THE LIFE CYCLE OF THE INTERVERTEBRAL DISCS
AND VERTEBRAL BODIES: A REVIEW

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A review of the current concepts of growth, maturation and development of the vertebral bodies and intervertebral discs.

Few people escape back problems and associated pain during the course of their lives and all individuals show degeneration of vertebral structures with advancing age. Nachemson (1976) considers that during life 80% of people will experience back pain to some extent and that for the 30 to 60 age group, it is the single most expensive ailment from a socio-economic viewpoint. Back pain is a purely subjective symptom which, while it never appears on death certificates, yet surfaces in a whole variety of disguises on sickness certificates (Glover, 1970; Troup, 1975). Back disorders cause an enormous loss in productive working days among all western communities in any one year. In 1968-1969 in the United Kingdom it was estimated that 13.27 million working days were lost because of back problems (Hodgson, 1973).

It is difficult to be precise about pathologies since almost every pathological change to which back pain has been attributed has subsequently been demonstrated in the symptom-free population (Troup, op. cit.). Reflecting this uncertainty in aetiology a vast literature has developed on many aspects of the subject (Nachemson, 1969). In recent years, the intervertebral disc is one structure which has received considerable attention as a likely source of back pain syndromes.

Because of their conjoint formation and development, the vertebral bodies and the intervertebral discs need to be considered together.

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DEVELOPMENT OF THE VERTEBRAL COLUMN
In the human, as in all chordates, the spinal segments are formed from a series of mesenchymal condensations surrounding a longitudinal notochord and a dorsal neural tube. The development of the human spine begins with the three layered stage of the embryo (about day 17) and is complete by the third decade of life (Schmorl and Junghanns, 1971).

In higher vertebrates, the presence of the notochord (of ectodermal origin) determines the longitudinal axis of the early embryo and induces mesodermal differentiation. By about five weeks, the prominent series of somites lie along each side of the notochord and neural tube. The somites originate by segmentation of the primarily cartilaginous column of mesoderm (Walmsley, 1953). The ventro-medial portion of the somites (the sclerotomes) migrate medially and meet with those of the opposite side in the midline, surrounding the notochord. This continuous mesenchymal (membranous) column differentiates into successive alternate light (cephalic) and dark (caudal) bands (Peacock, 1952; Schmorl and Junghanns, op. cit.), as shown in Fig. 1.

The onset of chondrification in the light bands (from which the vertebral bodies will form), results in a rapid increase in their height. Shortly after this, three primary centres of ossification appear in the cartilage model, one for the centrum (body) and two for the vertebral arch. Primary ossification begins about week nine and follows invasion.
of the cartilaginous model by periosteal vessels. This process begins initially in the lower thoracic and upper lumbar regions and extends more rapidly towards the caudal than the cranial end of the vertebral column.

By 24 weeks of foetal life, the centrum is capped on its cephalic and caudal aspects by cartilaginous plates which are remnants of the original cartilage template. It is from the central portions of these plates that longitudinal bone growth by endochondral ossification is continued (Bick and Copel, 1950). Full growth in the male is completed between the ages of 17 to 21 years, while in the female it is between 16 and 18 years of age (Rothman and Simeone, 1975).

By week 10, the dark bands have differentiated into a rudimentary anulus fibrosus consisting of peripherally placed fibroblasts arranged in lamellae fashion and a central notochordal segment. It is the latter which will interact with an intermediate area of undifferentiated “pre-cartilage” to form the nucleus pulposus (Peacock, op. cit.). At birth, the notochordal tissue is the major source of nuclear material, but the interspersed fibrous material and cartilage cells within it increase with age (Keyes and Compere, 1932). By the year 12, the nucleus pulposus is almost entirely composed of loose fibrocartilage with an abundant gelatinous matrix (Walmsley, op. cit.).

Vertebral Column and Spinal Cord

Until the third month of foetal life, the vertebral column and spinal cord are equal in length. Thereafter the column grows faster than the cord and the spinal cord which was originally at the level of the coccyx recedes up the spinal canal. At birth it is opposite the

**Growth and Maturation of the Vertebral Column**

When man is compared with other animals, marked differences are evident in the vertebral column. Apart from the neck, plantigrade animals possess a long gently curving column with the concavity being directed inferiorly (Cunningham, 1886; Clegg, 1968). In the human foetus, the vertebral column is curved from occiput to coccyx with its concavity facing anteriorly. From this common concave curve, counter curves develop as the static functions of the body develop and as the vertebral column adjusts itself to the upright position (Ballentyne, 1892; Calliet, 1964; Steindler, 1973).

Farfan (1973) considers that at birth the cervical curve begins to reverse itself and the lumbar curve is flat. However, Bagnall et al. (1975) determined that the secondary cervical curvature begins earlier than usually accepted and in harmony with the developing occipital bone. They related this development to the influence of both the substantial extensor nuchal musculature and to the proximal muscles of the upper limb on the cervical and upper thoracic region, and further suggest foetal head movement in interuterine life as a factor. Armstrong (1967) also considers that the secondary cervical curve begins to develop during late foetal life and that this is primarily due to the growth pattern of the disc, rather than the direct influence of the antigravity muscles. Armstrong and Bagnall et al. provide subjective rather than quantitative data to support their assertions. It is clear that a definite cervical curvature appears between 3 and 9 months of age, while the permanent lumbar curve comes with the upright posture at about one year. These curves continue to develop until cessation of vertebral column growth at the twelfth to seventeenth year (Farfan, op. cit.).
third lumbar vertebra and by the age of 5 years, it has reached the usual adult interspace of L1-L2 (Ballentyne, op. cit.; Farfan, op. cit.; Shapiro, 1975). Occasionally the conus medullaris may lie as high as T12-L1 or as low as L3 (Shapiro, op. cit.). Roth (1966) considers that the unequal growth of cord and column is an additional factor influencing the growth and development of the vertebral column and its curvatures.

During the first two years of postnatal life, the vertebral column more than doubles in length (Caffey, 1972). Thereafter the velocity of growth is considerably diminished. Growth is fairly consistent to 6 years of age and then proceeds more slowly between the ages of 6 and 10 in girls and 6 and 12 in boys. The adolescent growth spurt follows and occurs most frequently between 11 and 13 years of age in girls and 13 and 15 years of age in boys. Thereafter, the rate of growth decreases each year, so that after a further 3 years, the residual growth is inconsequential (Risser and Ferguson, 1936; Anderson et al., 1965).

At birth, the cervical spine constitutes one-quarter, the thoracic spine one-half, and the lumbar spine one-quarter, of the length of the vertebral column excluding the sacrum. Different regions of the vertebral column grow rapidly at different stages of development. In the adult the cervical spine is reduced to 1/5 or 1/6 of the total length, while the lumbar spine is increased until it comprises nearly 1/3 of the whole (Aebi, 1879; Ballentyne, op. cit.; Caffey, op. cit.; Farfan, op. cit.).

**Vertebral Body**

At birth, the bony centrum and the two halves of the neural arch are separated by cartilage. The two halves of the neural arch unite during the first year of life, initially in the upper lumbar region and then proceeding to the thoracic and cervical regions (Bick and Copel, op. cit.; Reichmann and Lewin, 1971; Schmorl and Junghanns, op. cit.). Horizontal growth of the vertebral body proceeds by periosteal ossification (Brandner, 1970) and is appositional in type (Knuttson, 1961; O'Brien, 1969; Caffey, op. cit.). This growth mainly occurs at the anterior and lateral surfaces of the vertebral body (Knuttson, op. cit.; O'Brien, op. cit.; Katzman et al., 1969), although Reichmann and Lewin (op. cit.) produce histological evidence of growth at the posterior surface of the lumbar vertebral bodies in children under 12 years. Carpenter (1961) found that union of the centrum with its respective arch is complete in the cervical spine by year three and in the lumbar spine by year six.

Postnatal longitudinal growth of the vertebral column is due to the proliferation of cartilage on the upper and lower zones of the primary ossification centre in the vertebral body (Harris, 1933; Bick and Copel, op. cit.; Moser, 1970; Caffey, op. cit.; Knuttson (op. cit.) and Gooding and Neuhauser (1965), agree that this growth is equal at the cephalic and caudal ends of the vertebral body. Beadle (1931) and Bick and Copel (op. cit.) state that there is no contribution to vertical growth and no trace of endochondral bone formation in the anular cartilages or rings epiphyses, which appear at 8-10 years and fuse at about 20 years. The whole vertebral body is bony and the endochondral ossification process complete between 16-21 years of age (Walmsley, op. cit.; Calvo, 1957; Taylor, 1973).

Progressive changes in the shape of the vertebral body are evident through the growth phase. At birth, the ossification centres are ovoid on lateral roentgenogram, the cephalic and caudal ends are convex and the height of the body is about the same as that of the adjacent disc space (Brandner, op. cit.; Schmorl and Junghanns, op. cit.; Caffey, op. cit.). Gradually between the ages of two and five years the vertebral body becomes more rectangular in shape with its vertical height less than its antero-posterior dimension and with an associated reduction in the intervertebral disc space relative to vertebral body height (Schmorl and Junghanns, op. cit.). Between six and eight years of age, step-like recesses appear at the superior and inferior aspects of the vertebral margin. This represents the early cartilaginous precursors of the anular rim surrounding the margins of the vertebrae. During the developmental period, the shape of the caudal and cephalic end plates changes from convex (as above) to concave (Gooding and Neuhauser, op. cit.). This con-

cavity which appears opposite the centrally situated nucleus pulposus in ambulant children, is not seen in the lumbar vertebral bodies of non-ambulant spastic children (Taylor, 1975).

Primary genetic factors are the principal governing influences on the pattern of growth of the vertebral bodies. However, during the growth period the column is also responsive to environmental stress, particularly weight bearing (Gooding and Neuhauser, op. cit.; Taylor, 1973; Caffey, op. cit.; Rothman and Simeone, op. cit.). Gooding and Neuhauser (op. cit.) demonstrated longitudinal overgrowth in children whose vertebral columns have never been subjected to the stresses of gravity and weight bearing. This relationship is maximum in the lumbar region where the normal stresses of weight bearing are greatest. Houston and Zaleski (1969) have also demonstrated a similar relationship between vertebral body size and weight bearing activities. However, these authors used an index which compared the vertical height and transverse diameters of the vertebral bodies rather than absolute figures to substantiate their claim of increased vertical height. Thus, what they demonstrated was a change in the shape of the vertebral bodies which may have been due to an increase in vertical height or to a decrease in the antero-posterior diameter, or to both. In contrast, Taylor (1975) showed that there is no evidence of increased growth in the midline of the lumbar vertebral bodies in non-ambulant spastic children. The square shape of the vertebrae in such cases is due to decreased antero-posterior diameter rather than to an increase in vertical height (Taylor, 1973, 1975).

In scoliosis, growth appears to be relatively inhibited on the concave side (which bears the greatest forces) and relatively increased on the convex side (Knutson, 1966; Roaf, 1960).

Age changes in the lumbar vertebrae are noticed as early as the second decade. Wada (1975) found osteophytes present in a number of Japanese subjects in the second decade and evidence of an increase with advancing age until osteophytes were present in all cases examined after the fifth decade. The highest frequency of osteophytes was found on the superior border of L4. Ford and Goodman (1966) reported that 47% of 1,614 patients examined had osteophyte formation in the lumbar region, while Torgerson and Dotter (1976) found an incidence of 52% of osteophytes in the lumbar spines of 604 patients. The latter study further demonstrated an increasing incidence of osteophytes with increasing age. The osteophytes were more prevalent anteriorly than posteriorly, a factor the authors attributed to the stronger bone attachment which the anterior ligament possesses. Schmorl and Junghanns (op. cit.) state clearly that osteophytic spurs are formed only after the cessation of growth of the individual and follow as a consequence of disc thinning and degeneration, heavy manual labour involving overstrain and/or altered biomechanics of the lumbar region.

Ericksen (1975) measured the vertebral bodies of L3 and L4 of 338 skeletons. Her results showed that the heights of the vertebral bodies tend to decrease, while the breadths increase with age. In 1974, Ericksen suggested that the increased broadening and slight loss of height would result in a shape change which would maintain stability while cancellous bone was lost during ageing. However, in her 1975 study, Ericksen found that some individuals accomplish the broadening of the vertebral bodies by periosteal apposition, while others do it by the development of vertical columns of periosteal bone, bridging the large osteophytes. In such ways, both the endplates and the middle of the vertebral body broaden and flaring is an unusual manifestation.

Osteoporosis is the most common of all of the abnormal processes involving bones including the vertebrae (Hall, 1976) and may follow as a consequence of (i) disease, (ii) a marked decrease in weight bearing, and (iii) the ageing process (Rothman and Simeone, op. cit.). Beyond the age of 65, osteoporosis is found (by X-ray) in 65.8% of women and 21.5% of men. In women the incidence increases by about 8% for each additional decade of life, whereas in man, a large increase does not occur until after age 76 (Gitman and Kamholz, 1965). The osteoporotic vertebral body loses a considerable part of its ability to carry weight. Evidence indicates that the intervertebral discs exert pressure upon the
adjacent surfaces of the vertebral body through the nucleus pulposus, causing an arch-like indentation (Schmorl and Junghanns, op. cit.). Barnett and Nordin (1959), Arnold et al. (1970), and Ericksen (1975) use a biconcavity index (midline vertebral body height divided by anterior vertebral body height) to measure the amount of inward bowsing of the lumbar endplates which is characteristic of the osteoporotic process.

In marked osteoporosis, very considerable compression of vertebral bodies may follow, resulting in wedging and collapse (Shapiro, op. cit.).

**Intervertebral Disc**

At birth, the disc is of considerable thickness and is bounded on its cephalic and caudal aspects by biconvex cartilaginous plates, as shown in Fig. 2 (Peacock, op. cit.; Walmsley, op. cit.; Galante, 1967; Taylor, 1973). The anulus fibrosus demonstrates a dense outer region of closely packed collagenous fibres in a concentric, complicated lamellar arrangement with a less concentrated area or transitional zone (Peacock, op. cit.) adjacent to the nucleus pulposus. There is a regular orientation of anular lamellae with a slight increase in thickness from the inner to the outer lamellae. The lamellae of the posterior areas of the disc are generally thinner than those of the anterior region and are partly interwoven with each other (Inoue and Takeda, 1975).

There is no sharp definition of anulus fibrosus from nucleus pulposus although the differentiation is more pronounced in young subjects (Naylor, 1962). Both anterior and posterior areas of anulus have arching fibres which terminate and attach deeply within the cartilage endplates of the vertebral bodies (Beadle, op. cit.; Peacock, op. cit.; Walmsley, op. cit.; Naylor, op. cit.; Galante, op. cit.).

The anulus fibrosus is intimately fused with the anterior and posterior longitudinal ligaments and with the epiphyseal ring region of the vertebral body by the strong Sharpey’s fibres (Carpenter, op. cit.; Naylor, op. cit.; Coventry, 1969). Nerve fibres have not been demonstrated within the anulus fibrosus (Pedersen et al., 1956). Polarised light studies have shown the continuity of the horizontal fibrous structure of the cartilage endplates with the curved lamellar pattern of the anulus fibrosus (Taylor, 1973). The narrow transitional area between the outer anulus and inner nucleus consists of fibrocartilage undergoing liquefactive changes, resulting in the separation of cartilage cells and fibres and their mingling with the mucoid substance at the periphery of the nucleus pulposus (Peacock, op. cit.).

**Figure 2**

Intervertebral disc and vertebral body of the neonate.

The nucleus pulposus is elliptical in its median sagittal sectional shape at birth and occupies half the antero-posterior dimension of the whole disc (Fig. 2). It consists of a mass of homogenous mucoid substance including a meshwork of notochordal cells contained under slight pressure within the anulus (Nachemson, 1960; Nachemson and Morris, 1964; Hall, op. cit.; Andersson et al., 1974). It is the notochord which is the main source of the nucleus up to the time of birth (Keyes and Compere, op. cit.; Bradford and Spurling, 1945; Peacock, op. cit.; Walmsley, op. cit.; Naylor, op. cit.; Taylor, 1973 and 1975). By four years of age, the mucoid nucleus pulposus consists of an irregular network of fine collagen fibres together with isolated clumps of notochordal cells, many of which are by now degenerate and including a high proportion
of frankly necrotic cells (Walmsley, op. cit.; Meachim and Cornah, 1970; Taylor, 1973). The nucleus of infancy and childhood occupies a large part (about half) of the area of the disc as seen in median sagittal section. As age increases, the boundary between the nucleus and the surrounding anulus becomes less distinct as the collagen fibre proportion of the nucleus increases (Peacock, op. cit.; Jonck, 1961; Meachim and Cornah, op. cit.). By the end of the growth phase, the nuclear material is less translucent, of firmer consistency and can no longer be described as notochordal (Warwick and Wilkins, 1973). By this stage it is a three dimensional lattice gel, with an irregular network of collagen fibrils in a matrix of muco-polysaccharide and containing a few scattered cells resembling chondrocytes. Unlike the anulus fibrosus, there is no connection of nuclear fibrils with the cartilage endplate (Inoue and Takeda, op. cit.).

The nucleus pulposus is mostly water which is retained by the physicochemical properties of the colloidal gel (Hendry, 1958). When less than fully hydrated the gel will absorb tissue fluid (even against strong mechanical pressure) until it is fully saturated (Charnley, 1952).

With increasing age, chemical changes occur which affect the mechanical properties of the nucleus (Gordon, 1961; Eyring, 1969; Schmorl and Junghanns, op. cit.). The collagen fibres of the nucleus become macroscopically coarser and merge gradually with those of the anulus, while showing increasing orientation and crystallisation on X-ray crystallography (Naylor et al., 1954; Horton, 1958). The proportion of muco-polysaccharide decreases and changes its chemical nature in that the ratio of keratin sulphate to chondroitin sulphate becomes greater (Naylor et al., op. cit.; Gordon, op. cit.; Gower and Pedrini, 1969; Adams and Muir, 1976). The elasticity, viscosity and water binding capacity of the nucleus decreases from about 90% at birth to about 70% in old age, while the anulus decreases from 76% to 70% in the same time span (Keyes and Compere, op. cit.; Gordon, op. cit.; Galante, op. cit.; Schmorl and Junghanns, op. cit.; Markolf and Morris, 1974). Nachemson (1960, 1969) considers that even though there is a considerable change in the appearance of the nucleus during post-natal development and maturation, the nucleus pulposus of the normal adult still behaves as a fluid in a container, distributing compression forces equally in all directions. Nevertheless, the ability of the disc to withstand compressive forces and to exhibit normal creep and relaxation characteristics depends on the intact anulus fibrosus as much as it does on the contained turgor of the nucleus pulposus (Brown et al., 1957; Virgin, 1958; Markolf and Morris, op. cit.; Nachemson, 1960).

Increased age affects the anulus fibrosus as well as the nucleus pulposus. In the anulus the lamellar fibres become hyalinised and foci of cartilaginous metaplasia appear together with random fibrosis (Galante, op. cit.; Hall, op. cit.).

Concentric cracks and cavities may be present as early as age 15, become more common as age increases (Hirsch and Schajowicz, 1952) and may result in anular tears (Kulak et al., 1976). These changes, together with the loss of fluid content and decreased turgor of the nucleus may lead to horizontal bulging of the periosteum from the vertebral body margins, with the formation of osteophytes (Friberg and Hirsch, 1949; Stevens, 1968). Coventry (op. cit.) considered the ageing process to be normal and one which produces little distress as a general rule, while posterior herniation (bulging, rupture, protrusion) is the most serious single pathological disability from the disc.

Mechanically, discs from older subjects demonstrate greater stiffness, residual deformation, and increased compressibility than discs from younger specimens and in general intradiscal pressures are higher (Nachemson, 1960; Gordon, op. cit.; Galante, op. cit.). Lawrence (1969) considered that almost two-thirds of the adult population showed radiological signs of disc degeneration. In 1931, Beadle stated that after the mid decades the findings of well preserved discs is the exception rather than the rule, while Naylor (op. cit.) wrote of the ageing process leading to disc thinning due to inspissation and a gradual reduction in the nucleus pulposus. These research workers were clinicians and were reviewing populations attending for
treatment of low back pain. It is possible that their views on the general population were clouded by the skewed populations they considered.

Cartilage plates cap the cephalic and caudal ends of the vertebral bodies and consist of parallel layers of hyaline cartilage about one millimetre in thickness (and thinner in the centre) into which the anulus fibrosus and the longitudinal vertebral ligaments attach. They act as a barrier between the vascular spongiosa of the vertebra and the avascular disc. The adult cartilage plate has numerous perforations which may serve as channels for fluid and chemical interchange between the disc and the vascular channels in the vertebral bodies (Naylor, op. cit.; Eyring, op. cit.). There has been some controversy as to whether the cartilage plates are part of the intervertebral disc or are endplates of the vertebral bodies. This situation was comprehensively reviewed by Taylor (1973, 1975).

Nachemson (1960) published his comprehensive study on intradiscal pressure in 121 lumbar discs (L1-L4) in 38 individuals following post-mortem and with an age range of 6 to 82 years. He demonstrated that:

1. the nucleus pulposus in the resting disc (removed from the cadaver and away from postural stress) has a very low inherent resting pressure which he considered could be neglected;
2. the loaded disc behaves hydrostatically in that it disseminates pressures equally in all circumferential directions to the anulus fibrosus;
3. lower pressure readings were recorded in children below the age of 16 years (three in the sample) when loading was applied;
4. the level of the lumbar spine (the L5-S1 disc was not included in the study) did not influence the pressures recorded;
5. the posterior vertebral structures (pedicles and joint processes) absorbed 20% of the vertical loading forces;
6. moderately degenerated discs showed similar pressure behaviour to intact discs and that the mechanical behaviour of a lumbar intervertebral disc does not undergo any appreciable changes provided that it is not the site of a very severe degeneration.

Nachemson and Morris (op. cit.) and Andersson et al. (1974) determined that intradiscal pressures in the living subjects were higher in the sitting than in the standing position. This was reinforced by Nachemson's (1965) study which showed a pressure increase when the lumbar spine was in 20° of forward flexion. In 1974, Andersson also demonstrated that the physiological lordotic lumbar curve exhibited lower pressures than when the column was in a straight or kyphotic position Andersson et al. (1976) showed a progressive increase in intradiscal pressure in the living when heavy loads were lifted or when (in most subjects) the valsava manoeuvre was performed.

Schmorl's nodes involve a vertical herniation of nuclear material through the cartilaginous plate and into the cancellous bone of the vertebral body (Schmorl, 1927; Bohmig, 1930; Gordon, op. cit.; Taylor, 1973). At these sites, the thickness of the cartilage plates is considerably reduced. Prolapases of disc material through the cartilage plates is frequently observed, occurs through the weak point and is associated with a persistent notochordal remnant (Bohmig, op. cit.). Taylor's (1973) study reinforced Bohmig's aetiological hypothesis of a fracture through a constantly thin part of the cartilage plate at the site of the former notochord.

Blood Supply

The vertebral column as a whole possesses an extensive anastomotic vascular system. The vertebral bodies are supplied by vessels which grow into the ossification centres from posterior, anterior and anterolateral directions. In addition the vertebral arches have an abundant blood supply. The close relationship of the blood supply of the vertebrae and the spinal cord has been well demonstrated by Hassler (1966), Dommisse (1974) and Crock (1975). The venous blood is collected in the vertebral body by the basivertebral veins and leaves through broad openings on the posterior vertebral body surface to join the longitudinal internal vertebral plexus.
The neonate demonstrates small blood vessels between the outer anular lamellae of the disc, while the nucleus is avascular through life, probably because of the high pressures under which it is contained (Gordon, op. cit.; Galante, op. cit.). The vessels to the anulus fibrosus have no connection with those supplying the vertebral bodies and are completely obliterated by the age of 4 years (Hirsch and Schajowicz, op. cit.; Galante, op. cit.).

**Physical Treatment**

A thorough understanding of the fundamental architecture of the back is of considerable importance to physiotherapists involved in the treatment of back pain syndromes. In recent years, it has become fashionable to emphasize back pain of discogenic origin. As this paper has demonstrated, the disc and vertebral bodies grow and age together, intimately united as one functional structure. The ageing process affects both elements and occurs concurrently. Trauma, too, affects the discs and the bodies, although in a more differential manner, depending on the type and nature of the insult. However, it is quite impossible to affect one of these structures alone, as the other must also be involved (even if to a lesser extent). It is indeed most unfortunate that the term "slipped disc" is in general community use, as it tends to direct people to consider a structure which is merely interposed between two pieces of bone, rather than for them to be aware of the real anatomical situation of intimate unity between discs and vertebral bodies.

It follows that physical therapy procedures should not be selective just to the disc, but should involve the total functional unit. Traction, mobilization and manipulation, exercise, abdominal pressure increase and postural correction are procedures used, singly or in combination to affect both intervertebral discs and vertebral bodies. We need to be as aware of the fact that our techniques have a considerable effect upon bony structures as we are of the effects which they have on the soft structures of disc, ligaments and interstitial fluid. These effects were extensively and critically reviewed by Nachemson (1969).


