracture appearances were classified by the ABQ method and the additional criteria for traumatic fracture. (a) Osteoporotic fracture: male donor age 84 years, mean BMD 0.443 g/cm^2, failure load 1.4 kN. The superior endplate of vertebra T12 has a smooth concave depression (arrow) following fracture and the trabeculae beneath the endplate are clearly damaged. Small vacuum phenomena are visible within the intervertebral disc. (b) Traumatic fracture: female donor age 76 years, mean BMD 0.483 g/cm^2, failure load 3.5 kN. The anterior half of the superior endplate of vertebra T12 has a focal depression after fracture (arrows). (c) No discernible fracture: male donor age 84 years, mean BMD 0.488 g/cm^2, failure load 1.6 kN. The endplates of both vertebrae were slightly oblique on both the pre- and post-loading radiographs. There is no evidence of fracture following loading, but there is a vacuum phenomenon (arrow) within the intervertebral disc towards the anterior border.

BMD [22]. Evidently, weak bones are more vulnerable to injury in all situations, including those that involve severe trauma and moderate habitual loading, whereas strong bones with high BMD are vulnerable only to severe trauma. Several specimens in the present study had the appearance of traumatic fracture while having relatively low BMD. It is possible that the cartilage or bony endplate may have been damaged during the lifetime of the donor, although this was not discernible on the pre-loading radiographs. If so, the previously damaged vertebra might fracture more easily and give the appearance of traumatic fracture. Roaf [15], for example, has suggested that previous damage may make a greater contribution to fracture than the force which induces the discernible fracture and this could be true even when BMD is normal. This may partially explain why an existing vertebral fracture increases the risk of incident fracture independently of BMD [23]. At the time of a traumatic vertebral fracture, other vertebrae may sustain non-discernible damage, which may predispose to later fracture as a result of relatively low trauma, and this may help explain why some of the "traumatic" specimens in our experiment failed at lower loads.

In clinical practice we have noticed a tendency sometimes to attribute prevalent vertebral fracture 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. We documented the specific appearances of these fractures over several years to formulate these additional criteria for the differentiation of traumatic and osteoporotic vertebral fractures. On a lateral projection radiograph, traumatic endplate depression is likely to be abrupt and sharply angulated, or focal, or mainly involve the vertebral ring. By contrast, in osteoporotic endplate fracture, the depression will form a broad smoother concave line.

Our criteria for the identification of traumatic vertebral fractures differ from the classification systems commonly used in clinical orthopedics such as the two column [13,14] and three column concepts [12]; these are more suited to the orthopaedic assessment of traumatic fracture for the purpose of evaluating spinal cord injury and stability of the spine. Most traumatic fractures seen in osteoporosis clinics are long-standing, so no anti-osteoporotic treatment is needed. If a traumatic fracture has occurred recently, the patient may need to

Table 2
Characteristics of donors.

Donor	Sex	Age at death	Number of specimens	Vertebral level of specimens
1	Female	42	5	T7–8, T9–10, T11–12, L1–2, L3–4
2	Female	51	4	T10–11, T12–L1, L2–3, L4–5
3	Female	51	4	T10–11, T12–L1, L2–3, L4–5
4	Female	58	4	T7–8, T9–10, L2–3, L4–5
5	Female	58	2	L1–2, L3–4
7	Female	64	1	T10–11
11	Female	76	4	T7–8, T9–10, T11–12, L3–4
12	Female	76	1	L1–2
13	Female	77	2	T10–11, T12–L1
14	Female	80	2	L1–2, L3–4
15	Female	80	3	T12–L1, L2–3, L4–5
16	Female	81	2	T9–10, L4–5
20	Female	83	2	L2–3, L4–5
23	Female	85	3	T8–9, L1–2, L3–4
27	Female	91	3	T7–8, L2–3, L4–5
6	Male	61	4	T9–10, T11–12, L1–2, L3–4
8	Male	66	3	T10–11, L1–2, L3–4
9	Male	67	1	T10–11
10	Male	74	2	T11–12, L1–2
17	Male	82	2	L1–2, L4–5
18	Male	82	4	T7–8, T11–12, L1–2, L4–5
19	Male	82	2	T8–9, T10–11,
21	Male	84	4	T7–8, T9–10, T11–12, L1–2
22	Male	84	2	T11–12, L3–4
24	Male	86	3	T10–11, T12-L1, L2–3
25	Male	88	2	T12-L1, L4–5
26	Male	89	2	T11–12, L2–3

T, thoracic vertebrae; L, lumbar vertebrae. All specimens are listed in ascending age for female donors, followed by male donors.

be referred to an orthopaedic surgeon to assess stability and potential neurological impairment. For example, a traumatic wedge fracture with more than 50% anterior height reduction could have associated damage to posterior ligaments, which would make the spine unstable. Impingement of the adjacent vertebra is the likely consequence [24–26].

In this study, we were able to test only the first three out of 9 criteria for traumatic fracture (Table 1). Nevertheless, we observed more fractures with traumatic ($n=26$) than with osteoporotic appearances ($n=16$). This raises the question as to whether we can expect to find a similar proportion of traumatic fractures in the elderly population. Certainly, living people could sustain some trauma-induced fractures which could mimic osteoporotic fractures. Compressive forces on the spine often rise to high levels during everyday activities, largely as a result of muscle tension. For example, lifting a 10-kg object in an unfavorable posture could generate a compressive force on the spine [9] as great as, or greater than the failure loads reported in the present study (Table 3), and a high impact trauma could be suffered by anyone. Osteoporotic patients with traumatic fractures would not be over treated if given anti-osteoporosis treatment, but they may also need to be referred to an orthopaedic surgeon if the fracture is acute.

All specimens failed mechanically on loading, but some had no discernible fracture of the vertebral body. One reason for this was that the changes were often subtle, due to the design of the loading experiment, but there could be several other possible explanations. Firstly, there could be damage that is undetected by conventional radiography, such as a traumatic Schmorl's node [27,28] or horizontal cracks in the endplate without a depression: these changes can be demonstrated by MRI [29]. Secondly, there may have been fracture at the cartilaginous rather than the bony endplate, which has been reported previously in specimens subjected to a similar loading regime [30]. Thirdly, the specimen may have sustained damage to the intervertebral disc rather than to the vertebral bodies. Experiments on young and middle-aged cadaveric spines have shown that compressive overload normally damages the vertebral body before any other structure [31,32] but this may not be the case for specimens from elderly donors, in whom the disc may be severely degenerated and the neural arches substantially load-bearing [33]. The youngest donor in this study was 42 years old and none of the specimens had normal (grade 1) discs. (Intervertebral discs were not removed prior to loading so that vertebral fractures could be induced by loads transmitted naturally via the disc.) Whatever explanation is favored for the non-discernible fractures, it is likely that relatively minor vertebral fractures occur in-vivo without being detected radiographically.

Table 3
Relationships between radiological appearances, failure load and BMD.

	"Osteoporotic" fracture ($n=16$)	"Traumatic" fracture ($n=26$)	No discernible fracture ($n=31$)	p-value
Failure Load, kN	1.80 (1.3, 2.4)	3.09* (2.7, 3.5)	3.24* (2.8, 3.6)	<0.001
BMD, g/cm^2	0.454 (0.305, 0.603)	0.668* (0.581, 0.784)	0.620 (0.513, 0.727)	0.08

Results are presented as mean values (95% confidence intervals). Results of the one-way ANOVA are in the final column. *Indicates significant differences from the "osteoporotic" fracture group, using post-hoc LSD tests ($p<0.05$).

To differentiate between 'traumatic' and 'osteoporotic' fractures in more severely injured vertebrae (items 4–6 in Table 1), we would need to compress the spine specimens by more than 4 mm. This would increase the risk of fracture to both of the vertebrae comprising a motion segment, and this in turn would make it difficult to determine which vertebra failed at which compressive load. Prospective in-vivo studies are necessary to evaluate secondary changes (items 7–9 in Table 1) following traumatic fracture, such as bridging osteophytes which would require a minimum of 3 months of follow-up.

The ABQ method has been validated longitudinally for the diagnosis of vertebral fracture [31] and the algorithm is effective for ruling out non-fracture deformities. The additional criteria for the differential diagnosis of traumatic fracture aim to reduce the probability of over-treating patients for osteoporosis, through helping physicians to explore the history of a possible traumatic event. Although in-vitro mechanical loading tests do not exactly replicate real life [32], the results of the present study may stimulate further examination of the nature of vertebral fractures in the elderly.

Acknowledgments

Dr Jin Luo's contribution to this research was funded by Action Medical Research and the Hospital Saving Association Charitable Trust. Manuscript preparation was partly funded by the National Institute for Health Research via its Biomedical Research Units (BRU) funding scheme for musculoskeletal health (April 2008 to March 2012). We would like to thank the 'BRU editorial board' and Sister Judith Finigan for their suggestions and comments on this manuscript. The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Appendix. Rationale for the ABQ criteria for distinguishing between traumatic and osteoporotic vertebral fractures

Vertical bulging of the endplate occurs when a spine specimen is subjected to compressive loading [34]. When this occurs, blood is forced out of the trabecular bone of the vertebral body into the peri-vertebral sinuses, and this is an important shock-absorbing mechanism. If the load is lower than the ultimate strength of the endplate, the bulging is reversible. The endplate is the weakest part of the specimen under compression [12,32,35]. Compression does not damage the human annulus fibrosus before the vertebral body [32,36] although the annulus can bulge radially after the nucleus pulposus loses volume following endplate fracture or disc degeneration [37]. The ultimate strength of the endplate depends on the support of trabeculae beneath it [30,38].

An osteoporotic vertebra has less resistance to compressive force, so the bony endplate can be easily depressed to form a concave fracture (Fig. 3a). If the anterior cortex receives more loading as a result of thoracic kyphosis, or if the vertebral cortex is loaded as a result of disc nucleus decompression [39], then a wedge or crush fracture can occur [5,40,41]. Following this, the cartilaginous endplate covering the bony endplate becomes stretched and it may subsequently rupture if the depression of the bony endplate is severe.

A normal vertebral body can withstand greater force before it reaches the point of traumatic fracture, and this may result in more severe damage as evidenced by vertical splits, bone fragments, neural arch fracture and fracture mainly at the vertebral ring, for example (Table 1). High impact trauma could also damage the endplate, the ligaments and the disc simultaneously. Damage to the endplate could result in focal fracture (Fig. 3b), or angulated or abrupt endplate fracture (Table 1). Ligamentous damage can cause impingement of the adjacent vertebrae (Table 1). Damage to the disc and ligaments could also produce secondary changes such as bridging osteophytes and sclerosis of the fractured endplates (Table 1).

References

[1] Ross PD. Clinical consequences of vertebral fractures. Am J Med 1997;30(suppl): 43S.

[2] Atkinson PJ. Variation in trabecular structure of vertebrae with age. Calcif Tissue Res 1967;1(1):24–32.

[3] Vernon-Roberts B, Pirie CJ. Healing trabecular microfractures in the bodies of lumbar vertebrae. Ann Rheum Dis 1973;32:406–12.

[4] McDonnell P, McHugh PE, O'Mahoney D. Vertebral osteoporosis and trabecular bone quality. Ann Biomed Eng 2007;35(2):170–89.

[5] Schmorl G, Junghanns H. Pathologic changes involving the osseous structure and the true articulations of the spine. In: Besemann EF, editor. The human spine in health and disease II. New York, London: Grune & Stratton; 1971. p. 104–35.

[6] Adams JC, Hamblen DL. Outline of fractures including joint injuries. 11th ed. Churchill Livingstone; 1999.

[7] Luo J, Skrzypiec DM, Pollintine P, et al. Mechanical efficacy of vertebroplasty: influence of cement type. Bone 2007;40:1110–9.

[8] McMillan DW, Garbutt G, Adams MA. Effect of sustained loading on the water content of intervertebral discs: implications for disc metabolism. Ann Rheum Dis 1996;55(12):880–7.

[9] Dolan P, Earley M, Adams MA. Bending and compressive stresses acting on the lumbar spine during lifting activities. J Biomech 1994;27(10):1237–48.

[10] Jiang G, Eastell R, Barrington NA, et al. Comparison of methods for the visual identification of prevalent vertebral fracture in osteoporosis. Osteoporos Int 2004;15(11):887–96.

[11] Ferrar L, Jiang G, Armbrecht G, et al. Is short vertebral height always an osteoporotic fracture? The Osteoporosis and Ultrasound Study (OPUS). Bone 2007;41(1):5–12.

[12] Denis F. The three column spine and its significance in the classification of acute thoracolumbar spinal injuries. Spine 1983;8:817–31.

[13] Holdsworth FW. Fractures, dislocations, and fracture—dislocations of the spine. J Bone Joint Surg Br 1963;45:6–20.

[14] Holdsworth FW. Fractures, dislocations, and fracture—dislocations of the spine. J Bone Joint Surg Am 1970;52:1534-1511.

[15] Roaf R. A study of the mechanics of spinal injuries. J Bone Joint Surg Br 1960;42: 810–23.

[16] Nicoll EA. Fracture of the dorso-lumbar spine. J Bone Joint Surg 1949;31:367–94.

[17] Lob A. Die wirbelsulenverletzungen und ihre ausheilung. Stuttgart: Thieme; 1954.

[18] Jones RW. The treatment of fractures and fracture dislocations of the spine. J Bone Joint Surg 1934;16:30–45.

[19] Davis AG. Fractures of the spine. J Bone Joint Surg 1929;11:133–56.

[20] Wallace JO. Crush fractures of the spine. J Bone Joint Surg 1923;5:28–69.

[21] Adams MA, Dolan P, Hutton WC. The stages of disc degeneration as revealed by discograms. J Bone Joint Surg Br 1986;68:36–41.

[22] Mackey DC, Lui LY, Cawthon PM, et al. High-trauma fractures and low bone mineral density in older women and men. JAMA 2007;298(20):2381–8.

[23] Ross PD, Davis JW, Epstein RS, et al. Pre-existing fractures and bone mass predict vertebral fracture incidence in women. Ann Intern Med 1991;114:919–23.

[24] Campbell SE, Phillips CD, Dubovsky E, et al. The value of CT in determining potential instability of simple wedge-compression fractures of the lumbar spine. AJNR 1995;16(7):1385–92.

[25] Nash CL, Schatzinger LH, Brown RH, et al. The unstable stable thoracic compression fracture: its problems and the use of spinal cord. Spine 1977;2(4): 261–5.

[26] Nagel DA, Koogle TA, Piziali RL, et al. Stability of the upper lumbar spine following progressive disruptions and the application of individual internal and external fixation devices. J Bone Joint Surg 1981;63(1):62–70.

[27] Zhao F, Pollintine P, Hole BD, et al. Discogenic origins of spinal instability. Spine 2005;30(23):2621–30.

[28] Rolander SD, Blair WE. Deformation and fracture of the lumbar vertebral end plate. Orthop Clin North Am 1975;6(1):75–81.

[29] Hamanishi C, Kawabata T, Yosii T, et al. Schmorl's nodes on MRI: their incidence and clinical relevance. Spine 1994;19:450–3.

[30] Zhao F, Pollintine P, Hole BD, et al. Vertebral fractures usually affect the cranial endplate because it is thinner and supported by less-dense trabecular bone. Bone 2009;44(2):372–9.

[31] Finigan J, Greenfield DM, Blumsohn A, et al. Risk factors for vertebral and nonvertebral fracture over 10 years: a population-based study in women. J Bone Miner Res 2008 Jan;23(1):75–85.

[32] Adams MA, Bogduk N, Burton K, Dolan P. The biomechanics of back pain 2nd ed. Churchill Livingstone; 2006.

[33] Adams MA, Pollintine P, Tobias JH, et al. Intervertebral disc degeneration can predispose to anterior vertebral fractures in the thoracolumbar spine. J Bone Miner Res 2006;21(9):1409–16.

[34] Brinckmann P, Frobin W, Hierholzer E, et al. Deformation of the vertebral endplate under axial loading of the spine. Spine 1983;8(8):851–6.

[35] Brinckmann P, Biggemann M, Hilweg D. Prediction of the compressive strength of human lumbar vertebrae. Spine 1989;14(6):606–10.

[36] Jayson ML, Herbert CM, Barks JS. Intervertebral discs: nuclear morphology and bursting pressures. Ann Rheum Dis 1973;32:308–15.

[37] Brinckmann P, Grootenboer H. Change of disc height, radial disc bulge, and intradiscal pressure from discectomy. An in vitro investigation on human lumbar discs Spine 1991;16(6):641–6.

[38] Hulme PA, Boyd SK, Ferguson SJ. Regional variation in vertebral bone morphology and its contribution to vertebral fracture strength. Bone 2007;41(6):946–57.

[39] Adams MA, McNally DS, Dolan P. 'Stress' distributions inside intervertebral discs. The effects of age and degeneration. J Bone Joint Surg Br 1996;78(6):965–72.

[40] Silva MJ, Keaveny TM, Hayes WC. Load sharing between the shell and centrum in the lumbar vertebral body. Spine 1997;22(2):140–50.

[41] Kurowski P, Kubo A. The relationship of degeneration of the intervertebral disc to mechanical loading conditions on lumbar vertebrae. Spine 1986;11:726–31.