Radiography Cannot Examine Disc Injuries Secondary to Burst Fracture

Quantitative Discomanometry Validation

Jaw-Lin Wang, PhD,* Manohar M. Panjabi, PhD,† Yoshihiko Kato, MD,† and Caroline Nguyen, BS†

Study Design. An *in vitro* biomechanical study.

Objective. To examine disc integrity at levels adjacent and next adjacent to the fractured vertebra and to determine if the disc injury can be revealed by radiographs.

Summary of Background Data. Thoracolumbar burst fracture is one of the most common spinal injuries. A fractured vertebra is easy to recognize, but the associated disc injuries are less well known. The disc injury may not be apparent in radiographic images. Quantitative discomanometry, which measures disc pressure and the injected volume, has been found to detect disc injury.

Methods. Nine specimens (T11–L3) with L1 burst fracture included adjacent discs (T12–L1 and L1–L2) and next-adjacent discs (T11–T12 and L2–L3) and were examined with radiographs and quantitative discomanometry, before and after the burst fracture. Statistical analyses were used to determine if the nine quantitative discomanometry parameters, in each of the four discs, were changed by the burst fracture and if the two next adjacent discs sustained different injuries.

Results. After the burst fracture both the adjacent discs were shown to be injured by both radiographic and quantitative discomanometry examinations. Whereas both next-adjacent discs were found to be uninjured by radiograph examination, the quantitative discomanometry found the lower next-adjacent disc (L2–L3) to be injured.

Conclusions. Quantitative discomanometry was successful in finding disc injury, where the radiographs found none. The lower level, next adjacent disc is susceptible to injury during the burst trauma. [Key words: quantitative discomanometry, radiography, disc injury, burst fracture, spine biomechanics] **Spine 2002;27:235–240**

Thoracolumbar burst fracture is one of the most common types of injury of the spine. It represents approximately 15% of all thoracolumbar injuries. Among them, 50–60% are with neurologic deficit.[4] The vertebral body is fractured, and multidirectional mechanical stability of thoracolumbar spine decreases after burst fracture.[12] The functional integrity of the discs after burst fracture, however, is not well investigated.

Discomanometry is defined as the technique of discography that provides qualitative functional evaluation of disc integrity. Quantitative discomanometry (QD) measures both the volume injected and pressure developed within the disc and thus quantifies the disc functional integrity.[3,10] QD studies have shown that there is a significant correlation between the disc pressure parameter and disc integrity.[13] With the pressure gauge needle properly placed in the center of the disc nucleus, QD was found to be a reproducible technique.[3] Nine QD parameters were identified from the pressure–volume curve. These parameters have been shown to quantitatively evaluate the degree of disc injury[13] and degeneration.[2]

Radiographic images are tools commonly used in clinical examination of spinal injuries. It is not known if radiography can identify the disc injury and quantify its severity. The purpose of the study was twofold: 1) to examine integrity of discs adjacent and next-adjacent to the fractured vertebra and 2) to determine if the disc injury can be revealed by radiographic examination.

Materials and Methods

Spine Specimens and Their Preparation. Nine fresh-frozen human cadaveric five-level spine specimens (T11–L3) with an average age of 51 years (range 21–74 years) were used. Each specimen was radiographed, carefully cleaned of muscle tissue, placed in double plastic bags, and frozen at −20 degrees C. The specimen was thawed, and 1.6-mm diameter steel balls were carefully glued inside the spinal canal to define its margins in the sagittal plane.[6] The specimen was provided with quick-setting epoxy mounts at both ends, embedding the upper half of T11 and the lower half of L3, while keeping the body of the L1 vertebra horizontal. The T11–T12 and L2–L3 functional spinal units (FSUs) were protected with tight-fitting braces to minimize injury during the impact (Figure 1)[7]. Briefly stated, the protection is achieved by wrapping the FSU with cellophane plastic wrap and then embedding the FSU in quick-setting epoxy collar. By placing two 2-mm-thick wooden pieces 180° apart around the FSU, the collar is divided into two halves. After complete curing of the epoxy, the collar halves are clamped together tightly with the help of a hose clamp. Subsequent to the burst fracture production, the clamp and collar halves are removed.

QD Apparatus. The technique of QD has been well documented.[2,3,10,13] Briefly, the QD apparatus is composed of a needle, a syringe, an injection pump, a load cell, and a computer (Figure 2). The system records both the volume injected and the resulting disc pressure increase. The system is cali-

From the *Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan, ROC, and the †Biomechanics Laboratory, Department of Orthopaedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut.
Supported by NIH grant ROI AR39209.
Acknowledgment date: January 10, 2001.
First revision date: March 28, 2001.
Second revision date: May 17, 2001.
Acceptance date: July 5, 2001.
Device status category: 1.
Conflict of interest category: 14.

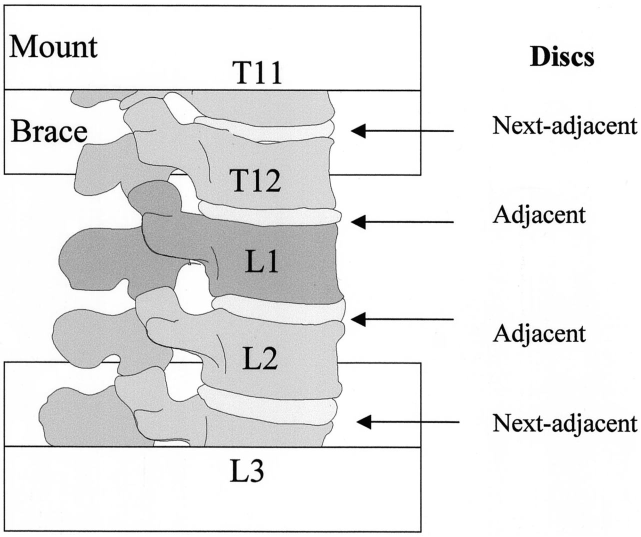


Figure 1. Schematics of a specimen preparation. Outer halves of the upper and lower vertebrae T11 and L3 were mounted in quick-setting resin, and the T11–T12 and L2–L3 levels were provided with tight-fitting braces to protect them during the L1 burst fracture production. Nomenclature for the four discs is also indicated.

brated, using a blocked-needle technique, to compensate for the elasticity of the plastic tubing and syringe.[10] The needle is carefully placed in the center of the disc nucleus. The QD was found to be a reproducible technique for measuring nine parameters obtained from the pressure–volume curve (Figure 3). These parameters can evaluate the degree of disc injury[13] or disc degeneration.[10]

Experimental Protocol. The experimental fracture production technique has been described previously.[6,7,12] A brief description follows. The specimens were impacted with a 3.6-kg initial mass and a 2-kg incremental mass, dropped from a 1.4-m height until a burst fracture was observed in the L1 vertebra. The burst fracture was detected by measuring the canal diameter after each impact using lateral radiographs. The canal was precisely identified by the images of the steel balls lining the canal. The burst fracture at L1 was produced in all nine specimens without any visible fractures of the other four vertebrae of the specimen. Before and after the burst fracture, QD was performed at each of the four disc levels and the pressure–volume data were recorded. Nine parameters were obtained from each pressure–volume curve,[3] as depicted in Figure 3.

Table 1. T12–L1: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Measured, Before and After Burst Fracture

QD Parameter	Before	After	*P* Value
Intrinsic pressure (kPa)	200 (131)	45 (18)	0.003*
Leakage pressure (kPa)	489 (174)	57 (35)	<0.001*
Initial slope (kPa/ml)	4968 (2307)	166 (313)	0.001*
Slope between 0.0 and 0.1 mL (kPa/ml)	2526 (1983)	339 (177)	0.005*
Slope between 1 and 4 mL (kPa/ml)	377 (366)	−2 (1.25)	0.007*
Pressure at 2 ml (kPa)	498 (159)	49 (36)	<0.001*
Pressure at 4 ml (kPa)	509 (142)	40 (30)	<0.001*
Maximum pressure (kPa)	465 (110)	64 (40)	<0.001*
Volume at maximum pressure (ml)	1.74 (1.85)	1.04 (1.42)	0.30

* Significant (*P* = 0.01).

Statistical Analysis. Two-way analysis of variance was used for each QD parameter to determine the differences between the before and after the burst fracture, and between the upper and lower next adjacent discs.

■ Results

Results are divided into two parts: 1) comparison of each disc level before and after the burst fracture (Tables 1–4) and 2) comparison of the upper and lower next adjacent discs, before and after the burst fracture (Tables 5 and 6).

Both discs adjacent to the burst fracture (*i.e.*, T12–L1 and L1–L2) showed dramatic changes because of the burst fracture injury (Tables 1 and 2). Seven of the nine QD parameters showed highly significant ($P < 0.01$) and one parameter significant ($P < 0.05$) decreases. The radiographic examination by an experienced spine surgeon

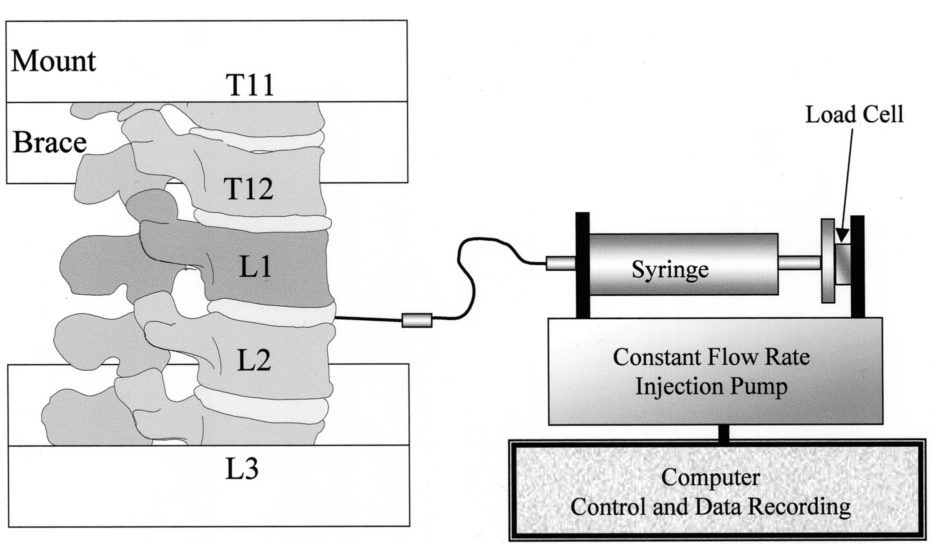


Figure 2. Apparatus for quantitative discomanometry (QD). Notice the constant-flow injection pump, which injects the saline into the disc *via* a syringe, a plastic tube, and a needle, and the computer that controls the pump, and records the disc pressure, *via* a load cell, and the injected volume. Result is the pressure–volume curve.

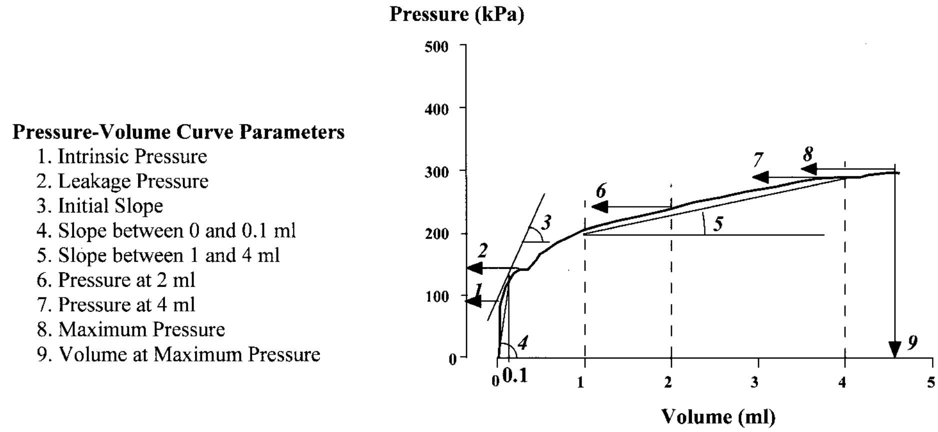


Figure 3. Schematics of a pressure–volume curve obtained using quantitative discomanometry, and the nine QD parameters.

(Y.K.) showed that these two discs were injured in association with the burst fracture. The discs lying between the intact vertebrae (*i.e.*, next adjacent upper and lower discs T11–T12 and L2–L3) showed no significant decreases in the QD parameters, except for the slope between 0 and 0.1 mL (parameter 4) of the L2–L3 disc (Tables 3 and 4). The radiographic examination was also negative (Figure 4).

Next we compared the next-adjacent discs with each other, before and after the burst fracture. Before the burst fracture eight of the nine parameters had lower values for the caudal disc L2–L3, but none of the decreases was significant, except for the slope between 1 and 4 ml (Table 5, parameter 5). However, after the burst fracture the differences between the upper and lower next-adjacent discs became significant for seven of the nine parameters (Table 6). Two of these parameters, namely, leakage pressure (parameter 2) and disc pressure at 2 ml (parameter 6), are shown in Figure 5.

■ Discussion

We used a realistic, quantitative, and well-proven burst fracture model, which included a five-vertebrae thoracolumbar (T11–L3) fresh cadaveric human spine specimen. The four discs were studied by radiography and QD before and after the experimental burst fracture of the L1

Table 2. L1–L2: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Measured, Before and After Burst Fracture

QD Parameter	Before	After	*P* Value
Intrinsic pressure (kPa)	164 (80)	73 (55)	0.022*
Leakage pressure (kPa)	448 (236)	84 (62)	<0.001†
Initial slope (kPa/ml)	4274 (2719)	563 (1585)	0.005†
Slope between 0.0 and 0.1 mL (kPa/ml)	2355 (1513)	547 (471)	0.005†
Slope between 1 and 4 mL (kPa/ml)	287 (231)	1.0 (6.4)	0.002†
Pressure at 2 ml (kPa)	468 (203)	74 (67)	<0.001†
Pressure at 4 ml (kPa)	482 (184)	66 (56)	<0.001†
Maximum pressure (kPa)	431 (138)	90 (66)	<0.001†
Volume at maximum pressure (ml)	1.52 (1.86)	1.03 (1.40)	0.18

* Significant ($P = 0.05$).
† Significant ($P = 0.01$).

Table 3. T11–T12: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Measured, Before and After Burst Fracture

QD Parameter	Before	After	*P* Value
Intrinsic pressure (kPa)	223 (93)	146 (119)	0.206
Leakage pressure (kPa)	600 (0)*	546 (162)	0.434
Initial slope (kPa/ml)	6000 (0)*	5459 (1623)	0.434
Slope between 0.0 and 0.1 mL (kPa/ml)	2439 (1229)	2818 (2081)	0.696
Slope between 1 and 4 mL (kPa/ml)	1091 (542)	3083 (2447)	0.074
Pressure at 2 ml (kPa)	600 (0)*	550 (150)	0.434
Pressure at 4 ml (kPa)	600 (0)*	549 (152)	0.436
Maximum pressure (kPa)	516 (19)	489 (126)	0.611
Volume at maximum pressure (ml)	0.43 (0.23)	0.75 (1.53)	0.629

* Pump capacity = 600 kPa.

Table 4. L2–L3: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Measured, Before and After Burst Fracture

QD Parameter	Before	After	*P* Value
Intrinsic pressure (kPa)	139 (83)	75 (42)	0.065
Leakage pressure (kPa)	546 (161)	226 (223)	0.129
Initial slope (kPa/ml)	5473 (1035)	2781 (3061)	0.060
Slope between 0.0 and 0.1 mL (kPa/ml)	1807 (904)	833 (802)	0.047*
Slope between 1 and 4 mL (kPa/ml)	268 (151)	127 (187)	0.331
Pressure at 2 ml (kPa)	448 (234)	252 (215)	0.117
Pressure at 4 ml (kPa)	462 (213)	285 (241)	0.169
Maximum pressure (kPa)	408 (138)	276 (188)	0.177
Volume at maximum pressure (ml)	1.43 (1.70)	2.52 (1.83)	0.269

* Significant ($P = 0.05$).

Table 5. Before Burst Fracture: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Adjacent Discs (T11–T12 and L2–L3)

QD Parameter	T11–T12	L2–L3	*P* Value
Intrinsic pressure (kPa)	223 (93)	139 (83)	0.130
Leakage pressure (kPa)	600 (0)*	546 (161)	0.435
Initial slope (kPa/ml)	6000 (0)*	5473 (1035)	0.242
Slope between 0.0 and 0.1 mL (kPa/ml)	2439 (1229)	1807 (904)	0.334
Slope between 1 and 4 mL (kPa/ml)	1091 (542)	268 (151)	0.010†
Pressure at 2 ml (kPa)	600 (0)*	448 (234)	0.145
Pressure at 4 ml (kPa)	600 (0)*	462 (213)	0.147
Maximum pressure (kPa)	516 (19)	408 (138)	0.168
Volume at maximum pressure (ml)	0.43 (0.23)	1.43 (1.70)	0.184

* Pump capacity = 600 kPa.
† Significant ($P = 0.01$).

Table 6. After Burst Fracture: Average (Standard Deviation) Values for the Nine Discomanometric Parameters Measured in T11–T12 and L2–L3 After Burst Fracture

QD Parameter	T11–T12	L2–L3	*P* Value
Intrinsic pressure (kPa)	146 (119)	75 (42)	0.108
Leakage pressure (kPa)	546 (162)	226 (223)	0.003*
Initial slope (kPa/ml)	5459 (1623)	2781 (3061)	0.034†
Slope between 0.0 and 0.1 mL (kPa/ml)	2818 (2081)	833 (802)	0.017†
Slope between 1 and 4 mL (kPa/ml)	3083 (2447)	127 (187)	0.331
Pressure at 2 ml (kPa)	550 (150)	252 (215)	0.004*
Pressure at 4 ml (kPa)	549 (152)	285 (241)	0.013†
Maximum pressure (kPa)	489 (126)	276 (188)	0.012†
Volume at maximum pressure (ml)	0.75 (1.53)	2.52 (1.83)	0.040†

* Significant ($P = 0.01$).
† Significant ($P = 0.05$).

vertebra. Although injuries of the discs adjacent to the L1 vertebra could be easily detected by radiography, injury to the next-adjacent disc was determined only by the QD technique. The lower next adjacent disc (L2–L3) was found to be injured.

QD is a reproducible tool to assess the functional integrity of the endplate-disc-endplate complex.[3] It is useful in evaluating the disc function, which cannot be determined by any imaging technique. The QD has been used *in vivo* for evaluating the degree of disc generation in ambiguous cases.[8] In the present study we used the QD technique to verify the functional integrity of the disc after the burst fracture. Specimens subjected to high-speed compression trauma showed a significant positive correlation between the radiographic qualitative evaluation of disc injuries and QD.

Previous studies have shown that lower levels of the lumbar spine are more susceptible to disc degeneration.[4,5,10] Similar results were found in the present study. In general, the QD parameters indicated decreasing disc integrity with increasing segmental level. This age-related degenerative change may be the result of the decrease of the diameter and pressure of the "functional nucleus" and increase in the anulus stress.[1]

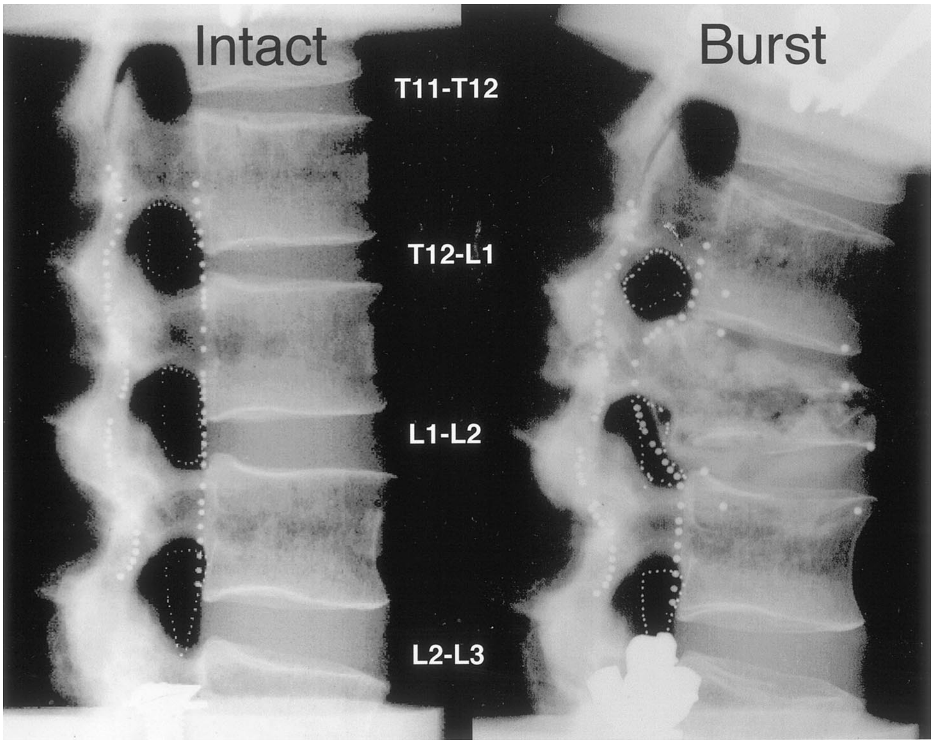
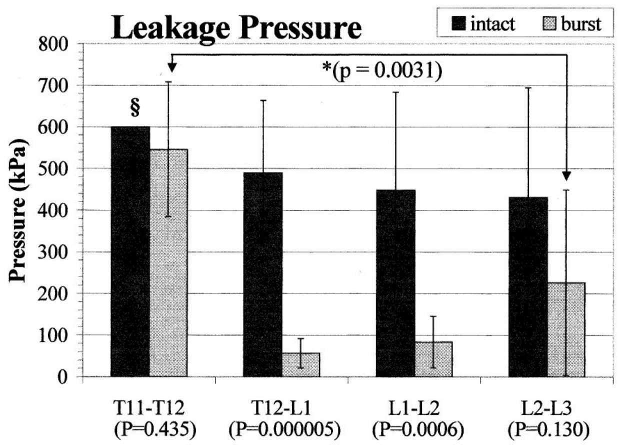
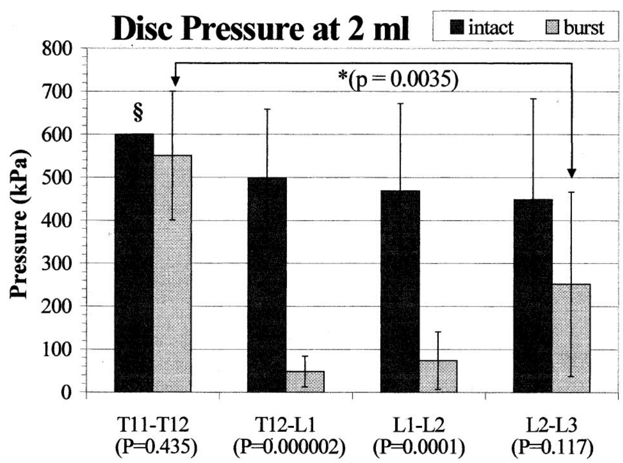


Figure 4. Radiographs of a spine specimen before and after the burst fracture of L1 vertebra. Radiographically, injuries of adjacent discs T12–L1 and L1–L2, but not of the next-adjacent discs T11–T12 and L2–L3, were observed. However, the quantitative discomanometry indicated injury also at the lower next-adjacent L2–L3 disc.



A



B

Figure 5. **A,** Leakage pressure (QD parameter 2), before and after the burst fracture. **B,** Disc pressure at 2 ml (QD parameter 6), before and after the burst fracture. Notice the after-burst fracture differences between the upper and lower next-adjacent discs T11–T12 and L2–L3.

In most of the lateral radiographic images taken after the burst fracture, no injuries to the next-adjacent discs were visible. However, changes in the QD parameters showed significant differences between the two next adjacent levels, indicating disc injury due to the burst fracture. The changes were greater in the lower next-adjacent disc than in the corresponding upper disc. In a similar burst fracture study of porcine cervical spine,[14,15] the lower-level disc (C4–C5) showed significant permanent deformation, but the upper level (C3–C4) did not. It is suspected that the lower next adjacent disc tends to be injured during impact fracture. The mechanism is not well understood.

The decreases in the leakage pressure and slope of the pressure–volume curve could be due either to the fracture of the endplate or to the development of fissures in the anulus fibrosus, during the burst fracture production. This is so because the endplate-disc anulus-endplate is an enclosure whose integrity is dependent on the two endplates and the disc anulus. The endplate is highly stressed by the disc during compression loading and is therefore likely to fracture, especially in relation to ligaments in high-speed trauma.[9] The high-speed impact loading during the burst fracture production may result in subfailure injury of the anulus fibers, similar to those observed in the ligaments.[11] Although endplate fractures have been well documented, the evidence for the development of subfailure microfissures in the anulus during the burst fracture production is still missing. Future studies may address this problem.

One of the limitations of the present study was the possible effect of the protective collars on the results. The protective collars were designed to produce burst fracture only of the L1 vertebra, in a five-vertebrae T11–L3 specimen. The next-adjacent discs, *i.e.*, T11–T12 and L2–L3, were thus protected from expansion in the transverse plane as were the vertebrae surrounding them. Although such rigid constraints do not exist *in vivo*, both the next-adjacent discs were protected equally. Thus, the comparison of these two discs with each other is quite valid. Comparisons of the same disc before and after the trauma were also valid, as the specimen served as its own control.

We found the QD to be a sensitive tool to detect the integrity of disc function. The results suggest that two parameters, the leakage pressure and disc pressure at 2 ml injection, are reliable QD parameters for determining the integrity of a disc. After the burst fracture injury, the inferior next adjacent disc was found to be injured even though there was no radiographically observed injury.

■ Key Points

- Using radiography and quantitative discomanometry (QD), four discs were examined in a five-vertebrae thoracolumbar (T11–L3) specimen, before and after L1 burst fracture production.
- Radiography detected injuries to the two discs adjacent to the burst fracture but found no injuries to the next adjacent discs.
- QD detected disc injuries at the two adjacent discs, as did the radiograph, but additionally, it found the lower next adjacent level to be injured.
- Clinical significance of the findings is that one should suspect an injury to the next adjacent disc inferior to the burst fracture.

References

1. Adams MA, McNally DS, Dolan P. 'Stress' distributions inside intervertebral discs: the effects of age and degeneration. J Bone Joint Surg Br 1996;78:965–72.
2. Fye MA, Southern EP, Panjabi MM, et al. Disc degeneration: a biomechanical study correlating MRI and quantitative discomanometry. Spine 2000;25: 2171–5.
3. Fye MA, Southern EP, Panjabi MM, et al. Quantitative discomanometry: technique and reproducibility in vitro. J Spinal Disord 1998;11:335–40.
4. Keene JS, Fisher SP, Vanderby R Jr, et al. Significance of acute post-traumatic bony encroachment of the neural canal. Spine 1989;14:799–802.
5. Keller TS, Hansson TH, Abram AC, et al. Regional variations in the compressive properties of lumbar vertebral trabeculae: effects of disc degeneration. Spine 1989;14:1012–9.

6. Kifune M, Panjabi MM, Arand M, et al. Fracture pattern and instability of thoracolumbar injuries. Eur Spine J 1995;4:98–103.
7. Kothe R, Panjabi MM, Liu W. Multidirectional instability of the thoracic spine due to iatrogenic pedicle injuries during transpedicular fixation: a biomechanical investigation. Spine 1997;22:1836–42.
8. Milette PC, Fontain S, Lepanto L, et al. Differentiating lumbar disc protrusions, disc bulges, and discs with normal contour but abnormal signal intensity: magnetic resonance imaging with discographic correlations. Spine 1999;24:44–53.
9. Noyes FR, Delucas JL, Torvik PJ. Biomechanics of anterior cruciate ligament failure: an analysis of strain rate sensitivity and mechanics of failure in primates. J Bone Joint Surg Am 1974;56:236–53.
10. Panjabi MM, Brown M, Lindahl S, et al. Intrinsic disc pressure as a measure of integrity of the lumbar spine. Spine 1988;13:913–7.
11. Panjabi MM, Moy P, Oxland T, et al. Subfailure injury affects the relaxation behavior of rabbit ACL. Clin Biomech 1999;14:24–31.
12. Panjabi MM, Oxland TR, Lin RM, et al. Thoracolumbar burst fracture: a biomechanical investigation of its multidirectional flexibility. Spine 1994;19:578–85.
13. Panjabi MM, Southern EP, Oxland TR, et al. Quantitative discomanometry and acute disc injuries: an experimental model. J Spinal Disord 1993;6:497–506.
14. Southern EP, Oxland TR, Panjabi MM, et al. Cervical spine injury patterns in three modes of high-speed trauma: a biomechanical porcine model. J Spinal Disord 1990;3:316–28.
15. Tsai KH, Chang GL, Lin RM. Differences in mechanical response between fractured and non-fractured spines under high-speed impact. Clin Biomech 1997;12:445–51.

Address correspondence to

Manohar M. Panjabi, PhD
Biomechanics Laboratory
Department of Orthopaedics and Rehabilitation
Yale University School of Medicine
P.O. Box 208071
New Haven, CT 06510
E-mail: manohar.panjabi@yale.edu