# DIURNAL CHANGES IN SPINAL MECHANICS AND THEIR CLINICAL SIGNIFICANCE

M. A. ADAMS, P. DOLAN, W. C. HUTTON, R. W. PORTER

*From the University of Bristol*

**Diurnal changes in the loads acting on the spine affect the water content and height of the intervertebral discs. We have reviewed the effects of these changes on spinal mechanics, and their possible clinical significance.**

**Cadaveric lumbar spines subjected to periods of creep loading show a disc height change similar to the physiological change. As a result intervertebral discs bulge more, become stiffer in compression and more flexible in bending. Disc tissue becomes more elastic as its water content falls, and its affinity for water increases. Disc prolapse becomes more difficult. The neural arch and associated ligaments resist an increasing proportion of the compressive and bending stresses acting on the spine. Observations on living people show that these changes are not fully compensated for by modified muscle activity.**

**We conclude that different spinal structures are more heavily loaded at different times of the day. Therefore, the time of onset of symptoms and signs, and any diurnal variation in their severity, may help us understand more about the pathophysiology of low back pain and sciatica.**

During the recumbency of sleep, the loading on the intervertebral discs is reduced, and their relatively unopposed swelling pressure results in them absorbing fluid and increasing in volume (Urban and McMullin 1988). The absorbed fluid is expelled during the day when the loading of the spine is increased. There is, thus, a diurnal variation in the fluid content and height of the discs which causes a variation in the mechanical properties of the spine.

We review the experimental evidence concerning these changes, and then discuss the changes in loading of different spinal structures at different times of the day. We then suggest that the time of onset of symptoms and signs, and any diurnal variation in their severity, might be an aid to diagnosis.

M. A. Adams, PhD, Research Fellow
P. Dolan, PhD, Research Fellow
Comparative Orthopaedic Research Unit, University of Bristol, Park Row, Bristol BS1 5LS, England.

W. C. Hutton, DSc, Professor
Department of Orthopaedics, Emory University, Atlanta, Georgia, USA.

R. W. Porter, MD, FRCS, Consultant Orthopaedic Surgeon
Doncaster Royal Infirmary, Armthorpe Road, Doncaster, South Yorkshire DN2 5LT, England.

Correspondence should be sent to Dr M. A. Adams.


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## CADAVERIC SPINES

Periods of creep loading of cadaveric lumbar spines cause a change in disc height similar to the diurnal change seen in vivo. Certain mechanical properties have been measured before and after the period of loading.

**Disc height.** Constant loading at 1 000 N for six hours (simulating light manual labour: Nachemson 1981) causes disc height to decrease by 1.53 $\pm$ 0.34 mm (Adams, Dolan and Hutton 1987). The height loss is rapid at first but much slower by the end of the six hours (Fig. 1). Similar results have been reported in other experiments (Adams and Hutton 1983; Koeller, Funke and Hartmann 1984). If the applied compressive force is increased at hourly intervals from 1 000 N to 2 000 N and then to 3 000 N in order to simulate manual labour of increasing severity, then the height loss shows no sign of slowing down, and the cumulative loss after three hours is 2.13 $\pm$ 0.35 mm (Adams et al 1987, see Fig. 1).

The average diurnal variation in human stature is about 19 mm (Tyrrell, Reilly and Troup 1985) which is mostly attributable to changes in disc height (De Puky 1935). A 19 mm change in stature corresponds to a change of about 1.5 mm in the height of each lumbar disc (Adams et al 1987), so the loading regimes discussed above are sufficient to simulate physiological diurnal reduction in disc height.

Changes in disc height are caused by fluid exchange and creep deformation of the annulus fibrosus (Koeller et al 1984). The relative importance of each mechanism probably depends upon the severity and duration of loading (Adams et al 1987) and factors such as age and the degree of disc degeneration.

The diurnal disc height change of 1.5 mm is of a similar magnitude to the normal narrowing of the lumbar discs expected with age (Koeller et al 1986). It could have a significant effect when there is pathology in the nerve root canal since the total height of the lumbar intervertebral foramen averages only about 15 to 20 mm (Panjabi, Takata and Goel 1983).

**Disc water content.** Creep loading reduces the water content of the discs. After four hours loading at about 700 N, when disc height is reduced by about 1.5 mm, the average fluid loss is 12% from the annulus and 5% from the nucleus (Adams and Hutton 1983). Discs from people under the age of 35 years lose almost twice this amount. Most of the fluid loss probably occurs in the first few hours of loading because longer-term creep tests cause only a little more fluid loss: 24 hours loading at about 1 000 N reduces the fluid content of annulus and nucleus by 11% and 8% respectively (Kraemer, Kolditz and Gowin 1985).

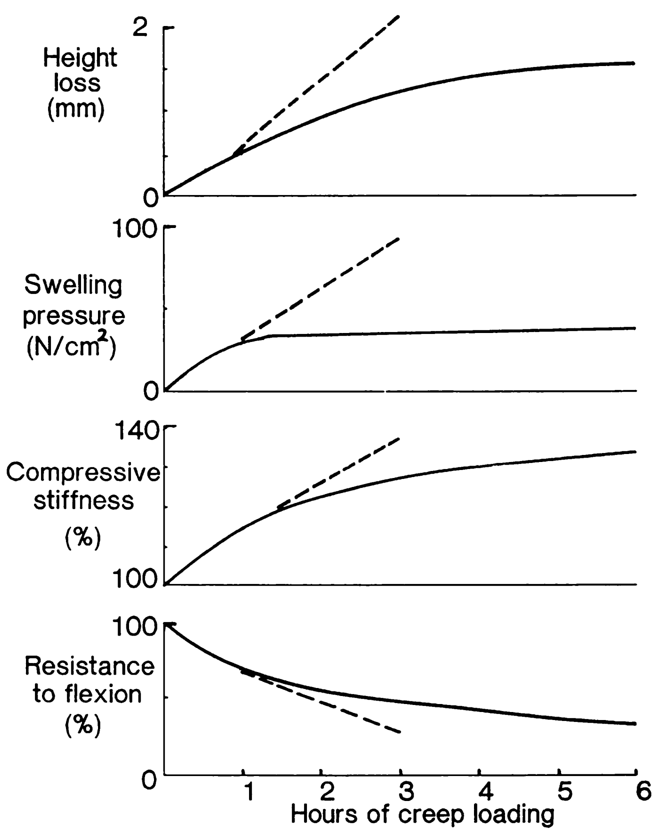


Fig. 1

The effect of compressive creep loading on some mechanical properties of lumbar motion segments. The solid lines refer to a constant compressive force of 1 000 N applied for six hours. The broken lines refer to a compressive force of 1 000 N in the first hour, 2 000 N in the second, and 3 000 N in the third. Resistance to flexion was measured at the physiological limit determined before creep loading. The 'swelling pressure' of an intervertebral disc is defined in the text.

Fluid loss is accompanied by a reduction in energy dissipation during a loading/unloading cycle (Koeller et al 1984). This means that the dehydrated disc behaves more like an elastic solid and less like a viscous fluid.

**Disc swelling pressure.** Disc swelling pressure can be defined as that physical pressure which must be applied to the disc in order to prevent it from swelling up in saline (Urban and McMullin 1988). It is a measure of the tissue's affinity for water.

Swelling pressure can be measured by adjusting the compressive force acting on a motion segment until there is no detectable change in disc height. This force is then divided by the cross-sectional area of the disc. Swelling pressure increases rapidly during creep loading as shown in Figure 1, and its rise can be accelerated by more intense loading (unpublished results from our laboratory, 1988). The clinical significance of swelling pressure is that it determines the rate at which a disc recovers lost height (and mechanical properties) at the end of a period of high loading.

**Compressive stiffness.** Creep loading increases the disc's compressive stiffness. The increase is about 50% after two to three hours of physiological cyclic loading (Koeller et al 1984) and can rise to 100% after 28 hours (Smeathers 1984). Motion segment stiffness is of clinical significance because it determines how much the disc and surrounding soft tissues deform during physiological dynamic loading of the spine.

**Disc bulging.** Radial bulging of the disc has been observed to increase after creep loading (Koeller et al 1984). The size of this increase has not been measured directly, but it may be inferred from the results of Brinckmann and Horst (1985). They altered the volume of the disc, either by injecting fluid into it or by fracturing the vertebral body end-plate, and found that the change in radial bulging was about one-third of the change in disc height. This suggests that the diurnal reduction in disc height of 1.5 mm should be accompanied by an increased radial bulge of about 0.5 mm. For comparison, the increased radial bulge caused by increasing the compressive force on the spine from 300 N (lying in bed) to 1 000 N (light manual work), is only about 0.2 mm (Brinckmann and Horst 1985).

Diurnal disc bulging will have clinical implications when the central or root canal is stenotic. The width of the intervertebral foramen is normally about 8 to 10 mm (Panjabi et al 1983) but it can be much less in the root canal and the lateral recess.

**Loading of the apophysial joints.** The compressive force on the apophysial joints has been measured when motion segments were loaded to simulate a typical sitting posture (lumbar spine slightly flexed) and an erect standing posture (spine in slight extension). Before creep, the apophysial joints resist little, if any, compressive force in either posture (Adams and Hutton 1980). After creep, there is little resistance in the flexed spine, but in the simulated standing posture the apophysial joints resist an average of 16% of the applied compressive force. In some cases, the proportion can be as high as 70%. In more extended postures, compressive creep loading can result in high stress concentrations on the lower margins of the apophysial joint surfaces (Dunlop, Adams and Hutton 1984) and capsule (Yang and King 1984).

**Forward bending properties.** Creep loading increases a motion segment's range of flexion by 2° or 3° (Adams et al 1987) which is equivalent to about 12.5° extra movement for the whole of the lumbar spine. At the physiological limit of flexion (as determined before creep loading) the motion segment's resistance to bending is reduced by about 70% (Fig. 1). The reduction for the disc and ligaments, measured separately, is 85% and 45% respectively.

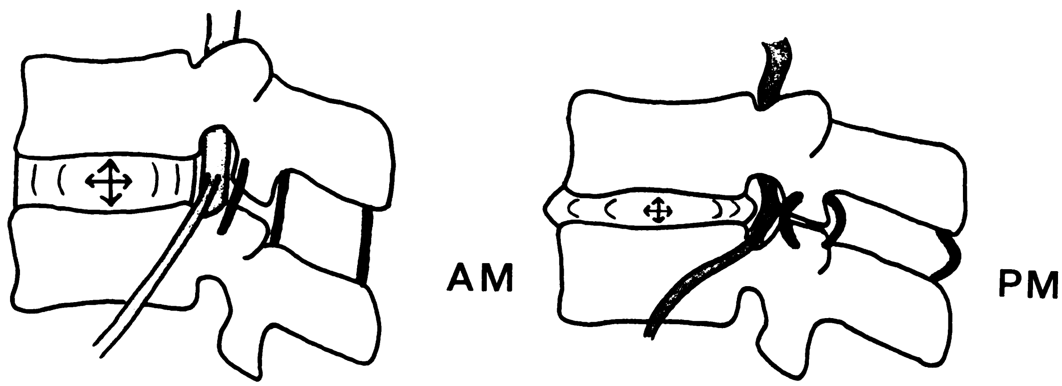


Fig. 2

Diagrams showing the diurnal changes in spinal mechanics (see Table I).

**Table I.** Diurnal variation of maximal stress on various structures in the lumbar spine

| | Period | Comment |
|---|---|---|
| Intervertebral disc | AM | Especially in bending |
| Posterior longitudinal ligament | AM | Especially in flexion |
| Vertebral body end-plate | AM | |
| Segmental nerve root | AM | Increased tension |
| | PM | Increased compression |
| Apophysial joint | | |
| Articular surface | PM | |
| Capsule and ligaments | AM | Flexion |
| | PM | Extension |
| Supra/interspinous ligaments | AM | Increased tension in flexion |
| | PM | Increased compression in extension |

These effects can probably be attributed to the reduce fluid content of the nucleus pulposus. If the fluid content is artificially raised (by injecting saline) or lowered (by injecting chymopapain) then there is a corresponding increase or decrease in the disc's resistance to bending (Andersson and Schultz 1979; Dolan, Adams and Hutton 1987).

These results indicate that, in life, flexion movements performed in the early morning generate much higher stresses in the osteoligamentous lumbar spine than do similar movements performed later in the day. Also, the discs resist a higher proportion of these increased stresses in the morning.

**Backward bending properties.** Creep loading reduces the disc's resistance to backward bending by about 40% (Adams, Dolan and Hutton 1988). This is balanced by increased resistance from the apophysial joints and spinous processes, so that the resistance to backward bending of the whole motion segment, and the range of movement, are unaltered by creep loading.

**Prolapsed intervertebral disc.** Some cadaveric discs can be induced to prolapse posteriorly by loading them in combined bending, shear and compression. Of 61 motion segments loaded in this way, 26 failed by posterior disc prolapse (Adams and Hutton 1982). The experiment was repeated on a further group of 19 motion segments from cadavers of a similar age range after they had been creep loaded (Adams et al 1987). Only two of these discs prolapsed, and they were both from the same spine.

Creep-loaded discs, in vivo, may also be less susceptible to prolapse, perhaps because of the reduced fluid content of the nucleus pulposus and the reduced flexion stresses in the posterior annulus.

## CLINICAL DIURNAL VARIATION

**Spinal posture and mobility.** It is possible that, in vivo, the muscles of the back and abdomen may modify spinal posture in order to compensate for some of the diurnal changes in the underlying spine. However, unpublished results from our laboratory show that the lumbar lordosis increases by about 3° during the day. This would increase the loading of the apophysial joints and compound the effects due to loss of disc height.

It could be thought that the higher bending stiffness of the osteoligamentous spine in the early morning would be offset by the trunk muscles restricting the range of bending, so that the bending stresses on the spine remain the same. However, the experimental evidence suggests that this does not happen to any significant extent. In vivo, the range of lumbar flexion is reduced by only 5° in the early morning (Adams et al 1987) whereas the range of flexion of the underlying spine is reduced by about 12.5° before creep loading (see above). Calculations comparing the in vivo and in vitro evidence suggest that, in life, bending stresses on the lumbar discs and ligaments can be increased by about 300% and 80% respectively in the early morning (Adams et al 1987).

The slight diurnal variation in the range of spinal movement in vivo may be partly attributable to muscle 'warm-up' (Baxter 1987). A similar effect has been observed in hip movements (Adams et al 1987) even though there is unlikely to be any variation in the mechanical properties of the underlying joints, since normnal articular cartilage does not swell up overnight like the disc.

**Low back pain.** There is little published information about diurnal variations in symptoms and signs, nor in the time of onset of low back pain. Varma (1987) recorded that 47% of 'first episodes' of back pain occurred in the early part of the working day. This agrees with a study by Evans et al (1980) who found that mine workers sustained spinal injury more commonly in the morning.

Accidents in general tend to become more frequent towards the end of a working shift, when people are tired and inattentive. These effects will tend to mask any trends due to changes in spinal mechanics and they must be taken into consideration in any surveys of diurnal variation in spinal injuries.

## DISCUSSION

The experimental evidence can be summarised as follows: with creep loading, the intervertebral discs lose height, bulge more, become stiffer in compression and more flexible in bending. Disc tissue becomes more elastic as its water content is reduced, and its affinity for water increases. Disc prolapse becomes less likely. The neural arch and associated ligaments resist an increasing proportion of the compressive and bending stresses acting on the spine. These results are summarised in Figure 2.

In life, these changes will occur mostly in the first few hours of the day, but the time scale and the magnitude of the changes will depend upon the severity of loading on the spine: heavy labour will have a greater effect, and in less time, than sedentary activity. The swelling pressure results suggest that the effects of intense loading will be reversed more rapidly than the effects of less intense activity of longer duration. Alternating periods of rest and activity throughout the day probably cause minor changes in spinal mechanics similar to the diurnal changes.

We suggest that diurnal variations in spinal mechanics are of clinical significance. Since different structures are more heavily loaded at different times of the day, the time of onset of a patient's symptoms, and any diurnal changes in their degree of severity, might help us to understand the pathophysiology of different back pain syndromes.

Table I lists some of the structures thought to be responsible for low back pain and sciatica, and indicates when they are most heavily loaded. The *disc* resists all of the compressive force on the spine in the morning, and in addition, is much more highly stressed during flexion and extension movements. A herniated disc, however, may behave differently from one with an intact annulus. The *posterior longitudinal ligament* is stretched more in the morning because of the increased height of the disc, although reduced radial bulging of the disc will counteract this effect to some extent. *Vertebral body end-plates* can be ruptured by increasing the fluid content of the nucleus pulposus (Jayson, Herbert and Barks 1973) so it is likely that the end-plates are more highly stressed in the morning when the discs are swollen with fluid.

The *segmental nerve roots* are stretched more in the morning because the spine is about 19 mm longer; but they are compressed more in the afternoon by extra radial bulging of the disc, by the reduced height of the intervertebral foramen, and by the buckling of the ligamentum flavum. The *apophysial joint surfaces* are pressed closer together in the afternoon, especially in lordotic postures and during backward bending, and at this time joint pain may be expected to increase. However, the *capsular ligaments* and the *supraspinous and interspinous ligaments* will all be most stretched during forward bending movements performed in the early morning because the increased disc height allows them less slack.

As we attempt to understand more about spinal pathology, clinical studies into the diurnal changes of spinal symptoms and signs could be rewarding.

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