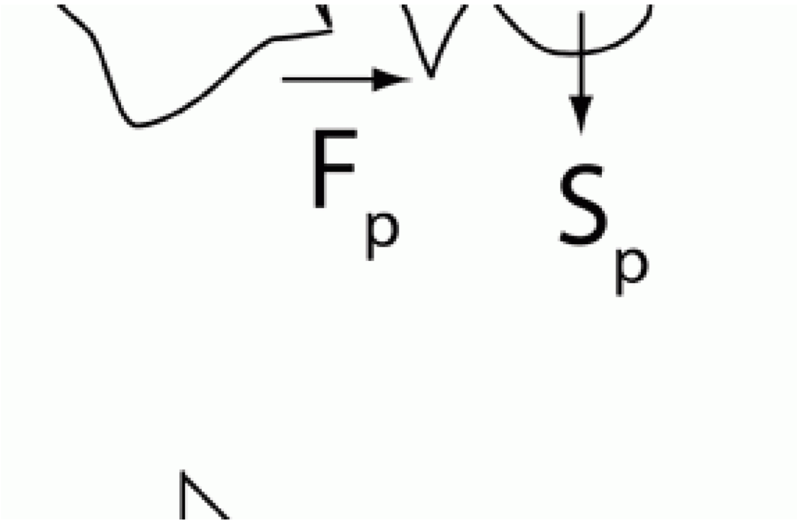
Dynamic Chiropractic



BACK PAIN

The Biomechanics of Spondylolysis, Part 1

IS IT EVER AN ACUTE TRAUMATIC EVENT?

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I was recently retained as a biomechanical expert in a personal-injury litigation in which a man, while stopped at a traffic signal, was struck from the rear by a police cruiser. The impact forced his car into an SUV directly in front of him. While the property damage to the police cruiser was relatively superficial as far as I could determine from photographs (no other information was available), the victim's midsized passenger car sustained significant damage to the rear bumper, trunk, lights and quarter panels, as well as rather extensive damage to the front bumper, grill, hood and front quarter panels. The damage to the rear of the SUV appeared superficial, although frame damage cannot be ruled out. It should be noted that police cruisers often have reinforced bumpers, but, even within the popular Crown Victoria model, there is a lot of variation in this modification from department to department.

The 30-year-old man complained immediately of low back pain and was transported to the hospital. In time, he underwent bi-level lumbar fusion at L3-4 and L4-5 with PEEK (poly-ether-ether-ketone) cage placement. The procedure utilized the transforaminal lumbar interbody fusion (TLIF) approach and no additional instrumentation (rods or screws) were used in the procedure. Subsequently, the man developed a rather profound lumbosacral plexopathy with very severe atrophy in both lower extremities - obviously a complication of surgery.

Interestingly, when a CT was performed later to assess the fusion integrity and, no doubt, to look for a cause of the postsurgical lumbosacral plexopathy, they discovered a bilateral pars defect at L5-S1. This apparently had not been seen earlier. I came into the case after the surgery had been performed; my primary task was the crash reconstruction and biomechanical assessment. However, I couldn't help but wonder whether the bilateral pars defects were pre-existing or represented an acute fracture due to the trauma. If they were an acute fracture, might they have been a major contributor to the man's pain? Might the surgical fusion procedure have been unnecessary? Might the man's lumbosacral plexopathy have been avoided altogether? Or, could the pars defects have developed as a consequence of the fusion?

These intriguing questions, of course, potentially invite new questions concerning the appropriateness of surgical and other treatment. And yet, the question of the acuteness of the pars defects are an issue for biomechanical assessment, as is the fusion integrity and the biomechanical stability of the PEEK cage procedure. So, I started with a search of the literature to find out what we know about the etiology of lumbar spondylolysis. Let's look at the assessment; in part 2, we'll delve into the biomechanical issues of the PEEK cage placement and provide a final denouement of my analysis.

Prevalence of Pars Interarticularis Fracture

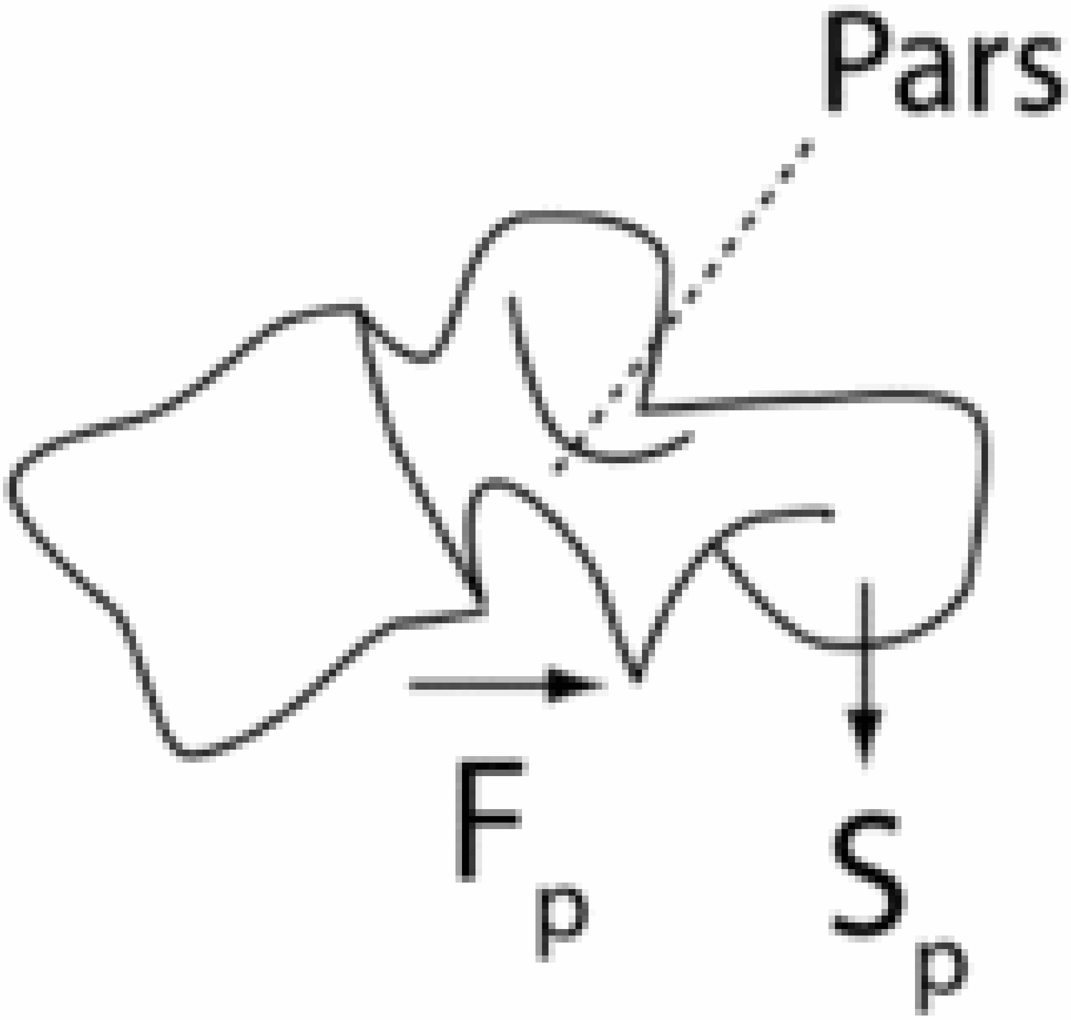
Most of us were taught that a pars defect is a form of fatigue fracture caused by repetitive stress in the area. It is never seen in a fetus, nor is it seen in people who have never walked. It is also not seen in primates who do not walk upright. It is seen only after the age of 5 years and is most commonly discovered in teenagers and young adults. It does seem to have a genetic predisposition and is seen in up to 50 percent among certain groups of Alaskan natives. It is most often seen in athletes who do a lot of acute trunk bending or very heavy lifting, such as gymnasts, swimmers, divers, weight-lifters, fast bowlers in cricket, etc.

While some have speculated that the fractures can be the result of an acute event, little has been written on the topic. There is a report of woman sustaining a bilateral L4 pars fracture in a motor vehicle collision (MVC).[1] Details of the collision were not revealed, but she was treated with three weeks of hospitalization (this was 1978, mind you). Earlier radiographs from 1973 showed no defects, so this was presumed to be a case of acute fracture.

There is another report of a man falling over a balcony, sustaining what the authors conjectured to be an extension and compression injury to the low back.[2] The acute nature of this bilateral L5 pars fracture was confirmed to some extent by the radiological appearance of having no sclerotic margins initially, and a callus formation that developed after period of bed rest and bracing. The lack of history of back pain, the author thought, added confirmation of the acuteness of the injury, although many individuals with pars defects do not have back pain.

A recent sample of 3,529 participants of the Framingham Heart Study was evaluated with multidetector CT imaging to assess aortic calcification.[3] The presence of spondylolysis was characterized by CT imaging. The prevalence of lumbar spondylolysis was found to be 11.5 percent, nearly twice the prevalence of previous plain-radiograph-based studies. No significant correlation was identified between spondylolysis and the occurrence of low back pain in this group. It is important, of course, to remember that the association between pars defects and low back pain may well be correlated in a population of low back pain sufferers. For example, among young athletes with pars defects, 77 percent were reported to have low back pain in an earlier study.[4] This suggests that the etiology of pars defects may vary between athletes and non-athletes.

Biomechanics of Pars Interarticularis Fracture


Pars
F p
S p

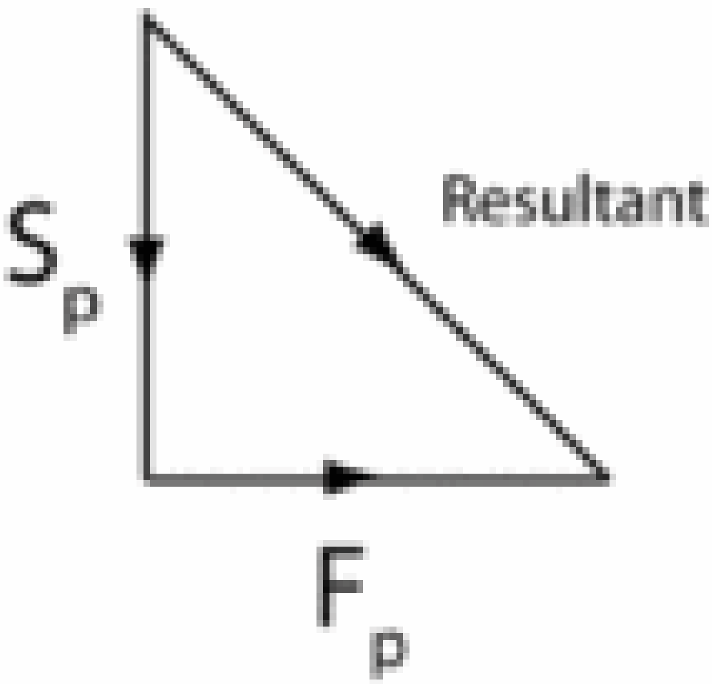

Resultant
S p
F p

Fig. 1: The force Fp was applied to the inferior facet as illustrated. The force Sp, which exists normally (but not in the experiment), is that generated by paraspinal musculature. The resultant vector of those forces is one of simple tension along the neutral axis of the pars. Note, however, that bone is stronger in compression than in tension.

Interestingly, spondylolysis has been seen following spine fusion.[1] Although these were older reports from the 1950s and 1960s, there was one recent report of a postsurgical pars defect developing in a patient who had been given a prosthetic disc; this was thought by the authors to be the first report of this complication in a non-fusion procedure.[5] From a biomechanical standpoint, it is likely that fusing one or more levels would result in stress risers in adjacent mobile motor units; let's leave that to our discussion of the PEEK cage instrumentation issue in part 2 of this series.

Biomechanical studies have looked at bending of the articular processes using cadaver spine elements.[6] They repetitively loaded the motor units in flexion and extension to simulate both bending modes, both with and without compressive loading. A load of about 1,000 N (225 lb-f) was applied initially to simulate unloaded bending. To simulate bending with compression, this load was increased to about 2,000 N. This is approximately the load induced by lifting a 25 lb weight with the back bent. (It is noteworthy that lifting with a bent back results in more shear loading and less compressive loading.) Loading was continued until the elastic limit was reached, indicating the beginning of the point of sprain of the supraspinous and interspinous ligaments. The elastic limit is determined by examination of the point on the force-deflection curve where the slope of the curve begins to flatten out, indicating an end to the linear (i.e., elastic) relationship between stress and strain.

Cyron, et al., applied loads to the inferior facets of cadaver lumbar vertebrae to impose a line of force perpendicular to the neutral axis of the pars.[7] They produced bilateral pars fractures with forces in the 2,000 N range in most specimens using a strain rate or displacement rate of 5 cm/second. The typical time to fracture was 100 msec, which is about the point of peak occupant loading we find in rear-impact MVC tests. The applied load in these cadaver tests was consistent with an extension motion of the lumbar spine. They noted that in flexion, although the combined forces exerted by the inferior facet and paraspinal muscles would be higher than in the erect position, the resultant force of the two vectors would be tensile in nature, rather than a bending moment, and, therefore, less likely to produce significant stress in the pars. (See Figure 1.)

Biomechanically, the forces acting on the lower lumbar region are illustrated in Figure 2 (note that force vectors and moment arms are not drawn precisely to scale). For static equilibrium equations, we would have the following:

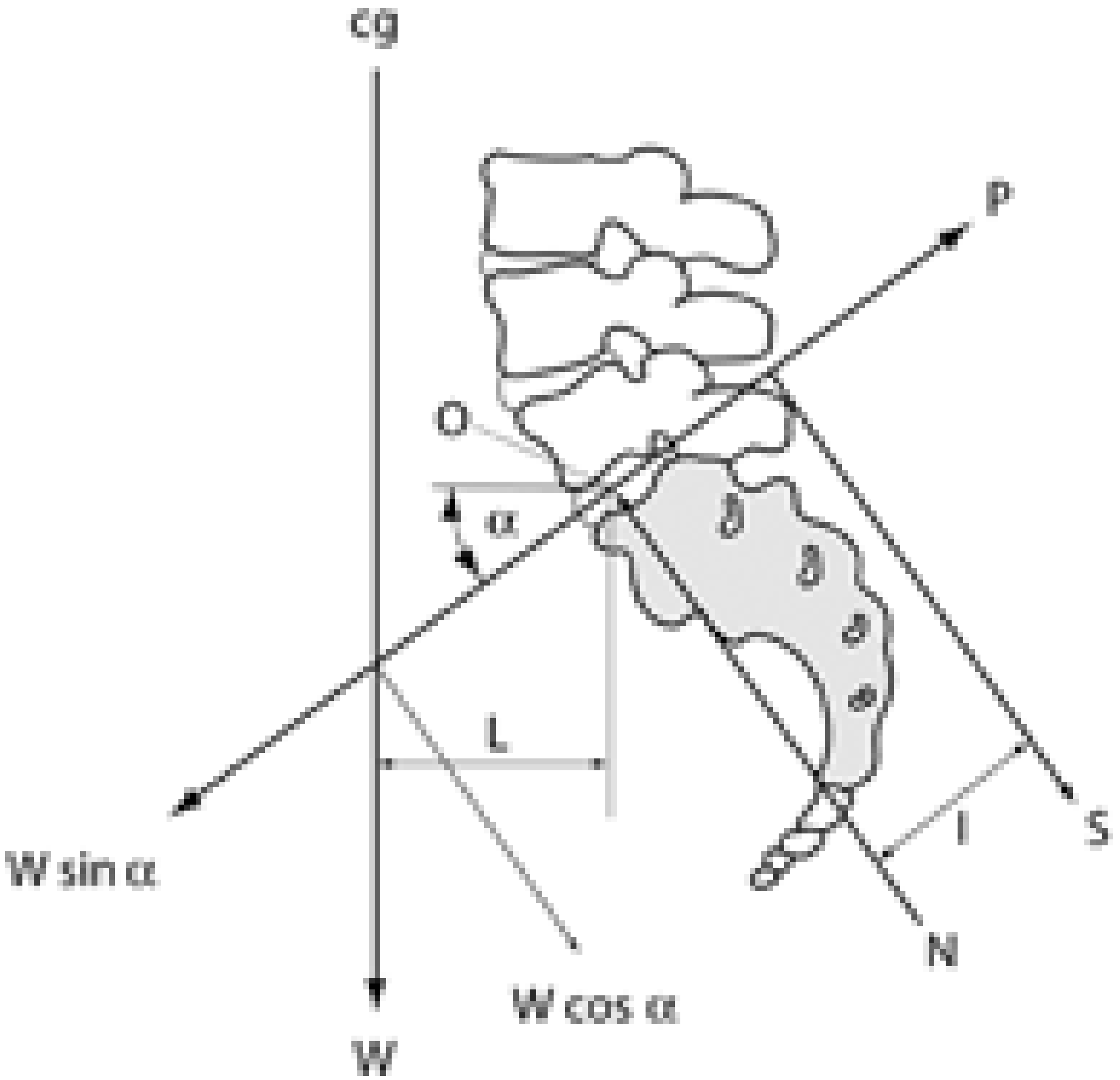


Fig. 2: The force of gravity acting through the center of gravity, cg, is the weight, W, which is greatest at L5. The origin, O, is the instantaneous axis of rotation. The effects of W and muscle force, S, are balanced by the normal force, N, the resistance to disc com-pression, and plane, P, the resistance to disc shear.

In related research, Cyron, et al., demonstrated that oscillating forces between 380 N and 760 N caused fatigue fractures of the pars in about 70 percent of specimens tested, sometimes after only a few thousand cycles.[8] Green, et al., conjectured, based on these earlier studies by Cyron, et al., [7-8] that flexion and extension bending, unloaded, was sufficient to produce fatigue fractures based on the amount of deflections (1.3 mm) they measured.[6] With a load, the deflections were actually lower. In agreement to Cyron, et al., however, they concluded that full extension poses a greater threat to the pars than full flexion.

Another group similarly utilized a materials testing device to load lumbar human cadaver spines.[4] They applied compressive, A-P bending, and rotational loads to specimens without discs. Although the lack of discs may have compromised the external validity of the study, the deformations under maximum loads of 2,544 N convinced the authors that the etiology of pars defects could be acutely traumatic or due to repetitive stress producing a fatigue fracture.

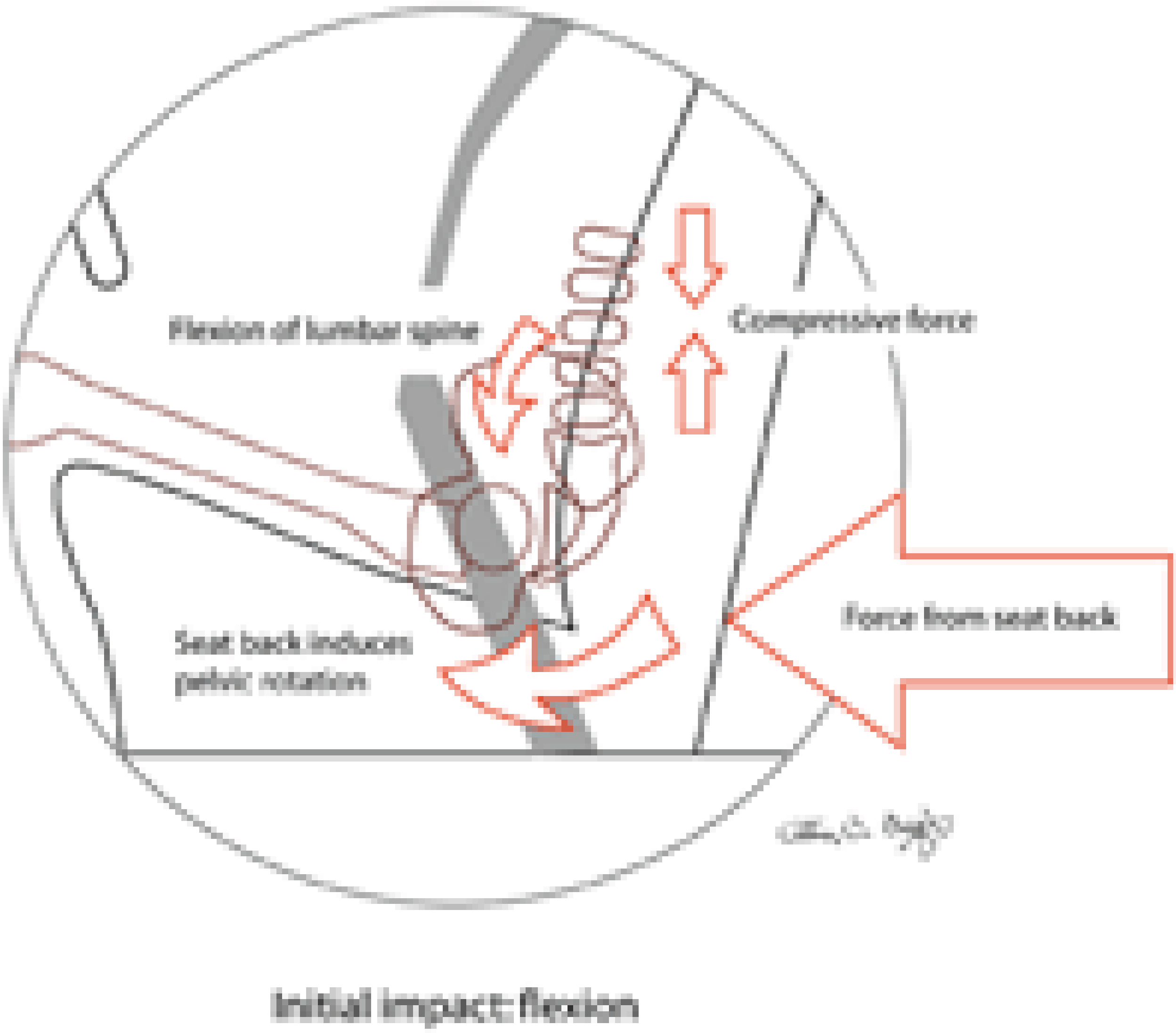


Fig. 3: Based on the results of our crash tests at the Spine Research Institute of San Diego, the initial response of the lumbar spine in a rear-impact crash is flattening of the spine with flexion and compression. This is followed immediately by extension, which coin-cides with the compressive phase.

So, what of the forces produced in a 15 mph rear-impact delta V collision? Recent cadaver sled tests simulating rear impacts at up to 10 mph indicate early forward pelvic rotation, which would be coincident of lumbar extension. (See Figure 3.) Our own crash tests, as well as those of others, have demonstrated a strong vertical acceleration of the lumbar and thoracic spine during the initial phase of a rear-impact crash test (i.e., the so-called vertical ramping effect). This produces a large axial compressive force in the lumbar region. In recent finite element analysis (FEA) simulations of rear-impact crashes of 15.5 mph, researchers reported the contact force between the pelvis and seat back was more than 7,000 N (close to 1,600 lb-f).[9] This would produce a horizontal (extensile) line of force, and would coincide with ramping and compression.

The definitive study has yet to be published to answer this question concerning acute vs. fatigue fracture. To determine whether such an injury is acute vs. the fatigue fracture type requires a bone scan or SPECT study and serial radiographs to look for callus formation (although callus may not form even after an acute fracture of the pars). Biomechanical studies, on balance, indicate that most cases of pars defects will be a type of fatigue fracture. But sufficient forces can develop within the boundaries of moderate or higher speed rear-impact motor-vehicle collisions to produce acute pars fractures.

Because of rearward ejection of occupants in high-speed, rear- impact crashes, seat manufacturing specifications were changed some time ago. This has resulted in a dramatic 32 percent increase in the key spinal biomechanical responses, over a range of crash severities, with a shift from the yielding seats of the 1980-1990s to the new, stiffer benchmark seats.[11] Horizontal placement of seat back frame elements can result in high-force points of contact in the lumbar region, concentrating bending, shear, and compressive loads on the lumbar spine, which also bears the greatest gravitational load in the spine. The pars interarticularis is most vulnerable to this combination of loading.

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