Increasing age brings about inevitable changes in the structure, shape and function of the human lumbar spine. The primary structural age change which occurs is a selective loss of the transversely oriented trabeculae within lumbar vertebrae, which causes them to become shorter, wider and more concave at their end-plate region. This in turn leads to a progressive alteration to the shape of the lumbar discs and, together with biochemical and histological change, brings about a reduction in spinal posture, flexibility and compliance and in the ability of the lumbar region to cope with sustained loading. This information is important for physiotherapists in their treatment of lumbar spinal disorders.

When the authors began their research partnership in the mid 1970s, they were aware that previous accounts of the growth, maturation and decline of the human vertebral column (VC) had been largely descriptive and contained little data. However, it was clear from studies of many communities, that increasing age after maturation was at least accompanied by a significant loss in stature (Twomey and Taylor 1994). At that time, it was usually assumed that the loss in stature was primarily due to thinning of the intervertebral discs (Armstrong 1967, Lawrence 1969) and probably also by changes in VC posture (Cyriax 1978, Schultz 1960). Thus the hypotheses to be tested were that:

(a) the reduction in stature was due in part to a reduction in the length of the VC;
(b) the loss in the length of the VC was primarily due to a loss in intervertebral disc (IVD) height;
(c) the loss in disc height would bring about subsequent zygaphyscal (Z) joint changes; and
(d) the IVD and Z joint changes would result in reduced ranges of spinal movement, and a reduction in the dimension of the spinal and intervertebral canals and foramina (Twomey 1981).

The study by the authors began with the understanding that low back pain (LBP) is the most common musculoskeletal disorder in industrialised societies and that most individuals suffer from at least minor back pain and dysfunction problems at some stage during their lives. Furthermore, the level of knowledge of the pathogenesis and treatment of LBP was extremely limited and, while it has increased very considerably during the two decades since then, understanding of it is still in its infancy. While medical and health science schools fail to give the structure and function of the spine the attention it deserves within crowded curricula, this situation is unlikely to alter significantly (Jayson 1980, Twomey and Taylor 1991).

Nevertheless, there has been a considerable increase in spinal research during the last two decades and thus the level of understanding of the relevant morphology and pathology has increased dramatically. This, associated with better diagnostic skills and a more reasoned approach to treatment, has permitted considerable advances in the physical therapy of LBP (Bogduk and Twomey 1991, Twomey and Taylor 1994).

This paper primarily considers the main aspects of the authors' collaborative research into the structure, function, age changes, pathology and physical treatment of the human lumbar spine since 1976. It includes observations on lifestyle, occupation and treatment where appropriate and indicates where fuller accounts of the studies referred to can be located.
From Page 19

The lumbar vertebrae

Bone is a dynamic tissue which is regulated by endocrine factors, nutrition and physical activity at all stages through the human life cycle, in both genders. In more recent years, attention has focused primarily on the influences of hormonal and calcium deficiencies on bone loss and gain, especially in women, although less emphasis in the literature has been placed on the physical activity component (Twomey and Taylor 1994). This is in spite of the well known relationship between bone density and physical activity, clearly enunciated by Wolff in 1892.

During childhood and adult life, the cortical shell of a vertebral body (VB) is thin and dense, while its cartilage covered end-plates contain multiple vascular perforations (Williams et al 1989). The cancellous bone contained within this shell constitutes two-thirds of all vertebral bone and is arranged in irregular plates or trabeculae 0.12 mm to 0.24 mm thick, and oriented parallel to the lines of stress. Thus it has both vertical and horizontal components as seen in Figure 1 (Twomey et al 1983). In the anterior two thirds of the lumbar VB, vertical trabeculae predominate, whereas in the posterior one third, there are increasing numbers of horizontal trabeculae running into it from the pedicles (Singh 1978). Within industrialised societies, osteopenia (asymptomatic bone loss) is common in old age in both genders, but especially in women (Twomey 1989). While this may be considered as a usual part of the ageing process, the critical level, when osteopenia becomes clinical osteoporosis (with bone collapse and infraction) remains a major clinical problem (Nordin et al 1980).

The authors' research clearly showed that while there is a reduction in the numbers of both the horizontal and vertically oriented trabeculae in old age, the principal and most significant loss is to the numbers of horizontal trabeculae as indicated by Figure 2 (Twomey et al 1983). This information
The change in averagedisc height (in mm) between the ages of 20-35 years and 60+ years in females.

The change in shape of lumbar vertebrae between young adults (20-35 years) and older adults years (60+ years) in both males and females.

The VBs of young adults are well able to resist the vertical compressive forces of body weight and muscle contraction because of their trabecular arrangement (Twomey et al 1983). The earlier selective loss of the horizontal trabeculae in old age means that the remaining vertical trabeculae lose their stiffness and are now unable to cope with the forces of body weight and eventually buckle and fracture. This in turn leads to microfractures through the end-plate region and eventual end-plate collapse (Twomey and Taylor 1988, 1994). It also demonstrates that the rigidity of lumbar VB resides more in its geometry than its mass and accords to Euler's theory, ie that the strength of the bony columns (vertical trabeculae) is dependent on the number of reinforcing cross-braces (horizontal trabeculae) which support them (Twomey et al 1983).

The loss of the vertical trabeculae is most marked below the nucleus pulposus of the IVD, the region of the disc most involved in transmitting compressive loads from one vertebra to the next (Twomey and Taylor 1987, Vernon- Roberts and Pirie 1977) and consequently, this is the area of most bone infraction, leading to collapse of the central area and increased concavity of the VB end-plate.

Thus, in old age, lumbar vertebrae are shorter, wider at the waist and more concave at their end-plate junctional regions as seen in Figure 3 (Twomey and Taylor 1988). Spinal osteoporosis is also linked with a loss of stature due to shortening of the trunk, which is in part due to the loss of bone substance and also to the change in VB shape which, in extreme cases, may proceed to VB wedging and collapse (Buchanan et al 1987).

This research poses the still unanswered question as to why there is the selective loss of horizontal trabeculae in lumbar VBs in older people. While it is generally assumed that hormonal factors are the primary influence in vertebral bone loss, it is also well known that mechanical factors affect bone structure at all stages during the life cycle (Jones et al 1977, Nordin et al 1980).

Exercise has a major effect on bone, causing cancellous bone to be organised parallel to the lines of regularly imposed stress (Dent and Watson 1966) and is a potent force in the prevention of osteoporosis, especially in post-menopausal women (Ayalon et al 1987, Bailey 1986, Twomey 1989). Hormonal deficiencies alone would be expected to lead to a generalised loss of cancellous bone, while the selective loss of horizontal trabeculae suggests that mechanical forces, eg exercise, are also important.

It is postulated that the reduced physical activity of old age is
From Page 21

The lumbar discs

Despite a long-standing clinical view that the ageing process is accompanied by thinning of lumbar intervertebral discs (IVD) there is no population data to substantiate such claims (Twomey and Taylor 1987, 1989 and 1994). Measurement studies clearly show that central disc height is usually maintained and may even be increased in old age in normal unselected populations (Twomey 1981, Twomey and Taylor 1985 and 1988). These post-mortem studies of 204 subjects of both genders and all age groups also show that while gross disc degeneration becomes more common in old age, it is by no means universal and affects a minority of discs in a minority of individuals.

The authors' research shows that small decreases in marginal IVD height are more than countered by an increase in central IVD height in most individuals (Figure 4). A two way analysis of variance shows a linear trend correlating disc thickness with stature for both genders at each disc level (p<.005). The young adults of both genders were, on average, taller than the old adults (Twomey and Taylor 1985).

Thus the contrast between declining stature and increasing disc thickness in older adults emphasises the trend toward increasing control disc thickness with increasing age (Twomey and Taylor 1985). The study also shows that the subjects with real disc thinning constitute a minority group within the general population. Most individuals reach old age without macroscopic evidence of degenerative change in most of their discs. In the minority who do show gross IVD degeneration and thinning, it is the lower two lumbar discs which are most often affected.

Possible causes of disc thinning, when it does occur, could be a loss of disc material resulting from herniation, or a loss of IVD volume due to dehydration. In most cases of Schmorl's nodes, where there is the intraspondious herniation of disc material into a lumbar VB (30 per cent of study cases), or of anular rupture, the loss of disc substance has an insignificant effect on disc volume because the amount lost is small, averaging 1 per cent of disc volume (Twomey 1981, Twomey and Taylor 1987). Furthermore, the stiffer lumbar discs of old age do not readily prolapse into end-plate fractures, despite the increasing incidence of end-plate microfractures in old age (Twomey and Taylor 1987). Similarly, the extent of loss of disc volume due to dehydration is probably small, given the knowledge that the greatest water loss in IVDs occurs during childhood and adolescence and not in middle and old age (Kraemer et al 1985, Puschel 1930). The water content of the anulus fibrosus remains fairly constant at 70 per cent during adult life, while that of the nucleus pulposus declines by only 6 per cent on average from early adult life to old age, compared with a 14 per cent reduction during maturation. These changes in fluid content reflect the progressive cellular and biochemical changes observed in the IVD throughout the life cycle (Bayliss et al 1988, Urban and McMullin 1988).

In attempting to account for the common clinical view that IVD degeneration with desiccation and thinning is inevitable in old age, due consideration must be paid to the methods of disc assessment and to bias in the selected clinical samples utilised (Twomey and Taylor 1985). Most samples listed in the literature have been drawn from patients presenting to clinicians with LBP problems. They are not representative of the population as a whole and probably comprise a greater proportion of subjects with disc degenerative changes, as these are a potent source of LBP (Bogduk and Twomey 1991, Crock 1986). Similarly, in radiographic assessment of disc shape, the increased horizontal dimensions of older IVDs, together with the slight decrease in marginal disc height associated with bone proliferation on the lumbar VB rims, may provide the mistaken impression of disc thinning and the changes to IVD shape with increased end-plate concavity are not observed (Twomey and Taylor 1988).

The large sample used in the authors' post-mortem study, with no selection for back problems, is more likely to be representative of the population as a whole. It also provides standard measurements of disc dimensions and shape through the life cycle, against which the disc dimensions of individual patients may be compared.

Thus the primary structural change which occurs in the lumbar spine in old age is a change in the shape of the VB beginning with the selective loss of transverse trabeculae. This in turn brings about corresponding changes in the shape of the lumbar discs.

Spinal canals and intervertebral foramina

The spinal canal (SC) and the intervertebral foramina (IVF) of the lumbar spine are containers and pathways for the terminal 2cm of spinal cord, the cauda equina and the nerve roots of the lumbar spinal nerves. With increasing age, these anatomical spaces may be reduced by bone or soft tissue hypertrophy. This narrowing or stenosis may compromise the neural structures or their vascular supply (Schonstrom 1994, Verbiest 1975).

The growth of the diameter of the spinal canal is virtually complete by age 10, and the remodelling and change in the basic shape of the SC is completed soon after this age (Reichmann and Lewin 1971). The prevalence of stenosis of the SC increases with ageing, although it may be seen as early as the second decade in some individuals, especially when the hypertrophic bone changes of increasing age occur into a congenitally narrow SC. The young lumbar SC is generally triangular in...
shape, although it may become trefoil at lower levels with ageing and, in lateral spinal stenosis, this trefoil shape may be considerably exaggerated (Eisenstein 1977). The lumbar IVF or nerve root tunnels are auricular in shape and the spinal nerves and vessels descend obliquely through the wider upper part of each canal, adjacent to the waist of the appropriate vertebral body and above the intervertebral disc (Twomey and Taylor 1994). The length of each tunnel corresponds to the transverse widths of the pedicles which form its roof and floor and their size is such that there is usually more than adequate space to contain the nerve roots and their accompanying vessels (Domnisse 1975). The IVF space can be compromised by disc bulging or narrowing, by osteophytes at the vertebral body or facet joint margins, by thickening of the ligamentum flavum and sclerosis of the bone on the antero-medial aspect of the facet joints (Taylor and Twomey 1986, Yong-Hing 1976).

The authors’ age-change studies of the dimensions of the spinal and intervertebral canals were made from 204 post-mortem lumbar spines (age range from 1 day to 97 years) grouped into six functional age groups for each gender (Twomey and Taylor 1988). The studies showed a significant decline in the antero-posterior diameter of the SC in both genders, although the transverse diameter of the SC increases in males and declines in females with ageing. The height of the IVF decreases in old age, but its antero-posterior width and its length both increase, while the ligamentum flavum shows a 50 per cent increase in thickness with ageing over a normal life span. These age changes in a normal, unselected population show that the neurovascular bundle has less space within the SC and IVFs in old age and that minor additional pathology is more likely to lead to stenosis and entrapment syndromes in the elderly than it is in the young (Twomey and Taylor 1988 and 1994).

The age changes in dimensions of the spinal canal result in a change in the cross-sectional diameter from triangular in young adult life to trefoil in old age. It is clear that this is due to the 50 per cent increase in thickness of the ligamentum flavum, together with hypertrophy of the sub-chondral bone plate of the articular facets of the lumbar facet joints, with osteophyte formation in some individuals. The hypertrophy of the antero-medial part of the lumbar facet joints probably is a response to sustained loading at the two extremes of normal sagittal range of lumbar motion (Twomey and Taylor 1987). A vertical ridge of hypertrophic bone extends from one facet joint to the next caudal facet joint. The interesting observation that the transverse diameter of the SC increases in males and declines in females in old age probably reflects the greater prevalence of osteoporosis in elderly adult females. The increasing width of lumbar vertebrae in elderly females has been shown to be due to the changes in the internal trabecular architecture of lumbar vertebrae which occurs in old age (Preteux et al 1985, Twomey and Taylor 1982).

The changes to the shape of the IVF are considered to be due to the osteoporotic and postural changes of the lumbar column which routinely occur in old age in both genders (Twomey and Taylor 1987). These changes provide the neurovascular bundle with “less room for manoeuvre” within the IV canal and could compromise the neural structures in older people (Twomey and Taylor 1988).

It is important that clinicians who usually deal with highly selected populations are aware of “normal” age changes found in an unselected population. Porter et al (1980) showed that subjects with narrowed SCs are up to 11 times more likely than those with a normal canal to suffer from nerve root entrapment after pathology such as intervertebral disc bulging. Current research including the authors’ study, supports the view that structural shape changes, such as those described in the SC and IVF, make the subjects much more vulnerable to entrapment syndromes and nerve root claudication problems in the event of any additional pathology.

Lumbar zygapophyseal joints

The coronally oriented zygapophyseal (Z) or facet joints of infancy develop into the biplanar joints of adolescence and adult life by growing in a posterior direction from their lateral margins (Reichmann 1971, Taylor and Twomey 1986). The biplanar orientation of the adult Z joints, when viewed in the horizontal plane as in a CT scan, restrict not only rotation but also excessive flexion (Twomey and Taylor 1987). In so doing, they protect the lumbar intervertebral discs from excessive shearing forces and subsequent damage (Twomey and Taylor 1987). Zygapophyseal joints remain capable of re-modelling through life. Asymmetry or tropism of Z joint angles is common, is regarded by many clinicians as a contributory cause of LBP and is present in about 25 per cent of individuals (Kenesi and Lesur 1985, Taylor and Twomey 1993).

The authors’ research, which was both descriptive and quantitative, was based on observations and measurements of lumbar facet joints from three spinal levels (L1-L2, L3-L4 and L4-L5) in 120 specimens derived at post mortem from individuals of both genders and with an age range of one day to 84 years. The methodology is clearly defined in previous papers (Taylor and Twomey 1986, Twomey and Taylor 1985). The research has since been extended to include measurement of the dimensions of facet joints in a large series of more than 200 CT scans of the lumbar spine (McCormick et al 1988).

In the adult, the joint shape shows some variation of the basic biplanar arrangement (horizontal section) in different individuals and at different levels, although there usually is a smaller coronal component (antero-medial one-third of the joint) and a larger sagittal component (postero-medial two-thirds of the joint). The L5-S1 joints are quite often flat and orientated about 30 degrees to the
From Page 23

median plane. The joints are enclosed by a fibrous capsule posteriorly and the highly elastic ligamentum flavum (LF) anteriorly (Figure 5). The fibrous capsule is reinforced by deep fibres from the multifidus muscle, aiding congruous joint contact in the posterior part of the joint, while the elastic LF maintains such congruity anteriorly. The joint possesses fat-filled synovial folds contained with large superior and inferior recesses. The fat pads, which are fibrous on their tips in older subjects, extend into the joint from the recesses as meniscoid inclusions and probably have an important role in joint lubrication, movement and shock absorption (Taylor and McCormick 1991, Twomey and Taylor 1994). In addition, there are intra-articular “menisci” extending into the joint from the lateral and medial capsule (Engel and Bogduk 1981, Giles and Taylor 1982). The joints receive a dual nerve supply from the medial descending branch of the dorsal ramus at its own level and from the level above (Bogduk et al 1982). The blood supply is from the lumbar segmental artery as it passes through the intervertebral foramen (Lewin et al 1961).

Age changes in the lumbar Z joints generally occur in the concave superior facet before they are seen in the corresponding inferior articular facet, often being observed in the fourth decade. The age changes typically evident in the anterior, coronal one-third of the joint differ substantially from those observed in the posterior sagittal two-thirds of the joint (Taylor and Twomey 1986, Twomey and Taylor 1994).

- **Coronal age changes**
  The relatively early age changes evident in the articular cartilage of the coronal one-third of the joint are those of chondromalacia with chondrocyte swelling and progressive vertical splitting of the articular cartilage. The sub-chondral bone plate (SCP) shows selective thickening and sclerosis in this region as part of normal growth and maturation (Figure 6). The changes principally affect the superior articular process and probably occur as a result of compression loading of the joint which occurs during lumbar flexion (Taylor and Twomey 1986, Twomey and Taylor 1983).

- **Sagittal changes**
  In the posterior, sagittally directed part of the joint, the later changes are quite different from those noted above. Thus there may be posterior marginal separation of articular cartilage from bone at its junction with the SCP, together with stretching and tearing of the capsule. This separation of articular cartilage may result in a detached piece of cartilage which still retains its anatomical connection to the innervated deep layer of the capsule. This separation of articular cartilage may result in a detached piece of cartilage which still retains its anatomical connection to the innervated deep layer of the capsule (Figure 6). These changes are more evident in the lower regions of the lumbar Z joints.

In older subjects, especially those over 50 years of age, there may be tearing of the LF or separation of its attachment to the joint facets. This normally accompanies general capsular laxity, suggesting instability of the affected lumbar segment. This incongruity and instability often involves a retrolisthesis of the inferior articular process relative to the superior process (McCormick et al 1988).

In post mortem studies, the increasing frequency with ageing of such changes at the posterior pole of the joint is very evident. The posterior capsule and overlying multifidus muscle may be stretched around the posterior margin of the retrolisthesed joint, causing metaplasia of articular cartilage on the inferior articular process. Joint incongruity and subluxation are also accompanied by an increase in the number and size of the fatty joint inclusions as compensation for the irregularity of the surfaces (Taylor and McCormick 1991, Twomey and Taylor 1991).

An extension of the Z joint study compared Z joints from the lumbar spines of 31 individuals who died following major trauma, mostly motor...
vehicle accidents (MVA), with those from a larger study of 204 individuals. It was evident that there was considerable additional damage to the Z joints of those subjects who died following MVA. This damage included both bony injuries and soft tissue damage. The bony injuries were evident as fractures of the superior articular process, either central fractures or infractions, or lateral fractures extending up into the mammillary processes on the posterior aspects of the superior articular processes (Figure 7). They were seen in 11 of the 31 subjects examined. Soft tissue injuries were more common and were in the articular cartilage or separation of articular cartilage from the underlying SCP, or combinations of these lesions. Healed injuries of a similar type, which were unrelated to the cause of death, were found in other lumbar spines. None of the lesions were diagnosed by standard post mortem radiological examination. It is suggested that in survivors of MVA, bony and soft tissue injuries to lumbar Z joints may result in considerable pain and dysfunction and may predispose toward early arthritis in those joints (Twomey et al 1989, Twomey and Taylor 1994). These observations are of considerable importance in the diagnosis, medical and physical management of LBP after high speed MVA.

Articular triad

The authors' basic studies of the morphology, development and age changes of the lumbar spine have concentrated on the elements of the "mobile segment" or "articular triad" (Figure 8). These descriptive phrases refer to an intervertebral disc and two synovial Z joints at the same spinal level. It is the interaction between these anterior and posterior joint structures, along the length of the vertebral column, which allows the spine its very considerable mobility. The consequence of the interdependence of the three joints of the triad is that failure of any one element (by trauma or degeneration)
inevitably leads to degenerative changes in the other elements. Within the articular triad, it is the IVD which is primarily responsible for weight transmission and shock absorption, while the function of the Z joints is to stabilise the motion segment, control its movement and protect the discs, associated neural structures and ligaments from stress. Old age is accompanied by an increasing incidence of degenerative changes in IVDs and Z joints with an increase in disc stiffness and a change in the shape and antero-posterior length of the disc-vertebral junction. These changes accompany a decline in the height of the vertebral column, a flattening of the lumbar lordosis, a decline in the range of spinal movements and an increase in the creep response of the spine to prolonged loading. These latter functional and mechanical elements of spinal behaviour will be considered later in this paper.

Lumbar movement

Although each articular triad allows only a few degrees of movement, lumbar spinal motion involves a complex interaction of mobile segments at multiple levels. The thickness and compliance of each lumbar disc, the dimensions and shape of its adjacent vertebral endplates, and the shape and orientation of the vertebral arch articular facets, are the factors which govern the extent of total movement possible and also provide the restraints necessary to limit excessive movement (Twomey and Taylor 1994).

The posterior lumbar elements, ie the articular facets, ligaments and muscles, specifically govern the type and extent of movement. The vertical and largely sagittal orientation of the strong biplanar joint facets provide a most effective limit to the movements of extension, axial rotation and side flexion. Lumbar flexion is limited both by the apposition of facet surfaces and by the increasing tension developed in the posterior ligaments and muscles (Adams and Hutton 1983, Taylor and Twomey 1986, Vernon-Roberts and Pirie 1977). There is considerable individual variation in facet orientation between individuals and also asymmetry of the orientation of lumbar facets at a particular level in the one individual (tropism) which is present in about 30 per cent of the population. Where tropism does occur, there is a difference in the type and amount of motion at the segmental level involved and also a change in the forces imposed on the intervertebral disc (Hagg and Wallner 1990).

- **Ranges of lumbar movement**

There have been many studies over recent decades using differing assessment techniques and methodologies, which have measured...
the range of lumbar movements. These are comprehensively described in Twomey and Taylor (1994).

In an effort to provide instrumentation that could be readily applied in the clinical situation and provide reasonably accurate, objective data, two instruments were devised to measure lumbar sagittal and horizontal plane movement (Farrell and Twomey 1982, Twomey and Taylor 1989 and 1994). The lumbar spondylometer measures lumbar sagittal motion, is readily applied to the exposed lumbo-sacral region and has good inter-test and inter-therapist reliability. Tests of its accuracy suggest that it underestimates adult lumbar sagittal movement by an average of 1 degree (Twomey 1981). Inter- and intra-operator repeatability trials show a high correlation, \( r = 0.85 \) (Farrell 1982). The use of the lumbar spondylometer (which was based on a larger instrument developed by Dunham in 1949) requires a thorough knowledge of the surface anatomy of the lumbar region, for it to be clinically useful.

Similarly, the externally obtained measurement of lumbar rotation in the clinical situation is possible by means of the lumbar rotometer. The apparatus is more cumbersome than the spondylometer and is thus more important as a research tool than as a clinical instrument. The rotometer produces reliable, consistent data and the measurements correlate well (\( r = 0.85 \)) with those obtained from cadaveric studies (Taylor and Twomey 1980, Twomey 1981). Later studies with cadaver spines suggest that the "axial rotation" measured is coupled with sagittal and coronal plane movements (McFadden and Taylor 1990).

Figure 9 clearly demonstrates a decline in the ranges of all lumbar movements (in living subjects), with increasing age. They were obtained from approximately 1000 subjects as part of the 1978 Busselton population survey (Taylor and Twomey 1980). This decline in movement ranges parallels the reductions which the authors reported in their extensive cadaveric studies using post-mortem material obtained within 24 hours of death. These studies are comprehensively reported elsewhere (Taylor and Twomey 1980, Twomey 1981, and Taylor and Taylor 1994).

The general reduction in ranges of spinal motion with increasing age in both genders occurs as a direct consequence of the increased stiffness of the IVD, in association with disc shape changes at the vertebral end-plates (Twomey and Taylor 1983). Disc thinning, since it occurs only in about 25 per cent of the discs of older people, is not a major influence in this reduction of movement ranges in old age. The 40 per cent increase in disc stiffness which occurs in older subjects (Twomey et al 1983) is associated with well documented histological and biochemical changes (Twomey and Taylor 1994).

The lumbar back muscles exert considerable control over active ranges of lumbar movement and it has been shown that, after suitable warm-up exercises, ranges of lumbar flexion increase by up to 3 degrees (Taylor and Twomey 1980). The same study also shows that a change in posture from upright stance to side-lying brings about an additional increase in range. It appears that the warm-up exercises achieve their effect by relaxation and stretching of the back muscles which resist full flexion from an erect posture and by the progressive loading and creep of the lumbar ligaments.

In another study which examined the factors which control and limit the movement of lumbar flexion, it was shown that the intact facet joints have a greater restraining role toward the limit of lumbar flexion than does the posterior ligamentous complex (Twomey and Taylor 1983). This study also clearly demonstrated that the forward rotation component of lumbar flexion is always associated with 2-3mm of ventral translation of one vertebra on the next. Thus the lumbar facets guide the forward rotation and resist the ventral slide. When the pedicles are sectioned, a much greater amount of ventral slide accompanies the increased rotation.

The lumbar vertebral arches thereby provide an essential restraint mechanism which prevents the transmission of shearing stresses to the intervertebral discs. If this restraint is ineffective due to facet degeneration or partial facet removal by surgery, it will eventually lead to instability with subsequent danger to the cauda equina and the nerve roots in the intervertebral foramina.

**Creep in the lumbar spine**

Stiffness in the IVDs and the progressive loading of the lumbar facet joints are the main factors which cause the normal range of flexion to come to a halt. However, sustained loading at the normal limit of flexion, does produce a progressive increase in flexion. This extra movement is due to "creep", the progressive deformation of the vertebral structures under a constant load, when the forces are not large enough to cause permanent damage to the ligament, cartilage and bone under stress.

- **Axial creep**

In the erect standing position, the IVDs bear about 85 per cent of the axial compressive load, with the remainder carried by the facet joints (Miller et al 1983). Such axial loads, if maintained, cause the discs to lose height progressively as fluid is expressed and until the chemical forces developed within them equals the externally applied loads. Thus, provided that the forces involved are below the levels which would cause permanent damage, the greater the external force, the greater the loss of height which occurs (Kazarian 1975).

From the time at which an individual arises in the morning, the load of body weight and associated muscle activity acts as an axial compressive force, the structures under load "creep" until equilibrium is reached and an individual's stature declines. On rest, when body weight and thus axial loading is relieved, the IVDs and other soft structures are able to rehydrate and thus stature is restored (Koreska et al 1977). Tyrell et al's (1985) studies have shown that a period of rest in
From Page 27

Lumbar flexion brings about a more rapid increase in rehydration than does rest in extension. This occurs since flexion acts as a distracting force on the lumbar region, allowing the IVDs to imbibe water at a greater rate (Twomey and Taylor 1994).

- **Flexion creep**
  
  Full range lumbar flexion causes the anterior IVD region to be compressed, while the posterior region is stretched; the facet joint articular surfaces are pressed tightly together, while the posterior spinal ligaments are also stretched (Twomey and Taylor 1983). Under these circumstances, sustained loading at the limit of flexion causes creep to occur in the above compressed and stretched tissues and is evident as an increase in the overall range of flexion possible (Figure 10). The authors’ studies show that the amount of flexion “creep” in elderly spines is greater than in the young and that both the creep and the recovery from creep (when the loading is removed) occur over a longer period of time in older persons. During this process of prolonged loading and creep, fluid is extruded from the soft tissues, circulation of fluid within the disc is reduced and they become relatively deprived of nutrients, especially if the position is sustained for a long period. Repetitive prolonged loading eventually causes cartilage degeneration and bone hypertrophy within the articular triad (Taylor and Twomey 1986).

  When the amount of flexion creep after sustained loading is large, then recovery back to the original starting position (once the load is removed) is quite slow. The soft tissues require a considerable period of time to be able to imbibe sufficient fluid to return to their original state. There are many occupational groups such as bricklayers, shearsers, roofing carpenters and the like who work at or toward the limit of lumbar flexion for long periods. Once they have achieved their working posture, there is often little movement away from full flexion and little opportunity for recovery between work episodes. Thus it is not surprising that most shearsers complain of chronic low back pain and can readily recount many episodes of acute pain (Sewell 1989). These occupational groups require ergonomic advice and alterations to their working conditions if the situation is to be rectified (Twomey et al 1988). An additional problem with loading the spine in a flexed posture is that the facet joints are not fully congruent in flexion and offer less effective restraint to axial rotation. Combined flexion and axial rotation is the combination most likely to overstretched the disc and tear the annulus.

**Impact loading in lumbar extension**

The range of lumbar extension is controlled by bone apposition rather than ligamentous tension, and ceases when the inferior articular facets are forced against the laminae of the vertebrae beneath, or occasionally when spinous processes “kiss” (in older people) (Oliver 1990). This is evident in the hypertrophy of compact bone in the laminae beneath the inferior zygapophysial joint recess (Twomey and Taylor 1994). When hyperextension occurs, there is also stretching of the anterior soft tissues, especially the anterior longitudinal ligament and the anterior anulus fibrosus.

  There are few examples of sustained working postures in full lumbar extension and thus creep due to this mechanism is rare. However, prolonged standing in the upright posture indicates a tendency for the axial load of body weight to increase lumbar lordosis (Twomey and Taylor 1994). In this way, the lumbar facet joints will take an increasing proportion of the load of body weight. Although long, sustained loading in lordosis is rare, a number of sporting activities involve full extension movements of an explosive nature.

  These movements are often repetitive and involve high impact loading in full extension. Thus gymnasts, fast bowlers in cricket, footballers and high jumpers are among the athletes who impose tremendous forces through their posterior arch complex in this way. During these sports, there are episodes, often involving landing from a height, when the chisel-like inferior articular processes of the lumbar facet joints are forced down suddenly on the laminae of the vertebrae below. The forces involved are considerable and repetition over long periods of time.
results in soft tissue inflammation and bone sclerosis that may become evident on radiological examination, but which may eventually cause the laminae to fracture, perhaps with displacement (Twomey et al. 1988, Yang and King 1984). The bone area that absorbs this force is the pars interarticularis region of the lamina, between the zygapophyseal facets.

The pars interarticularis is the site at which spondylolysis occurs with subsequent risk of spondylolisthesis. It is quite likely that it is the repetitive combination of alternative, explosive full range extension, followed immediately by sudden forceful flexion, which places the enormous strains on the pars region. This extension/flexion repetitive strain may cause fatigue fracture in a way similar to that of fatigue in metal caused by successive opposite movements and is canvassed in a previous paper (Twomey et al. 1988).

**Segmental instability**

Studies on lumbar segmental instability have used both cadaver and radiological material. The cadaver study (McFadden and Taylor 1990) suggested that an unstable segment was more easily identified by the presence of abnormal axial rotary movement than by abnormal translation. There appeared to be a combination of disc damage and unilateral facet subluxation. This could also be demonstrated in CT scans where the unifacetal subluxation involved retrolisthesis of the inferior articular process from the corresponding superior articular process, often with remodelling changes in the subluxed joint (Taylor and Twomey 1992). These changes could be statistically related to back pain only in patients under 50 years of age. Axial rotary instability may result from axial rotary strains, particularly when the spine is loaded in a flexed, rotated position. Such symptomatic instability may well be detectable using passive movement techniques of examination.

**Conclusion**

The authors’ research on the age-related changes and the function of the lumbar spine has helped to establish the pattern of structural and biomechanical changes which occur in the lumbar region as an inevitable part of the life-cycle of most individuals. At the same time, the influence of pathology and the effects of trauma to the spinal elements and to function have been investigated. Although these studies have been extended and changed from the original hypotheses, they have clearly developed from the original premise. The morphological changes in the size and shape of lumbar vertebrae and discs, together with the histological and biochemical changes of ageing, lead to a structure which is less flexible and compliant and reacts more slowly to conditions of sustained loading. This information provides part of the necessary background understanding to physiotherapists involved in the treatment of the low back region of individuals of differing ages. The older lumbar spine should not be treated in the same way as the lumbar spine in a younger individual, as its ability to respond to physical therapy is markedly different.

**References**


