36. Influence of circadian variation on spinal examination

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Since man's habits are governed largely by regular environmental and social rhythms it is not surprising that many physiological measurements (e.g. temperature) show a more or less regular 24 hour variation. The term 'diurnal' is frequently used for a rhythm whose period is one day. As the word is also used to distinguish night and day, Conroy & Mills (1970) preferred the use of 'circadian' to indicate a period of approximately 24 hours. Both terms are used in current literature.

Recently there has been a significant upsurge in interest in diurnal 'variation' or 'changes', especially as they relate to changes in height, the disc, and, to some extent, to joint ranges and flexibility.

VARIATION IN HEIGHT

In 1777 de Montbeillard described the decrease in height of his son during the course of the day and this variation has since been demonstrated by several workers. In a much-quoted paper, De Puky (1936) showed from a sample of over 1200 people that, on average, a person is 1% shorter by evening compared with the morning. In addition to this he mentioned a corresponding figure of 2% for children and 0.5% for 70–80 year olds.

Tyrell et al (1985) noted that 54% of the total diurnal change was lost in the first hour after rising and 83% in the first 3 hours and 45 minutes. Some 71% was regained in the first half of the night. The mean circadian variation that they recorded was 19.3 mm, or 1.1% of stature. It is generally agreed in the literature that these observed changes in stature are more a result of being horizontal or vertical than of any intrinsic, or endogenous, circadian rhythm. Goode & Theodore (1983) demonstrated this in two subjects who rose at 7 a.m. and immediately returned to bed for 3 hours. When they were measured again their heights had not changed. The substantial effects of gravity on body height is exemplified by astronauts who apparently show increases of up to 10 cm on returning to earth (Kazarian 1974).

The disc has been implicated as a major factor in daily height fluctuation, (De Puky 1936, Markolf & Morris 1974) and it is well established that the disc exhibits viscoelastic properties (Virgin 1951, Markolf 1972). The disc responds elastically to loading and unloading for short periods of time, as in vibrations or shocks. However, if a load is applied for a long time, in addition to the elastic response, creep deformation of the annulus fibrosus occurs as well as fluid loss from the disc generally (Koeller et al 1984). During the recumbency of sleep, the loading on the intervertebral discs is reduced, and their relatively unopposed swelling pressure leads to absorption of fluid and increase in volume (Urban & McMullin 1988).

Average fluid loss from an individual lumbar disc which has lost height in vitro is 12% from the annulus and 5% from the nucleus (Adams & Hutton 1983). Losses from discs of subjects under 35 years were noted as almost twice this amount. Age-related variation in disc hydration and water loss may partly explain the age variations in height loss noted by De Puky (1936).

Traction may mimic or even accelerate the overnight effects of recumbency. Warden & Humphry (1964) have shown 'substantial' increases in body height as a result of traction forces on the spine. Twomey (1985) has demonstrated vertebral separation occurring on lumbar cadaver material with only 9 kg of force.

VARIATION IN FLEXIBILITY

Variation in flexibility over 24 hours is of much concern to those of us who base a large part of our treatment protocol on observed, and measured, changes in ranges of movement. The subject has been reviewed and discussed in detail elsewhere (Gifford, 1985, 1987), but it should be emphasized that this area of research is as yet virtually untouched. Like height variation one would expect flexibility to vary depending on the subjects activity level. Results from preliminary normative studies show that this may not wholly be the case (Gifford 1985).

Variation in flexibility in finger-tip-to-floor distance shows a clear pattern of: maximum 'stiffness' occurring

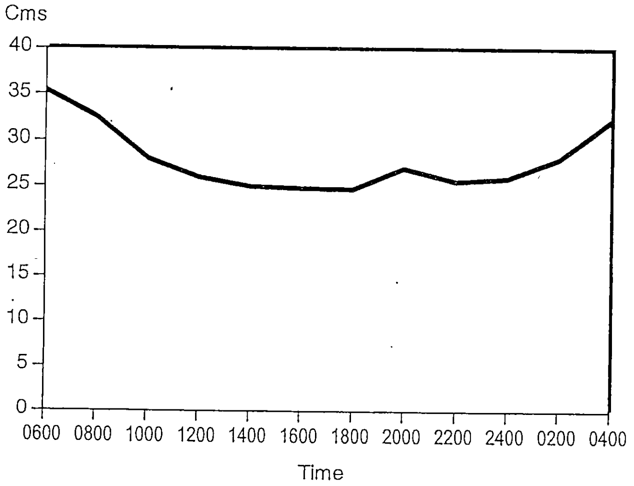

Fig. 36.1 Circadian variation in finger-tip-to-floor (mean values) (Gifford 1985).

early in the morning at, or prior to, rising; maximum flexibility occurring around 6.00 p.m., and, in some subjects, a slight stiffening occurring in the early evening (Fig. 36.1). The mean variation in the 25 subjects investigated was 14.4 cm and ranged from 5.5 cm to as much as 26.2 cm (Gifford 1985, 1987).

Diurnal changes in lumbar flexion have been confirmed recently by Adams et al (1987), but only two measures were made, one in the early morning and one in the afternoon. These authors interestingly found that the early morning result, taken 10 minutes after rising, could also be achieved up to 2 hours after rising on subsequent measures, by getting the subject to lie down before the test for a period of time equal to the time spent between rising and lying down. This suggests that recumbency *is* a strong factor in this measure. Of the 21 subjects they examined, all achieved more range in the afternoon regardless of age, sex, lumbar lordosis in standing or extent of lumbar flexion. The average increase was 5.0° ± 1.9°.

Work undertaken by Gifford (Gifford 1985) on 25 subjects measured every 2 hours, showed a mean variation of 13.12° (SD = 3.11°), quite a lot more than the 5.0° of Adams and co-workers. Gifford (1987) commented that gradually increasing flexibility occurred from 6 a.m. and peaked during late afternoon or early evening. It seems as if lumbar flexibility starts to improve before rising, continues through the day, and then decreases during the evening before going to bed. It is possible that performing only two measurements in this kind of research will give a false overall picture (Conroy & Mills 1970). Adams et al (1987) found that in vitro 'creep-loading' an individual lumbar segment produced increases in range of between 2 and 3°, which is equivalent to about 12.5° for the whole lumbar spine (Adams et al 1990)—a figure closer in value to the 13.12° given above.

Lumbar extension, also investigated by Gifford (1985), shows an overall 24 hour change similar to lumbar flexion, although maximum flexibility occurred slightly earlier at around 2 p.m. Two subjects were noted whose pattern was a reversal of this in that they showed a progressive stiffening through the day and an increase in flexibility overnight. A mean variation in extension range over 24 hours of 9.64° (SD = 3.51°) was recorded.

A diurnal pattern of straight leg raising, while showing a rise in range through the day and fall at night did not provide a very dramatic picture (Gifford 1985, 1987). The mean variation over 24 hours was 9.92° (SD = 2.74°). Recent work by Porter & Trailescu (1990) on the analysis of diurnal changes in pathologically limited straight leg raises, sheds interesting light on disc diagnosis and mechanisms of pathology. They looked at 28 patients who had a diagnosis of lumbar disc protrusion. Typical symptoms were of a sciatic distribution below the knee and signs of limited SLR of 50° or less, and either a 'list', or at least two neurological changes. Measurements of the range of SLR were performed in all patients before getting up and then at intervals of ¼ hour, ½ hour, 1 hour, 3 hours and 5 hours. Twenty of the patients had mean increases in SLR range of 16.9° (SD = 7.1°), one showing as much as 38°. The authors noted that most of the gains occurred in the first hour after rising, and that two hours of recumbency after testing brought the range *back* to near the baseline value recorded on rising. The remaining eight patients showed unimpressive or no diurnal changes. Porter & Trailescu (1990) explained their results in terms of disc hydration and changes in the tension of a disc protrusion. They hypothesized that a weakened disc protrusion acts like a safety valve, bulging further with increasing hydration (as in recumbency), the outer fibres becoming tense at the expense of increasing the disc space (vide supra).

> When the patient stands upright, initially there is even more tension in the outer annular fibres as the external load is increased, but gradually the fluid is expressed from the disc with a reduction in its volume, until a new equilibrium is reached. When the patient then lies down for the examination of straight leg raising, a reduction in the external load produces a relatively flaccid protrusion. Straight leg raising if it is related to the tension of the protrusion, will then be improved. This cycle requires a protrusion which has intact outer annular fibres. (Porter & Trailescu 1990)

Porter & Trailescu (1990) acknowledged that changes in disc height will increase tension on a tethered nerve root and that diurnal changes in lumbar lordosis would also affect the root. They laudably suggest that all factors may act in combination. It is interesting to note, and supportive of their hypothesis, that five of the eight patients who showed little diurnal change, or none at all, went to surgery and were found to have complete annular tears or frank protrusions. A trunk list away from the painful side may be an attempt to decrease the symptom provoking annular bulge on the other side. Trunk lists which are worse in the morning and improve through the day may be a result of diminishing disc hydration and hence the size and tension of the bulge. Similar diurnal changes might explain why many patients with a disc protrusion need help with their socks or stockings in the morning, but have little difficulty later in the day (Porter & Trailescu 1990).

Porter & Trailescu (1990) observed that proven L5/S1 disc protrusions showed less diurnal change than those at L4/5 and suggested that this may be due to the relatively reduced proteoglycan content (decreased osmotic pressure) and the low hydration of the lumbosacral disc.

DIURNAL VARIATION IN BIOMECHANICS OF THE SPINE

Diurnal changes in disc volume, responsible for height variations, are likely to have marked effects on vertebral relationships and as a result affect biomechanics and pathological and anatomical relationships. Adams et al (1987) recorded average losses of 1.53 mm per lumbar disc in their creep-loaded specimens. They calculated that the lumbar spine would account for 7.65 mm loss in body height and that the thoracic and cervical spines would represent 10.2 mm and 3.06 mm respectively—this total of 20.9 mm being similar to the physiological height changes of 19.3 mm noted by others.

As disc volume decreases so the vertebrae approximate, the intervertebral foramen diminish in size, the disc bulges radially, the zygapophyseal joints progressively share more of the compressive loads, and all longitudinal ligaments tend to slacken—as do the capsular, supraspinous and interspinous ligaments.

THE INTERVERTEBRAL FORAMEN AND NERVE ROOT

Since the average height of the lumbar intervetebral foramen is about 15 to 20 mm (Panjabi et al 1983) a loss of 1.5 mm could have a significant effect, especially when there is pathological invasion of the space. Radial disc bulging may further complicate matters. Inferences from the work of Brinckmann & Horst (1985) suggest that for a diurnal reduction in disc height of 1.5 mm there should be an increased radial bulge of about 0.5 mm. A bulge of only 0.2 mm was caused by increasing compressive forces from 300 N to 1000 N, the equivalent of going from lying down to light manual work.

The influence upon root canal stenosis of diurnal changes in disc bulging is also likely to have provocative effects on the nerve root.

Segmental nerve roots and, for that matter, the whole length of the spinal canal, neuraxis, brain and meninges, are probably influenced by increased tension in the morning due to the spine's increased length. This may relate clinically to the behaviour of many spine-related symptom pictures, including headache syndromes. Problems in juveniles who have just undergone a growth spurt of the spine and whose symptoms are worse through the night and ease on rising could relate to changes in tension of an already tight neuraxis and meningial sheath.

ZYGAPOPHYSEAL JOINTS

With loss of height the zygapophyseal joints will be brought more closely together ~~and the facet tips will~~ start to resist compressive forces. Spinous processes also move closer. Adams & Hutton (1983) noted that a loss in height of only 0.9 mm would cause the facets to resist about 16% of the compressive force in the erect posture. Apparently the forces can be as high as 70% (Adams et al 1990). Further insight into the daily stresses suffered by these joints is made if one considers that the lumbar lordosis increases by about 3° during the day (Adams et al 1990). High stress concentrations tend to occur in the lower margins of the joint surfaces (Dunlop et al 1984) and in the adjacent capsule (Yang & King 1984) in more extended postures. As a consequence of this it could be argued that lumbar extension and rotation would diminish as the day progresses. However, Adams et al (1988) demonstrated that simulating height loss by creep loading lumbar spine material reduced the disc's resistance to backward bending by about 40%. They proposed that this increase in disc suppleness balanced the increased resistance from the zygapophyseal joints and spinous processes and that the range of extension would not be altered via this mechanism. Most of the subjects in the study by Gifford (1985) demonstrated moderate increases of extension range, and the range of two subjects actually decreased through the day. Perhaps this highlights the inter-subject variability of biomechanical and anatomical factors involved.

THOUGHTS ON VULNERABILITY AND ADVICE TO PATIENTS

As the spine loses height so its flexion range tends to increase. This may be as much as 2–3° per segment in the lumbar spine. Adams et al (1987) determined that a disc's resistance to bending would be reduced by about 84% and the ligaments by 44%. Thus, any form of bending (or extending, or combinations of) undertaken in the early morning will generate considerably higher stresses than later in the day. Calculations suggest that, in life, bending stresses on the lumbar discs and ligaments can be increased by 334% and 79% respectively in the early morning (Adams et al 1987). It has been found that it is far harder to induce a posterior prolapse in disc material which has been creep-loaded (to simulate height loss) than it is in specimens which have not (Adams & Hutton 1982, Adams et al 1987). This is more than likely to apply in vivo and should make us aware that the disc especially is under greater stress in the first few hours of the day and will be far more susceptible to injury.

From most of the available literature it would appear that the first 3–4 hours after rising are the most critical 'danger' times. The 'key' safety time may be less than this in normal spines. Edwards (1989) and Sullivan & McGill (1990) noted a rapid decrease in height when subjects first stood up in the morning, and Reilly et al (1984) noted a 54% loss in height during the first hour after rising. However loss in stature does seem to relate to the type of activity undertaken and the amount of physical stress one is subject to. Heavy labour will have a greater effect, and in less time, than sedentary activity (Adams et al 1990). Foreman & Troup (1987), investigating stature loss in nurses, noted that this loss was greatest during their 8 hour working shifts than during a 12 hour period on their days off. They may be more susceptible either to the disc accumulating fatigue damage or to sudden injury such as prolapse, firstly, early in their shift, and secondly, during the rest day if they undertake any sudden or heavy physical activity.

Even the type of chair seems to influence the rate of height loss, slight gains in height being shown in easy chairs where plenty of back and arm support is available (Eklund & Corlett 1984).

Older subjects may lose height more quickly after rising (Edwards 1989). Older and more degenerate discs tend to creep at a faster rate than younger less degenerated discs (Keller et al 1987) and are presumably less likely to be susceptible to the type of mechanisms under discussion.

In an attempt to quantify the effects of vibration on loss of height as experienced by workers such as bus drivers, heavy construction and equipment operators and aircraft pilots, Sullivan & McGill (1990) revealed some interesting and rather unexpected results. They found that when their subjects were exposed to a controlled vibration test they demonstrated a rapid loss of height as expected. Height losses soon recovered to their average 'creep' response' within 2 hours. However, they found that all subjects exposed to vibration actually were taller later in the day than they were on control days. They hypothesized that the vibration actually caused minor mechanical injury with a consequent inflammatory response causing accumulation of protein-rich exudate within the disc as well as additional fluids. The combination of increased fluid and raised osmotic pressure within the discs resulted in the relative increase in height later in the day. This may in part explain the mechanism of stiffening experienced by these types of workers, and even manual workers, at the end of the day after sitting in easy chairs.

TRACTION

It seems reasonable to assume that one of the major effects of spinal traction is to decrease disc swelling pressure and hence increase its fluid content, thus partially overcoming its natural tendency to lose height with upright activity. It is not uncommon for post traction forward flexibility and SLR range to decrease significantly in patients with presumed 'disc' pathology. This fits nicely with the pathological model outlined by Porter & Trailescu (1990) discussed above. Short periods of traction may mimic the effects of the 2 hour recumbency mentioned in their paper and could be used as a diagnostic aid. These authors suggest that 'if the size of a protrusion changes, then imaging a disc also may be affected by diurnal changes, perhaps explaining some negative radiculograms in patients with surgically proven discs.' The examination of diurnal disc changes by MRI imaging is alluded to in their paper (Porter & Trailescu 1990) and the results will be of great interest. It may be that the use of traction prior to repeat imaging or radiculogram in these 'negative' categories will confirm the gross effects of traction suggested above.

OTHER FACTORS IN FLEXIBILITY VARIATION

So far the disc has been highlighted as a major influence on patterns of changes in flexibility. Small changes in range of movements have been attributed to muscle 'warm up' factors (Baxter 1987). Adams et al (1987) noted variation in hip movements but felt that there was unlikely to be any variation in the mechanical properties of the underlying joints.

Connective tissues

It is well known that collagenous tissues express fluid and progressively elongate when they are repeatedly stretched and released (Hukins 1982). On removal of the stress the fluid driven out is slowly re-absorbed, or recovered, and the tissue slowly creeps back to its original length. The longer the stress is applied the longer the tissue takes to recover (Twomey & Taylor 1982). This could partially account for increasing flexibility when joints are repetitively stressed through the day and their slow recovery during recumbency. It should be realized that connective tissues are stressed during movements in mid-range positions. Johns & Wright (1962) demonstrated that, in the cat wrist joint, the contributions of various tissues to joint stiffness in the mid-range were: capsule 47%; muscle 41%; tendons 10%; and skin 2%. Thus, mid-range joint movements driving out fluid from tissues responsible for limiting movement would aid in increasing that joint's range of movement. Any end-range posture or stretching movement would obviously speed up the process.

Muscle

Collagenous tissues within muscle will be subject to the same effects as those discussed above. Certainly these components of muscle are regarded as the main restrictors to muscle stretch (Banus & Zetlin 1938, Kabo et al 1982). Additional factors highlighted by Gossman et al (1982) may be relevant to diurnal flexibility variation. They believe that length-associated changes can take place from within a few hours of a muscle being immobilized. Typically the number of sarcomeres decrease if the muscle remains in a shortened position. Further, the presence of any neurological hyperactivity, as in pain states or spasticity, leads to the more rapid and greater development of muscle tightness. Williams & Goldspink (1984) have shown that very rapidly increasing concentrations of perimysium occurs in immobilized rabbit muscle.

Muscle tone may be an important consideration. It seems feasible that circadian changes in flexibility, through changes in muscle tone, are a result of fluctuations in central nervous system activity.

Remember that the patient's ability to bend forward involves passive stress on tissues such as joints, ligaments, nerves and meninges as well as active elongation of muscle groups such as the hamstrings (Ortengren & Andersson 1977). Some hamstring muscle activity has been recorded during gentle stretching of the SLR (Moore & Hutton 1980).

Arthritis and inflammation

Morning stiffness accompanied by severe discomfort has long been recognized as part of the symptomatic picture in rheumatoid arthritis and some inflammatory arthropathies such as ankylosing spondylitis (Bennett & Birch 1967). However, it is also a common feature of injury-related disorders as well as the more benign degenerative arthropathies. Inflammation appears to be the common denominator and oedema is believed to be a major factor in causing stiffness (Wright 1959, Scott 1960, Kowanko et al 1981). Variation in oedema may be merely a result of the mechanical effects of movement, or more subtle circadian variations in things such as adrenal corticosteroid production, blood neutrophil counts and immune complexes (Harkness et al 1982).

The duration of symptoms/stiffness is also of diagnostic significance (McKenna & Wright 1990) and is often used as an indicator of the severity of inflammation. Thus administration of steroids or non-steroidal anti-inflammatory drugs significantly diminishes morning stiffness and reduces pain in many 'inflammatory' conditions.

CLINICAL THOUGHTS

The 24 hour variation in symptoms and signs seen in daily clinical evaluation are a result of a combination of physiological and mechanical responses. The following is an example of the type of thinking that knowledge of diurnal changes can give us. It should be emphasized that many other features of examination—such as history, behaviour of symptoms related to movement and the general nature of the disorder—must be considered as well.

Pain progressively worse overnight: mechanisms

Increasing disc fluid pressure

It is likely that an intrinsic focus of damage to a disc will cause pain since the outer fibres of the annulus are innervated via the sinuvertebral nerve. Normal overnight increases in fluid pressure may slowly irritate already sensitive damaged disc tissues. Pain will be provoked markedly on first rising and is quite likely to be relieved by manoeuvres which reduce disc pressure—such as taking weight through the arms, and traction. Beware of short-duration but severe post-traction pain. Increasing disc pressure could place irritative mechanical forces onto damaged or pathological vertebral body end-plates.

Increasing spinal canal length

1. Increasing spinal canal length puts a longitudinal tension on meningeal tissues and the neuraxis. It therefore may have irritative mechanical effects on sensitive dura/arachnoid/dural ligaments as well as on major and minor cord lesions such as cord neuopraxia. Longitudinal changes may also influence any pathological tethering of the dura. Diurnal changes in neurological symptoms and signs may be enlightening. Barring other irritative forces, symptoms should decrease on rising and improve through the day. Traction should provoke symptoms.

2. Increased tension will occur on all longitudinal ligaments, supraspinous ligaments, interspinous ligaments, ligamentum flavum and the zygapophyseal capsule.

Increasing tension on nerve root

This can occur (a) within the spinal canal, (b) at the intervertebral foramen, or (c) possibly beyond the intervertebral foramen. Many other factors obviously have to be considered such as limb position which effects the tension on peripheral nerves and their roots. The behaviour of symptoms at these areas will most likely depend on abnormalities such as disc bulging/herniation, spinal stenosis and degenerative changes. Thus, a sensitive dural sleeve in a stenotic lateral recess may be aggravated by the physiological effects of recumbency on the spinal canal length but relieved with upright postures and gentle activity.

Increasing tension on sensitive tissues due to increasing inflammatory exudate/oedema/swelling

It is most likely that the source of symptoms in either injury or degenerative disorders is primarily a physiological response and that mechanical factors are imposed secondarily. The effect of movement and posture on fluid within connective tissues and specialized tissues such as the disc have been discussed. These issues may go part way in explaining diurnal changes in flexibility in normals. It is likely that similar forces brought to bear on inflamed tissues will cause a dispersal of oedema and, if these forces are non-irritative to sensitive tissues, they will bring about a short-term cessation of symptoms and increase in pain-free ranges of movement. The example of a minor sprain of the lateral ankle ligaments, which are stiff and cause limping for the first 10 to 30 minutes after rising, illustrates this simply. Gentle mobilizing techniques easily improve range, but later, rest results in a return of stiffness. The more severe the inflammation the longer it takes to free in the morning and the quicker it returns with rest. This is exemplified by typical rheumatoid arthritis and nasty flare-ups in degenerative disorders such as hip arthrosis and spondylosis.

The last clinical thought is to stress that day-to-day changes in ranges of movement occur even at the same time of day (Gifford 1985, 1987) and that ranges change markedly through the day. If therapists base success of treatment solely on gains in range of movement they are entering a very questionable area. Emphasis must be on symptomatic relief. Consideration of the effects of diurnal variations on symptoms and signs must be considered vital.

Research that involves accurate recording of range of movement has to consider the time at which the measurements were made and knowledge of any day-to-day fluctuations before any reliable conclusions can be drawn.

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