dependence among philosophy, science, and technique (art) in chiropractic. The exchange among components of the discipline of chiropractic is necessary and desirable, and requires some mental exertion. Rather than serving as a defensive, political crutch for the profession, philosophy ought to be a source of guidance and inspiration for the development of a first-class science of chiropractic technique. Prepared by a familiarity with the legitimate roles of all three areas of chiropractic thought, the chiropractor can take pride in what we have learned so far and maintain enthusiasm for the task awaiting us.

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Biomechanics of the spine has historically been presented as an abstract subject, somehow separate from clinical applications. This chapter has been written to bring each anatomical and biomechanical premise or fact directly into the clinical situation, thus providing a central focus. The chiropractor must be an expert in spinal biomechanics and have the ability to apply the information in the clinical situation.

The spinal column is a complex structure. This complexity can often confuse the student clinician. Fortunately, some areas of the spine are well studied, such as the lumbar spine. There are insufficient basic science data or clinical research for other regions of the spine. Furthermore, the organization of such a complex topic is difficult because of the multiple interactions between the separate anatomical parts and physiological components.

The spinal column has the primary function of protecting the delicate spinal cord and nerve roots from injury. Protection of the nervous system is provided primarily by the articular structures (e.g., bone, ligament), but mechanisms do exist in the nervous system itself (e.g., spinal cord) that protect it from injury.

The function of protection takes place in a very hostile environment, one in which large loads and bending moments are encountered and transmitted, during which demands of normal physiologic movement must necessarily be preserved. In this awkward environment, things often go awry and injury results.

The presentation of clinical anatomy and biomechanics of the spine can take a number of directions. This discussion proceeds from the inside out, highlighting the major focus of the chiropractic physician, the nervous system.

**SPINAL CORD**

**Biomechanics**

Much more is to be learned about the physical properties and the functional mechanics of the spinal cord. When removed of circumferential attachments, nerves, and dentate ligaments, the spinal cord will lengthen by 10% under its own weight in the vertical position. This very flexible behavior changes to stiff resistance when an attempt is made to deform it further (1). The load-displacement curve for the spinal cord, therefore, has two distinct phases (Fig. 2.1):

1. The first is characterized by a large displacement with minimal applied forces.
2. The next phase shows little deformation under larger forces.

Forces in the initial phase are up to 0.01 N (0.04 oz.). The second phase can support 20–30 N (4.5–6.7 lb/f) before the tissues begin to rupture.

The spinal cord must adapt to the changes in length of the spinal canal during physiological motion. Flexion and lateral bending will effectively lengthen the spinal canal, necessitating accommodation by the cord and nerve roots (Fig. 2.2). Most of the change in length occurs at the posterior portion of the spinal cord (Fig. 2.3A-B). Two mechanisms are responsible for the change in length. The first is characterized by a folding/unfolding accordion-like action of the posterior cord. The second, which is only responsible for approximately 25 to 30% of the length change, is due to the elastic stretch/compression of the spinal cord tissue itself. In the cervical spine, the neutral, lordotic cervical region shows the posterior cord folded like an accordion (Fig. 2.3A). During flexion, the cord first

![Figure 2.1](image_url)
vous system disorders, such as tic douloureux or cervical migraine, can often be provoked with cervical flexion (1).

FUNCTIONAL SPINAL UNIT

The term functional spinal unit (FSU) or motion segment refers to two adjacent vertebrae and the ligamentous and soft tissue elements that connect them. In the thoracic spine the posterior rib articulations are also included in the description. The motion segment has the same functional characteristics as the region of the spine of which it is a part (2, 3). The articulations from occiput to C2, and the sacroiliac region, are described in detail in Chapters 6 and 11. The anatomical parts of the FSU or motion segment from C2 to S1 are as follows (Fig. 2.4):

1. The central joint: vertebral bodies, intervertebral disc (anulus and nucleus), anterior and posterior longitudinal ligaments;
2. The posterior joints and articular capsule; and
3. The ligaments between the neural arches: supraspinous, interspinous, intertransverse, and the ligamentum flavum.

The effect of annular and nuclear injury at a single FSU on movement has been demonstrated by Panjabi et al. (4). A lumbar motion segment was tested before and after annulus removal, and later, with a combination of annulus and nucleus removal. The mechanical properties were determined by imposing a predetermined torque around each of the cardinal axes (X, Y, Z) (Fig. 2.5). Vertebral movement after each application of torque was then measured in degrees. As can be seen in Figure 2.6, although both injuries had effects, nucleus removal (with annulus injury) caused the most increase in motion. This occurred in all directions, excluding compression (−Y)

Figure 2.2. The spinal canal shortens during extension and lengthens during flexion.

Figure 2.3. Mechanism by which the spinal cord changes length (See text). A, Neutral Position. B, Flexion.

Figure 2.4. The functional spinal unit or motion segment. A) posterior longitudinal lig., B) intertransverse lig., C) supraspinous lig., D) interspinous lig., E) ligamentum flavum, F) articular capsule, G) intervertebral disc, H) anterior longitudinal lig.
Figure 2.5. The cardinal planes of the human. Each plane is formed by two axes. The sagittal plane is formed by the Y and Z axes, the coronal plane by the Y and X axes, and the transverse plane by the X and Z axes.

or bending towards the side of injury (±θZ). The lack of significant biomechanical change after experimental injury at the disc of the motion segment when loaded under compression has been termed the “self-sealing phenomenon” (5).

With the effects of specific disc injuries in mind, the implications for exercise or ergonomic prescription, are as follows:

1. The patient should not laterally flex away from the side of injury as this will cause the greatest increase in motion.
2. Movements that cause compression at the site of the injury, such as extension for a posterior, central annular bulge, or right lateral bending in the case of right sided disc injury, should be encouraged. If these movements increase pain or dysfunction, then they should be discontinued.

Panjabi et al. (4) have postulated the process whereby the effects from injury at a single FSU spread to the surrounding motion segments, thus influencing entire spinal regions (Fig. 2.7). Unequal movement of the FSU caused by central injury will then spread to the posterior articulations (Fig. 2.8).

Three-Joint Complex

Function and dysfunction at the motion segment should be analyzed from a three-joint perspective (6). The disc and the two facet joints make up a tripod of complex joint interactions. The center of axial rotation (θY) for the disc and the facets is close to the center of the disc (7). This center, about which the vertebra rotates, will change position when there is motion restriction (fixation dysfunction). This is usually due to trauma and adhesions in portions of the disc or facet joints. The center or axis of rotation can also change position because of ligamentous laxity or rupture. The changed axis will load the joints of the FSU in an asymmetrical manner. This asymmetrical loading renders the individual susceptible to continued reinjury when the spine is loaded symmetrically, because the dysfunctional motion segment will cause loads to be focused at particular sites. The abnormal movement of the FSU, from damage to the disc alone, will gradually lead to subsequent injury and degeneration at the posterior joints. Lumbar facet degeneration rarely occurs before disc degeneration (8).

Intervertebral Disc

Annulus Fibrosis. The annulus fibrosis consists of a narrow outer zone of collagenous fibers and a wider inner zone of fibrocartilage which surrounds the nucleus pulposus (9). The annulus consists of approximately 15 to 25 distinct layers—depending on the circumferential location, the spine level and the age of the individual (10). The architectural pattern of the annulus is a fabric of lamellae with all the fibers in each lamina running in the same direction. The adjacent laminae have a similar structure, but these collagen fibers run in the opposite direction. The fiber angle, with respect to the horizontal, varies within the lamellae. Gallante (11) has determined that the fiber angle is approximately 28 degrees for the outer layers and 22 degrees for the inner lamellae (Fig. 2.9).

This angle to the horizontal increases when the posterior annulus is distracted, such as during forward bending. Collagen fibers are strongest when loaded along their longitudinal axis. Gallante (11) has further shown that the annular fibers tensed at 30 degrees to the horizontal are approximately three times stronger than those fibers that are loaded horizontally.

The tensile strength of the lumbar annulus is greatest at the posterior and anterior periphery (12). These areas are loaded most during flexion and extension motion. Although there is added strength for resisting flexion this is not true for axial rotation (Y axis). During axial rotation, the torque is applied perpendicular to the fiber orientation (Fig. 2.10) of the annulus. The annulus is

STRUCTURAL INJURY RESULTS IN ASYMMETRIC MOVEMENT OF ONE VERTEBRA WITH RESPECT TO THE SUBJACENT VERTEBRA

SINCE EACH VERTEBRA SURROUNDING THE INJURED DISC ARTICULATES WITH THE VERTEBRAE BOTH ABOVE AND BELOW, FOUR VERTEBRAE OR THREE FSUs ARE AFFECTED

Figure 2.7. Single joint injury leads to multiple levels of involvement.

THE DISTURBED KINEMATICS OF THE FSU WILL LEAD TO UNEQUAL MOVEMENTS OF THE RIGHT AND LEFT FACET JOINTS

UNEQUAL LOAD SHARING

HIGH LOAD ON ONE FACET

CARTILAGE DEGENERATION, FACET ATROPHY, NARROWING OF THE IVF

Figure 2.8. The pathogenesis of spinal degeneration.
fibers attach to the periphery of the cartilaginous portion of the end-plate (3). The proximity of the entire posterior annular border and the posterior longitudinal ligament to the anterior aspect of the spinal canal and lateral recesses is clinically important if a space occupying lesion is present (e.g., disc protrusion). Because of the attachment of the disc to the vertebral body, adjustments can be delivered to the vertebra in an attempt to influence the position of displaced annular or nuclear material.

**Nucleus Pulposus.** The nucleus pulposus, a gel-like mucopolysaccharide structure, resides in the posterior central axis of the disc (Fig. 2.11). It has a dry weight of only 15% of its wet weight. This percentage of water varies considerably with age as well as with the state of health of the disc and the surrounding osseous structures (3). Fluids are passed in and out of the annulus and nucleus primarily by diffusion (15). The adult nucleus contains no blood or nerve supply. Nutrients are delivered to the tissues and cells through diffusion. The diurnal variation in water content, and joint movement, are necessary for optimal disc function.

Figure 2.9. The fiber orientation of the annulus fibrosis. The orientation is nearly 30 degrees from the horizontal at the periphery when the motion segment is not flexed or extended. The fiber angle approaches 20 degrees near the nucleus. Based on data from Galante JO. Tensile properties of the human lumbar annulus fibrosis. Acta Orthopaedica Scand 1967; Suppl. 100.

Figure 2.10. During flexion, the posterior annulus is distracted. Under this type of loading (white arrows) the annulus is quite capable of resisting the external force. In the distracted position the annulus is less able to resist axial torsion (dark arrow).

extremely vulnerable under this type of load (13). The disc is a highly specialized structure but by virtue of its specialization it cannot resist all loads in an equal manner. This is the anisotropic character of the annulus.

The annulus is extensively connected to the vertebrae it separates. In the adult, the outer laminations attach to the cortex of the vertebral body via Sharpey's fibers thus creating a strong junction. The intermediate fibers pass from one end-plate to the other, whereas the innermost

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8 Anisotropy: Having different mechanical properties with unlike directions or spatial orientations (2,14). For example, the intervertebral disc is much stiffer when loaded in compression than when tensile forces are applied, due to the increase in hydrostatic pressure of the nucleus during compression. This is an example of disc anisotropy. Movements of the spine also have anisotropic patterns. The lumbar spine for example, is more flexible (less stiff) during flexion and extension than axial rotation (Y axis). This behavior is due, in part, to the configuration of the posterior joints.

Figure 2.11. The nucleus pulposus lies in the posterior center portion of the disc, as evidenced in this individual with multiple nuclear invaginations into the vertebral bodies.
The lumbar nucleus occupies approximately 30 to 50% of the total disc cross sectional area (2). The spherical shape of the nucleus is readily recognizable in the young or normal spine (3,7,16). With degeneration from trauma, the nucleus begins a gradual process of dehydration that renders it less distinct from the annulus fibrosis. The spherical shape can be markedly distorted in the degenerated spine (12). It has been stated that the normal nucleus is dumbbell shaped (17). This is based on the preliminary work of Brown et al. (12), in which two aged specimens displayed this appearance. A dumbbell-shaped nucleus is most likely related to degeneration of the motion segment.

The annulus and nucleus constitute a functional unit, the effectiveness of which depends on the integrity of each component. Any major dysfunction of the motion segment must be accompanied by, if not chiefly caused by, a breakdown in normal nucleus-annulus structural and functional relationships.

Compression loads applied to the central articulation involve the redistribution of axial compressive forces from the nucleus horizontally outward, to the annulus (18) (Fig. 2.12). The nucleus is tightly bound peripherally and held under pressure by the annulus. A nucleus pulposus dehydrated from degeneration is less able to sustain fluid pressure. This decreases the central load on the endplates during compression and distributes the axial load more peripherally.

The danger of compressive overload at the central joint is an argument for limiting certain sport activities for the young. Activities such as powerlifting and gymnastics can cause severe axial (Y axis) compression. End-plate invagination and Schmorl’s nodes are more likely in the compressed young or nondegenerated disc, because of the prominent, highly pressurized nucleus (19,20).

A study by Horne et al. (21) found that competitive water ski jumping leads to a higher incidence of vertebral trauma, including the abnormalities associated with Scheuermann’s disease. Sward et al. (22) showed that elite male gymnasts had a higher incidence of disc degeneration (evaluated by magnetic resonance imaging, MRI), thoracolumbar abnormalities (e.g., Schmorl’s nodes), and back pain. Jackson et al. (23) found a history of low-back pain significant enough to disrupt training in 25% of female gymnasts. The mean age of this group was 14 years.

Wrestlers (24), football players (25), heavy weight lifters (26), gymnasts (22,24) and other athletes who subject their spines to extreme axial loads seem to be at risk (Figs. 2.13–2.18). The radiological findings of the study by Sward et al. (24) suggests both traumatic changes to the motion segments as well as disturbed vertebral growth.

Both the age of onset of athletic activity and the degree of mechanical load on the axial skeleton are important factors in the development of these abnormalities. Sward
increased fluid uptake, thus raising intradiscal tension and pressure (28) (Fig. 2.20). Although the nucleus has no nerve endings, the outer layers of the annulus are innervated by pain fibers from the recurrent meningeal nerve which are stimulated when there is injury in the area (18). It may take up to three days after a trauma for the disc to swell to its maximum. It is important to relate this information to the patient if they are examined immediately after a trauma because the pain may increase substantially over the ensuing few days. The cervical and lumbar discs have the greatest ability to imbibe fluid (2). This can occur during recumbency or antigravity, and after trauma.

Diurnal changes in the straight leg raising test have been investigated by Porter and Trailescu (29). They found that patients with lower lumbar disc protrusion had a decrease in straight leg raising after two hours of recumbency. Diurnal change in straight leg raising is probably related to the disc’s proteoglycan content, its hydration, and other factors. Clinical observations have shown that a patient with an inflamed lumbar disc is more difficult to adjust immediately after a night’s sleep. It is therefore preferable to treat these patients later in the day, or after they have spent several hours upright or moving about. The degenerated disc, in contrast, is more easily adjusted when more fluid is present in the disc, because this will usually facilitate movement.

The increase in fluid in the nucleus after recumbency was analyzed in vivo by Adams et al. (30). The results showed that the range of movement of the lumbar spine increased about 5° during the day. In a separate analysis of cadaver lumbar segments they determined that creep loading of the joint increases the range of lumbar flexion by about 12.5°. Their conclusions were that forward bending movements subject the spine to higher bending stresses in the morning compared with later in the day. The increase is about 80% for the ligaments of the neural arch and 300% for the intervertebral disc. Lumbar discs and ligaments are therefore at greater risk of injury in the early morning.

### End-plate

The hyaline cartilage vertebral end-plates have an important role in transporting nutrients to the avascular disc. Brown and Tsaltas (31) found that there is a decrease in diffusion of substances in aging end-plates. Fractures of these structures are the most common pathology detected during lumbar spine dissection (3). Bernick and Cailliet (32) studied lumbar vertebrae varying in age from birth to 73 years. Their findings indicated that there is a gradual calcification of the end-plate with age. Abnormalities were commonly detected in the microvasculature and nutrient spaces or canals that would then retard the passage of substances from the blood into the bone, cartilage and disc. Roberts et al. (33) have determined that when
Schmorl's nodes are present, the disc and end-plate at the location of the node show loss of proteoglycan compared with the surrounding tissues.

Disc Shape

The normal disc shape is slightly thicker anteriorly in the lordotic cervical and lumbar spine, and thus helps to form the secondary curves. The kyphosis of the thoracic spine is formed by the wedge shape of the thoracic vertebral bodies; the discs are relatively equal in anterior and posterior thickness (9).

The disc space can best be observed on the lateral spinal radiograph. Its appearance provides important information for the practitioner in locating and evaluating the VSC (See Radiographic Disc Evaluation and Chapters 4 and 5).

Biomechanics of the Disc

The crossed arrangement of the annulus allows and resists axial torsion ($\theta Y$), flexion/extension ($\theta X$), lateral bending ($\theta Z$), and shear ($\pm Z, \pm X$). The disc is an extremely stiff structure when subjected to mechanical loading. For example, during compression of the spine, the disc is much stiffer than the vertebral body. The latter will fracture when the FSU is overloaded.

Compression. The disc is more stiff under compression than when under tension. This is due to the increase in hydrostatic pressure of the nucleus pulposus (2,34). Compression overload causes the vertebral body or end-plate to fail rather than the disc. Experiments by Virgin (5) failed to herniate the lumbar discs under compression overload, even in the presence of an open communication to the nucleus through annular removal. End-plate invaginations and sclerosis, Schmorl's nodes, and compression or burst fractures, are all radiographic signs of trauma from compression overload.

Compression of the disc causes increased internal pressures, which have been measured experimentally by Nachemson (35). As can be seen in Figure 2.21, the load on the L3–4 disc varies considerably with different body positions (See Chapter 7).

Modeling of human mechanics using only data from disc pressure measurements is inadequate. In most cases the different body positions represent quasistatic condi-
tions that are generally not reflective of how the individual would execute a task (e.g., lifting) (36). For example, as the various measurements are taken in a static, forward flexed position, the ligamentous stretch or creep of the lumbodorsal fascia and midline ligaments will cause progressive recruitment of the erector spinae muscles thus increasing internal disc pressures. The contribution of the ligamentous system to the execution of a dynamic lift is substantial (See Biomechanics of Lifting) (Fig. 2.22).

**Torsion (Y axis).** The intervertebral disc resists rotational displacement by developing tension in the annular fibers. Resistance is also offered by the posterior joints. Their contribution is substantial in the upper lumbar spine where their sagittal orientation causes impaction of the joint on forced rotation. In the lower lumbar spine, however, where the facets are more oblique, they play less of a role in limiting rotation (See Chapter 7). Here, the zygapophyseal joints are designed to resist anterior shear, which is greatest in the lower lumbars, especially L5-S1. To counter axial rotation of the L5-S1 motion segment, the iliolumbar ligaments provide added resistance (37). Torsion is restricted at the thoracolumbar junction by the mortise-like configuration of the posterior joints (38).

More cephalad, the rib cage has a primary role in limiting axial rotation.

Farfan et al. (39) rotated lower lumbar disc specimens to failure in an attempt to determine their torque strength. The average failure torque was 25% less in degenerated discs indicating a decreased ability to resist this motion. Degeneration consisted of dehydration of the nucleus, and circumferential and radial fissures of the annulus. There tended to be greater torque strength for the more rounded discs. Under mechanical loading, Farfan (3) determined that the lumbar annulus begins to develop tension at approximately 2 degrees of rotation with micromotion occurring shortly thereafter in some cases (Fig. 2.23). Loud snapping sounds were often heard from some specimens because of annular tearing. These sounds were reminiscent of the "snap" often reported by patients during lumbar spine injury. Factors that decrease the torque strength of the motion segment include:

1. Little contribution from the posterior joints as in the lower lumbar spine;
2. Iliolumbar ligaments (present at L5 but not at L4);
3. Retrolisthesis of the segment causing a separation of the facet joints which decreases their effectiveness in resisting rotation;
4. Previous degeneration: circumferential tears, radial fissures, etc.;
5. Flexion of the motion segment. This orients the posterior fibers more vertically thus decreasing their ability to resist forces perpendicular to the longitudinal axis of the collagen fibers (13) (Fig. 2.10); and
6. An ovoid disc shape.

**Shear.** Horizontal translational displacements of the disc (±Z, ±X) are markedly restricted by the annulus. A high force is required to cause an abnormal displacement in horizontal translation. Although stiffness of the spine is greatest during compression, large values are also seen during shear loading. It is greater, for example, during
shear than during axial rotation or lateral bending (5,12,40–42). The presence of laterolisthesis or retrolisthesis is indicative of severe disruption of the restraining mechanisms of the annulus (11,43). This disruption often does not manifest itself radiologically until severe plastic deformation of the annulus has occurred, usually over the course of many years. For this reason, laterolisthesis is more common in the geriatric spine.

The lumbar posterior joints also have a role in limiting shear forces in the lumbar spine, especially during anterior (+Z) and lateral shear (±X). Depending upon the extent of the initial trauma to the disc, retrolisthesis can often be detected radiographically at an early age (Fig. 2.24). The zygapophyseal joints offer little resistance to posterior shear forces. The cervical and upper thoracic zygapophyseal joints tend to restrict anteroposterior (Z axis) shear and flexion extension (θX) much more than the central joint of that region, in contrast to the lumbar disc.

**Vibration.** Sullivan and McGill (44) examined the relation between whole-body vibration and decreases in spine length beyond normal diurnal changes. Their results indicated that there is a loss of height in the spine after 30 minutes of vibration. There appeared to be a recovery in height on the day the subject underwent vibration, such that these subjects were even taller than the controls at the end of the day. The authors speculated that this could be caused by an inflammatory response in the disc substance from vibrational injury.

**Creep.** Creep is defined as a deformation of a viscoelastic tissue (e.g., ligament) in response to a constant, suddenly applied load (2) (Fig. 2.25). Higher forces or loads tend to produce greater deformation of spinal ligaments as well as faster rates of creep. Kazarian (45) performed creep tests on lumbar discs during compression loading (Fig. 2.26). The discs were graded based on their level of degeneration. Non-degenerated discs creep slowly and reach their final deformation value after considerable time. In contrast, the more degenerated disc has a faster rate of creep.

Creep effects are noticeable for all ligaments that are under constant loads. Injury seems to increase creep,
which implies that adjusting the motion segment into the direction of ligamentous laxity would accelerate this effect.

**Hysteresis.** Hysteresis is defined as a failure of either one or two related phenomena to keep pace with the other (14). Loading produces a particular load-displacement curve for ligamentous structures (e.g., intervertebral disc), but gradual release of the load produces a different load-displacement curve (Fig. 2.27). This loss of energy (i.e., delay) is referred to as hysteresis and is a characteristic of all biological tissues when subjected to a load/unload cycle. Hysteresis in action occurs, for example, when a person jumps down from a height. The shock energy from impact is absorbed (i.e., a delayed return) all the way from the feet to the brain by the vertebrae, discs, and extremity joints (2). Virgin (5) found that the larger the load applied, the greater the hysteresis. He also determined that hysteresis decreased when the disc was loaded a second time. This loss of hysteresis after the second load implies that the disc may not be able to withstand repetitive loads effectively (See Fatigue Tolerance). Hysteresis is much

![Figure 2.20. The mechanism of the swollen disc and production of pain. Modified from White AA, Panjabi MM. Clinical biomechanics of the spine. 2nd ed. Philadelphia: J.B. Lippincott Co., 1990:397. Based on data from Naylor A. Intervertebral disc prolapse and degeneration; the biochemical and biophysical approach. Spine 1976;1:106–114.](image)


![Figure 2.22. The role of the ligamentous and muscular elements in balancing the loads of body weight (BW) and a weight held in the hands (W). Modified from Gracovetsky S. Function of the spine. J Biomed Eng 1986;8:219.](image)
less in the aged or degenerated disc, making the elderly more susceptible to trauma from external forces.

Fatigue Tolerance. The disc is not able to withstand repetitive cyclic loading and unloading for long periods of time. Fatigue induced failure leads to degeneration of the motion segment (46). Brown et al. (12) performed a fatigue tolerance test on a lumbar disc. A repetitive (1100 cycles/min.) forward bending motion of 5 degrees with axial compression of 15 lbs was induced on a lumbar motion segment. The disc began to show signs of failure after only 200 cycles and completely failed after 1000 cycles (less than one minute). The fatigue life of the disc is low in vitro and is difficult to determine in vivo. Individuals in occupations involving repetitive load/unload cycles, such as in the trucking industry, often have a higher incidence of low back pain and disc herniation (47). This may be due, in part, to hysteresis and fatigue tolerance characteristics of the motion segment.
Goel et al. (48) found an increase in retrodisplacement of the motion segment after experimental pure cyclic flexion bending of a ligamentous lumbar spine for five hours. This displacement is due to a loosening of the disc substance, primarily the annulus.

Liu et al. (49) studied the effects of cyclic torsional loads on lumbar discs. They found that torsional fatigue loads had a number of undesirable effects: (a) leakage of synovial fluid at the apophyseal joints, (b) fibrillation of the facet cartilage surface, and (c) fracture of various elements of the vertebrae. Their conclusions suggested that prolonged exposure to cyclic torsional loads producing more than 1.5 degrees of angular displacement per segment is detrimental to elements of the lumbar spine.

Degeneration

The onset of disc degeneration in the early stages corresponds with the onset of symptoms (3,50). Some individuals, however, experience no symptoms at all. In these cases, early signs of spinal degeneration can only be determined through objective analytical procedures, such as MRI.

There is some certainty that the first pathological changes occur in the annulus. These early changes take the form of small circumferential separations between the annular lamellae. Evidence of lamellar separation has been reported as early as eight years of age (3). In the vast majority of disc injuries, healing occurs in the form of granulation tissue and vascularization. The new blood supply comes from the outer annulus and the end-plate. If there is damage to either of these tissues, the rate of healing will be slowed. The repair mechanisms tend to hydrolyze the disc contents and remove loose fragments while stabilizing the remainder of the disc (3). The neutralizing of the loose material within the disc secures the joint and provides less material for possible extrusion or entrapment.

The usual progressive nature of the degeneration of the intervertebral disc includes increasing involvement of the annular lamellae as more concentric cracks appear. These fissures do not communicate at first with the nucleus. The location of the lamellar separations varies with the particular disc. At the L4 and L5 levels they occur most commonly in the posterior and posterolateral annulus (3).

Degenerative changes of the disc occur peripherally before involving the nucleus. No nucleus change occurs without advanced structural changes in the annulus (3). Radial fissures in the annulus appear much later and coalesce with previously existing circumferential tears. These radial fissures begin in the innermost lamellae near the nucleus and progress outward. Interestingly, these radial fissures are most commonly found in the thoracic spine (51).

With injury and degeneration the disc becomes less resistant to torsional forces. After repeated postural stressing, the already compromised disc is the weak link in the closed kinematic chain and will be the first to be re-injured.

Zygapophyseal Joints

The zygapophyseal joints consist of cartilaginous facet surfaces, synovium, and capsular ligaments. Supporting the facet joints are the capsular ligaments that are relatively “baggy” to allow for a large range of motion, especially in the cervical spine. The anteromedial border of the capsule makes up the posterior portion of the inter-
vertebral foramen. This close relationship is of significance when telescoping of the facet joints occurs during retrolisthesis (Fig. 2.28). The proximity to the IVF is also of importance when hypertrophy of the capsule or surrounding bone occurs.

The shapes of the facet joints vary considerably from one level to the next, and with the state of health of the joint. Differences in shape from one side of the same motion segment to the other are relatively common. This anomaly alters the normal functional aspects of the joint accordingly. Facet anomaly developed after birth may well be associated with asymmetrical development of the disc and vertebral body in response to unequal torsional stresses in early life (3). Radiographically evaluating vertebral positions in stressed postures must be accompanied by the appropriate analysis of the facet planes in the neutral position. Functional changes caused by anomaly must not be confused with interarticular dysfunction from soft tissue disturbance.

The zygapophyseal joints function mainly to guide and limit movement of the motion segment (15). They are not designed for the support of a significant percentage of weight in axial compression in the lumbar spine (2). The mid cervical spine has facets that support a greater proportion of the axial compressive load. The compressive loads of the cervical region are normally not relatively high. Because of the minimal strength of the region, compression injury of the cervical spine can take the form of fracture, partial and full dislocations, and severe soft tissue disruptions.

When the intervertebral disc is normal, gross injuries of the neural arch and facet joints are not seen (3). Computerized tomographic evidence of lumbar facet pathology has not been detected in the absence of degenerative changes at the disc, as evaluated with MRI (8). Abnormalities of the disc will lead to increased free motion at the facet joints. Compression fractures of the lamina of these joints are commonplace (3).

Disruption of a zygapophyseal joint follows a progressive pattern common to any diarthrodial joint. Early changes include synovitis with possible synovial folding between the joint. Interarticular adhesions occur as the degenerative process continues. With repeated strains, capsular laxity and osteophyte formation occur.

Degeneration commonly leads to positional dyskinesia, especially retrolisthesis (52). A gradual reduction in disc height, enlargement of the facets, and posterior displacement result in stenosis of the spinal canal and lateral recesses.

Aging and Degeneration

It is the opinion of Farfan (6) that aging and degenerative processes are not synonymous. His conclusion is based on the fact that many elderly and young joints behave similarly with regards to their mechanical properties. Degenerated joints, however, behave stiffer than normal articulations. An increase in stiffness in the joint is characteristic of scar formation. Scar formation only occurs after injury. The accumulation of effects from various traumas throughout an individual’s life is most likely responsible for the changes in mechanical properties seen in many aged specimens.

Scar formation alters the mechanical properties of the joint, rendering it less able to withstand external loads which heightens the possibility of reinjury. A downward spiral of degenerative processes usually affects the joint. The more often it is reinjured and scarred, the more likely it will be injured again. This is one of the reasons there cannot be a 100% structural and functional recovery after injury to the three-joint complex.

With these considerations in mind, an adjunctive maneuver directed into a joint should not compromise the soft tissue structures. This precaution will avoid injury and inflammation with subsequent scar formation. As restricted mobility in the three-joint complex is diminished, close monitoring of the joint with reliable methods of movement assessment is essential. The results of follow-up examinations will determine the need and frequency of adjunctive procedures. There is no indication for adjusting or manipulating a normally functioning or hypermobile articulation.
The aim of chiropractic care of the degenerated joint is slightly different from that of care for one less deranged. Symptoms play a more critical role in determining the frequency of adjustments, because normalization of the functional or structural aspects of a degenerated joint is unlikely. The clinician should be cautious in attempting to reverse years of joint pathology.

**Spine Ligaments**

Spinal ligaments (e.g., PLL, supraspinous, ligamentum flavum, etc.) are uniaxial structures and are most effective in resisting loads in the direction in which the collagen fibers run. The interspinous ligament, for example, resists flexion of the spine much more effectively than axial rotation or shear forces.

During physiologic ranges of motion, very little force is required to move the motion segment because of the relatively low resistance provided by the various ligaments. This force becomes great, however, as the FSU approaches the trauma range. For the ligamentum flavum, approximately seven times more energy is absorbed in the trauma range compared to the physiological range. Thus, ligaments perform two quite contrasting functions:

1. To allow and guide smooth motion in the physiological range with a minimum of resistance and expenditure of energy from the organism, and
2. To absorb large quantities of energy near the trauma range thereby protecting the spinal cord during potentially traumatic situations.

As the ligaments reach the end of their elastic range they influence the position of the instantaneous axis of rotation for the FSU. This is especially true if pathologies exist such as adhesion formation or ligamentous laxity. Ligamentous injury will manifest itself as abnormal positions of the FSU when the segment is put through a particular motion. Alar or transverse ligament disruptions can be detected radiographically (cine or plain film) by moving the upper cervical spine in axial rotation (Y axis), lateral bending (Z axis) or flexion (+X) (See Chapter 11). If the ligament stays within its physiologic range of motion, it will stretch and elastically recover during various movements, termed elastic deformation. If the ligament is stretched beyond its range of motion, it will recover to some extent but portions of it will remain stretched. This is known as plastic deformation. The amount of plastic deformation that takes place during a trauma is dependent, in large part, on the magnitude of the forces involved. Ligamentous injury also results in scar formation which reduces the content of elastic fibers in the structure. Less elasticity will tend to make the joint function abnormally and make it more prone to reinjury.

After experimental injury, it takes at least six weeks for a tendon to regain 80% of its tensile strength. The recovery time for a ligamentous injury is probably close to this value, depending on the blood supply in the region. This fact is important to consider in the management of the patient who may obtain rapid symptomatic improvement but has not functionally recovered enough to participate in rigorous activity, hard labor, or rehabilitative exercises. These activities may put a strain on ligaments not yet fully healed. Bed rest, however, is not indicated except in extreme circumstances. Passive movements and walking should be encouraged as a form of therapy. Movement during repair diminishes collagen cross-linking and allows scar tissue to be laid down along the stress points of the motion segment. The antigraity effect of walking in a pool may enable a patient to actively move various articulations, even if normal ambulation is impossible.

The role of stretching in spinal rehabilitation deserves some discussion. In the athlete where joint flexibility is requisite to performing a particular activity, flexible ligamentous and muscle elements are important. Athletes usually have well-developed musculature and it is the muscles that provide an important role in stability for the motion segments. When these individuals cease to participate in their particular sporting activities, their muscles atrophy, and more of a burden is placed on the ligaments. If their occupation involves sedentary ergonomics, creep of the ligaments could increase symptomatology. After an extremely flexible athlete (e.g., gymnast) has retired from sporting activities, it would be wise to avoid sedentary occupations. In contrast, the inflexible person will do much better in a more sedentary occupation. If this individual is placed in a job where large demands are made on the flexibility of the spine, there may be increased risk for injury. Stretching activities must therefore be implemented with regard to the demands placed on the individual's spine throughout the day. Stretching of chronically shortened ligaments and tendons caused by scarring and fixation dysfunction of the motion segment will be beneficial for the individual. Caution must be taken to avoid further stretching of ligaments that have undergone plastic deformation.

**The Vertebrae**

*Landmark Identification.* It is important to be aware of the various shapes of the vertebrae in a particular spinal region to enhance accuracy in locating the appropriate dysfunctional motion segment. Accuracy of vertebral count is critical in ensuring specificity of contact and force when applying manual therapy. Static palpation for determining motion segment location must be compared with the radiograph, because anomalies in the number of vertebrae often occurs. For example, there can be thirteen thoracic vertebrae or six lumbers, which if unknown, could lead to the application of a force at the wrong motion segment. Also, the shapes of the various spinous processes can vary from their “common appearance.”
Because it is often difficult to palpate the mid-cervical spine, landmarks of the lower cervical spine are often used to determine the location of the dysfunctional motion segment in this region. The vertebral prominence is such a landmark but is not always the seventh cervical vertebra. In the past, a method whereby the cervical spine was extended hypothetically aided the practitioner in determining the C7 vertebra. It was said that the sixth cervical "tucks" on extension. The cervical spine does not "tuck." In fact, the sixth and all cervical vertebrae tip inferiorward \((-\theta_{X}\) and often posteriorward (if disc damage is present) during extension movement. The palpator detects a disappearance of the bone under the fingertips when extending the cervical spine. This has led to the assumption that the vertebra is moving away during this movement. The ligamentum nuchae is actually buckling and bulging over the spinous processes, increasing the distance between fingertip and spinous process. If T1 is actually vertebral prominence and C7 is relatively small, then C7 may feel as if it is "tucking." A better, but by no means foolproof, method to determine the spinal levels, is to flex the cervical spine and determine the most prominent vertebra(e). Generally during flexion, C7 and T1 should have the most protuberant spinous processes. If in doubt, a flexion radiograph can be made of the cervical spine with a small radiopaque object attached to the skin over a boney protuberance. The physical count can then be considered in light of the radiograph.

It is a good rule to palpate at least twice when locating a vertebral segment, unless the count is unambiguous. When moving the patient from the sitting to a prone position, a point marked on the skin may move away from the vertebral location it is intended to identify. Usually the mark moves cephalad in the cervical and thoracic spine, but to ensure specificity, the spinous process can be contacted while the patient changes positions. This becomes more critical when the patient is difficult to palpate, such as in obesity. The use of the inferior border of the scapulae to determine vertebral location should be avoided because of its inherent inaccuracy.

Caution is advised when asking the patient to identify the offending motion segment while the doctor palpates. The most symptomatic spinous process may be a hypermobile motion segment which is contraindicated for a manipulation. Palpable tenderness is an important finding in isolating the VSC (See Chapter 4) but does not substitute for a comprehensive examination.

Trabeculae. The trabeculae of the vertebral body are arranged both vertically (columns) and horizontally (ties), much like the frame of a skyscraper (Fig. 2.29 A and B). The horizontal trabeculae effectively increase the compressive strength of the vertebral body. This can be explained by the engineering principle or theory of Euler (2). There is a gradual loss in the horizontal trabeculae and progressive thickening of the vertical trabeculae with age (55) (Fig. 2.30 A and B). A fifty percent reduction of the horizontal trabeculae will reduce the compressive strength of the bone to \(\frac{1}{4}\) of its original value (56). Reduction in the cross sectional area of the vertical trabeculae will reduce the compressive strength as well. Trabecular loss and thinning occur in osteoporosis, making the bone susceptible to fracture.

It seems that the rate of bone loss with age is similar for both males and females. Women, however, seem to start this gradual loss with less bone than their male counterparts. Bone mineral content of lumbar vertebrae also correlates with the height and weight of the individual (57). This correlation is in agreement with the findings of Nilsson (58), who showed that the majority of femoral neck fractures occurred in slender women. Compressive strength of the vertebral body decreases considerably beyond the age of forty.

![Figure 2.29A,B.](image1) ![Figure 2.30A,B.](image2)  
The trabeculae of the vertebral body are arranged both vertically and horizontally. With age and various disorders (e.g., osteoporosis), there is a gradual loss of both horizontal and vertical trabeculae thus weakening the structure.
**Biomechanics.** The intervertebral disc is not the shock absorber for the spine. Spinal shock absorption is provided to some extent by the sagittal curves (59) and primarily by a hydraulic mechanism of the vertebral body (6). During loading there is a collapse of the intertrabecular spaces. This collapse constrains the movement of the bone marrow thus providing a hydraulic cushion. The cancellous core of the vertebral body deforms approximately 9.5% before failing, compared with only 2% for the cortical shell (2). The disc, much stiffer than the vertebral body, will cause the end-plate/cortex to fail during compression overload.

The compression strength of the vertebral body increases caudally, in proportion to the progressive increase in axial compression loads (2). The center portion of the end-plate has the greatest compressive strength (60). This strength counters the increased pressure in the area by the nucleus pulposus. If compression overload occurs, however, the central portion will be the first to fail because of the concentrated amount of stress placed there. In degenerated discs, where the nucleus has dehydrated, compression loads are distributed more peripherally. In these patients, peripheral fractures of the end-plate or vertebral body are more common (2). The young are at more risk for developing nuclear invaginations of the end-plate or Schmorl's nodes, due to compressive overload. A well-hydrated nucleus pulposus will burst through the end-plate during loading. If a fracture is characteristic of an injury that occurred when the nucleus was well hydrated (e.g., central end-plate depression), it is often the case that the injury occurred when the individual was younger. A fracture of the periphery of the vertebral body usually means that more load was transferred through the annulus which often occurs when there is dehydration of the nucleus. There is a tendency towards dehydration of the nucleus as one ages.

Because bone is a dynamic tissue, it will readily adapt to a changing environment. Bone remodeling from mechanical stress (Wolff's Law) is an example of adaptation. The effects of gravitational stress on the posture of the spine is an important argument for attempting to maintain the sagittal curves of the spinal column. In the cervical spine, for example, a kyphotic cervical curve will place more compressive stress on the anterior vertebral bodies. The increased load will cause their normal box-like shape to become deformed, creating a protuberance at the anterior (Fig. 2.31).

Bone compensation caused by alterations in the mobility of the FSU can be detected radiographically. The appearance of a traction osteophyte (Fig. 2.32) at the ante-

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**Figure 2.31.** The lateral cervical radiograph demonstrates bone remodeling of the anterior portion of the vertebral bodies due to abnormal stresses in this individual with a hypolordotic cervical spine.

**Figure 2.32.** Anterior traction osteophytes caused by hypermobility at the motion segment. There is a degenerative spondylolisthesis at L4.
rior or posterior portion of the vertebral body may imply increased tractional forces at the annulus and longitudinal ligaments because of hypermobility or instability.

Radiographic Disc Evaluation

An evaluation of the disc space height on the lateral radiograph has led to a numerical classification system of the stages of disc swelling through degeneration (61). A widened disc space appearance on the lateral film, correlated with the clinical picture, may be due to an increased fluid uptake within the disc and is designated as a D1 disc (Fig. 2.33). The remainder of the classification scheme is reserved for progressive stages of the degenerative process.

When the disc space height begins to decrease, most of the diminishment in size occurs posterior to the nucleus because of previous injury at the annulus. This is true primarily of the cervical and lumbar regions. Degeneration of the thoracic motion segments is presented in Chapter 8. In lumbar spine injury, 90% of the damage is posterior to the nucleus. The first stage of disc degeneration is called a D2 disc and shows a small decrease in the posterior aspect of the disc space with a concomitant slight posteriority (retrolisthesis) of the vertebral body (Fig. 2.34). Because of the angulation of the facet joints and the diminishment of the posterior disc, the vertebral body shows a slight inferiorward tipping ($-\theta X$).

As the creep properties of the deranged joint continue, the disc height diminishes and the positional dyskinesia increases. There is a tendency towards greater malalignment of the FSU in the geriatric, due entirely to the degenerative process. The D3 disc is very thin at the posterior with very little change occurring at the anterior portion of the disc (Fig. 2.35).

As the destructive processes in the disc continue, the anterior portion becomes progressively more involved. The early stage of total disc thinning is classified as a D4. Here, the dimensions of the disc have been reduced to approximately two-thirds of the original height (Fig. 2.36). Disc narrowing can cause the zygapophyseal joints to carry up to 70% of the intervertebral load. This will
then lead to secondary osteoarthritic changes occurring within the hyaline articular cartilage (62).

A D5 disc shows the space reduced to ⅔ of its original height (Fig. 2.37). Depending on the extent of injury and reinjury, a D5 disc shows up from 5 to 20 years after the initial trauma. The development of a D5 disc within five years of injury would signify enormous trauma to the motion segment or disc surgery such as chemonucleolysis (chymopapain injection).

When the disc is nearly gone and the vertebral bodies are about to undergo natural fusion, this is termed a D6 disc (Fig. 2.38). The greater the extent of degeneration, the more prolonged the care and the worse the prognosis for alleviation of objective findings. At some stage, however, symptomatology will gradually diminish. This is likely caused by the lessened amount of tissue able to become inflamed, provided the individual is relatively sedentary. Individuals with degenerative joint disease usually have reduced functional capacities. For example, range of motion can be markedly reduced, depending on the extent of degeneration. The D6 disc holds the worse prognosis and the D2 or D1 disc, the more favorable.

Knowledge of the classification scheme is helpful when conferring with another doctor about a patient.

**Coordinate System**

The right-handed orthogonal coordinate system (RHOCS) is used for communication of the kinematic aspects of the spinal column (63,64). Vertebral position and movement can be accurately and unambiguously described with this listing system for all six degrees of freedom of the motion segment. Because the RHOCS has been proposed as an international standard for defining body parts, it will be referred to as the “international system” (65). This system should be the primary method of communication for the various configurations and movements of the motion segment and should be adopted by the chiropractic profession (65–67). Continuation of multiple, sometimes arbitrary listing systems leads to confusion in the student and among practitioners, especially when referral of a patient is required.

By convention, the listing of movement or position of the motion segment is with respect to the vertebra below (2). This is an important point to consider, especially when we present the kinematics and subluxation complexes of the upper cervical region. This is in contrast to many “upper cervical” listing schemes that list the atlas with respect to the occiput.

The X axis runs from the center of the motion segment straight left (+X) or right (−X). The Z axis runs from the posterior (−Z), to the anterior (+Z) through the X axis, whereas the Y axis, which is also referred to as the longitudinal axis, runs in a caudal (−Y) cephalad (+Y) direction. Rotation clockwise (+θ), or counterclockwise
gers will then curl in the direction of positive rotation (+θ). Translation is movement along the axis and can be in a positive or negative direction (Fig. 2.39).

**Rigid Body**

A rigid body is a collection of particles joined together rigidly. In the basic sense it cannot deform. In spinal kinematics, the vertebrae, although they can deform slightly, are considered rigid bodies.

**Degrees of Freedom**

The motion segment has six degrees of freedom characterized by translation along, and rotation about, each of the three orthogonal axes (Fig. 2.39). Because of the specialized functions and structure of the different motion segments, there is variation in the amount of each degree of freedom.

**ROTATION**

Rotation is defined as a spinning or angular displacement of a body about some axis (6θ). This axis may be located outside or inside the rotating body. If the rigid body is rotating in planar motion there is a line in the body or a hypothetical extension of the line that does not move (Fig. 2.40) This line is termed the instantaneous axis of rotation.

The motion segment rarely moves about a single fixed axis of rotation, but rather a locus of instantaneous axes of rotation termed a centrodre. In experiments by Seligman and Gertzbein et al. (69,70), it was determined that the shape and location of the centrodre changed as a reflection of disc degeneration at the L4-L5 motion segment during flexion-extension movements (Fig. 2.41A-E). When compared with gross dissection, the analysis technique predicted abnormalities of the disc in 94% of the cases. It is interesting that the discs with only minor anatomical changes showed the most aberrant motion char-
characteristics of the FSU (Fig. 2.41B). As the level of pathology increased, so did the tendency for the centrodre to become more centralized. It also tended to move from its normal position in the posterior center of the disc to a location in the upper portion of the vertebral body below (Fig. 2.41E). This was reflective of the increased translation of the motion segment. As translation is increased, the center of rotation must move further away from the described motion (Fig. 2.42 A-B).

The appearance of a very erratic centrodre in slightly degenerated specimens in vitro seems to correlate well with the level of symptomatology in patients with little degeneration. This group often experiences severe disabling back pain in the absence of marked radiological signs. Aberrations in the pattern of movement of the motion segment may partially explain this seeming contradiction. The use of more sensitive measures for detection of joint pathology, such as MRI (See Chapter 7) and centrodre analysis, may provide more insight into these phenomena. Ogston et al. (71) have tested the usefulness of centrodre analysis in human subjects, the results of which look promising.

TRANSLATION

Translation is defined as a movement along or parallel to an axis (68). A rigid body is in translation when movement is such that all particles in the body at a given time...
have the same direction of motion relative to a fixed point (Fig. 2.43).

Range of Motion

The difference between the physiological extremes of movement of the motion segment is defined as the range of motion. Translational movement is expressed in meters or inches and rotational movement in degrees. The load-displacement curve of the motion segment (i.e., the ligamentous elements) through its range of motion has two phases (2) (Fig. 2.44).

Neutral Zone

The first phase of the range of motion has been termed the neutral zone (NZ) (Fig. 2.44). This portion of the range of motion is usually quite small. In some areas of the spine however, such as the atlanto-axial articulation, the neutral zone makes up 75% (30 degrees) of the total range of motion for axial rotation (Y axis). The neutral zone can be thought of as the free-play or “slop” of the motion segment.

During a spinal adjustment the free-play must be reduced with the application of a preload before the high velocity thrust. In the lumbar spine, the neutral zone for Y axis rotation is 0.4 degrees. This small neutral zone expresses itself during manipulation by producing audible “releases” after axial rotation or torque. Bringing the lumbar spine “to tension” in axial rotation (Y axis) is easy compared with other degrees of freedom (e.g., flexion/extension). The doctor must keep in mind, however, that although audible “releases” may be more easily obtained during certain thrusts, this is not an implicit indication that these are the preferred directions of movement for reduction of abnormal kinematics of the motion segment. This is especially true for most adjustments to the lumbar-sacral articulations, where posterior to anterior thrusts (+Z) are preferred to rotational (Y axis) maneuvers.

Knowledge of the various neutral zones of the spinal column (Table 2.1) is important when studying the art of adjusting. Large neutral zones at some motion segments may explain, in part, why bringing a joint “to tension” (applying preload) is more difficult. As the doctor incorporates more finesse and acceleration with the adjustment, the relevance of the neutral zone decreases. High acceleration can overcome the moment of inertia of the FSU during the thrust.

The neutral zone of a motion segment tends to increase after ligamentous sprain or with disc degeneration (72). Panjabi and coworkers (73), have suggested that the neutral zone is a better indicator of stability than range of motion.

Elastic Zone

The elastic zone is the displacement from the neutral zone to the end of the range of motion (Fig. 2.44). The greatest portion of the range of motion is generally made up of the
elastic zone with the exception of C1-C2. The elastic zone is primarily what is restored after a successful adjustment. When the motion segment moves beyond the elastic zone, plastic deformation (i.e. trauma) of the supporting elements begins to occur.

**Coupling**

Coupling is defined as motion in which rotation or translation of a rigid body about or along one axis, is consistently associated with simultaneous rotation or translation about or along another axis (2). Lumbar lateral flexion (+θZ) is coupled with a simultaneous axial rotation (+θY) and flexion (+θX). The beginning movement is sometimes referred to as the main motion, the secondary or dependent motions then follow the main motion.

Pearcy (13) is of the opinion that the phrase “accompanying movements” be used instead of “coupling” to describe this biomechanical phenomenon. Coupling, in the engineering sense, usually refers to objects being coupled rather than movements.

The normal coupling patterns of axial rotation during full spine lateral flexion are depicted in Figure 2.45. The direction of spinous rotation is indicated with arrows. Larger arrows indicate relatively greater secondary motions. During full spine lateral flexion, the changeover in coupling pattern occurs at the midthoracic region.

If the thoracic spine is laterally flexed without involv-

![Figure 2.45. Direction of spinous process movement during full-spine lateral bending. Modified from White AA, Panjabi MM. Clinical biomechanics of the spine. 2nd ed. Philadelphia: J.B. Lippincott Co.,](image)

![Figure 2.46. Direction of spinous process movement during lateral flexion of the cervical and thoracic spine.](image)

ing the lumbar spine, the spinouses tend to rotate towards the convexity of bend throughout (Fig. 2.46). The coupling of axial rotation with lateral flexion is quite small in the thoracic spine. It should always be kept in mind that coupled motions occur in multiple planes.

The intrinsic mechanism of axial rotation with lateral bending depends primarily on the soft tissue tensions such as muscles and ligaments, rather than the arrangement of the articular facets (74). Abnormal coupling patterns are more reflective of soft tissue dysfunctions and therefore may respond to different rehabilitative therapies such as adjustments or specific exercises. In some areas (e.g., upper cervical), normal coupling patterns are more dependent on facet geometry. Variations in coupling patterns are commonly seen in individuals with facet anomaly.

**Pattern of Motion**

Pattern of motion is defined as the configuration of a path that the geometric center of a vertebra describes as it moves through its range of motion (2). Patterns of motion of the upper and lower cervical spine during flexion/extension have been studied (75). Knowledge of the various normal patterns of motion for the motion segment is important when administering an adjustment. As can be seen in Figure 2.47, a thrust aimed at moving the motion segment from an extended to a flexed position using the C7 spinous process as a lever would have to follow an arc-
ing path. Therefore, the thrust vector must change during the adjustment process, beginning with a more inferior to superior motion followed with a posterior to anterior direction towards the end.

**MUSCLES**

In the 18th century, Euler studied the effects of loads applied to vertical columns. He would apply increasing weights to cylindrical bars with their bases fixed. As the loads became too great for the structure to hold, the bar collapsed; Euler termed this the critical load. Lucas (2) has determined that the spine also has a critical load. Experiments on cadavers with their rib cages and muscles removed, show that the spine will collapse under a load of approximately 20 Newtons (4.4 lb.). This experimental evidence is quite convincing that the spinal musculature (Fig. 2.48) and rib cage have extraordinary roles in maintaining spinal stability.

Clinical observations tend to show that highly condi-
tioned athletes respond very quickly to treatment, insofar as symptomatology is concerned. The response, however, depends on the relative nature of the injury. In the scenario of severe spinal trauma, with all other things being equal, the stronger the muscular system, the more rapid the rehabilitation. Although the ligaments do have an important role in FSU stability, it seems that the paravertebral and abdominal muscles, and the associated fascial elements, have equally critical functions. They are responsible for moving the individual safely through space, counteracting dangerous loads capable of injury, and protecting the spine via reflexive splinting mechanisms once the loads become too great and injury has resulted.

Reflex muscular contraction or spasm after an injury is a response secondary to the joint dysfunction and is mediated through the arthrogenic reflex (6). Many clinicians have sought to reduce the muscle spasm thinking it has caused the joint injury. Injury results from a failure of the muscular and ligamentous systems in the support of an external load. Spinal models have suggested that a muscle cannot exert enough force to suddenly damage the ligaments of the joint. If the muscles could exert enough force to damage a joint, their action would be self-destructive for the body (76). Prolonged asymmetrical muscular contractions, however, can result in ligamentous deformation of the motion segment. Fixation dysfunction caused by muscular factors could result in immobilization degeneration (See Chapter 3).

Although pain is often derived from the muscle spasm, it should be thought of as a protective mechanism. The spasm should diminish as the nerve and joint dysfunction in the region normalize because the muscular system is under abundant neurological control. Additional treatment, therefore, is rarely needed beyond the articular level. Although in some instances, such as in the absence of regular or effective care, the muscular response becomes self perpetuating (See Chapter 3: Spinal Learning,) necessitating intervention. Soft tissue pathologies, such as trigger points or myofascitis, often require direct treatment of the involved areas.

Exercise

It is the authors' opinion that asymmetric exercises (e.g., isometric, etc.) are integral to the rehabilitation of spinal function. The exertion of an asymmetric load via unilateral stretching and exercise may have a gradual reversing effect on the creep deformation that accompanies fixation dysfunction and positional dyskinesia. The maneuver will also activate previously passive muscle elements (77). Applied movements in any of the six degrees of freedom, either singularly or in combination, may be used to aid the reversal of creep deformation.

The maneuvers are usually implemented after analysis of specific stress radiography performed in different quasistatic stressed positions. Essentially, the design of a maneuver is to stress the spinal ligaments and muscular elements opposite their presenting dysfunctional configuration and to rehabilitate the intrinsic spinal muscles. The combination of lengthening contracted soft tissue elements and active contraction of previously passive muscular elements to achieve bilateral symmetry, is the therapeutic goal. A very specific motion will be done to the limit of the desired movement (not necessarily to the end-range of motion), and the end-position will be held initially for 10 to 30 seconds before reassuming a neutral position. A typical maneuver of this type may consist of ten movements to one side followed by one similar movement to the opposite side, repeated twice per session. The above session would likely be repeated up to three times per day for a period of at least 6-8 weeks. Exercises of this type may be implemented on a continuous basis depending on the therapeutic objectives.

Posttreatment radiological evaluation is usually necessary to gauge progress. Multiple radiologic examinations should be performed with discretion, considering the risk/benefit ratio for the patient. The doctor must use clinical judgment to determine which comparative radiological examinations are necessary (See Chapter 5). The lack of controlled studies for the use of these various procedures makes it more difficult to determine the most effective protocol. Frequent radiologic examinations and exercise consultation in the absence of clear benefit do not make the best use of the patient's resources (i.e. financial and biological). Resolving the issues of appropriate radiologic and exercise protocols should be a high priority for the chiropractic profession.

Patient compliance is generally the biggest obstacle in any exercise program. The intricacy of asymmetric exercises make patient compliance even more difficult. Experience has been that it is not unusual to require a minimum of six consecutive sessions of instruction and supervised exercise with periodic review to achieve the proper implementation of the specific maneuvers. The patient must be highly motivated in order for the maneuvers to have a positive effect. Exercise maneuvers do not provide the benefits of adjustments and visa versa.

STATIC UPRIGHT POSTURE

Frontal Plane (XY)

Ideally, the normal upright spine should be relatively straight with the centers of mass of the skull and vertebrae of the spinal column centered squarely over the sacrum and pelvis (Fig. 2.49). If anomaly of the vertebral body (e.g., wedge vertebra) or abnormalities of the soft tissues (e.g., shortened muscle) exists, then a 'straight' spine is not the preferred posture. In the absence of anomaly, the spine may adopt a slightly curved position in an attempt to compensate for prolonged asymmetrical postures while
Abnormal posture in the coronal plane, such as scoliosis, is often associated with spinal adaptation of both soft and hard tissues. This finding has been described as Wolff's Law (78). Mechanical loads applied to bone will activate osteoblastic and osteoclastic activity and cause bone remodeling. Heuter-Volkmann's Law states that asymmetric stresses on the vertebra will lead to uneven growth of the epiphyseal plate in the young (2). There is also some evidence that the collagen matrix of the intervertebral disc is another example of Wolff's Law in action (79).

Sagittal Plane (YZ)

The thoracic and sacral curves are primary and are formed by the wedge-like configuration of the vertebra or sacral segments. The cervical and lumbar curves are termed secondary because they are not present in utero. As the infant begins to lift the head at approximately the 3rd month, while in the prone position, the muscular contractions of the posterior muscles "pulls-in" the cervical lordosis (Fig. 2.50A) (80). This action continues as the child adopts the crawl method of locomotion (Fig. 2.50B). The lumbar curve begins to form as the child learns to stand and walk (Fig. 2.50C).

The apices of the normal sagittal curves are as follows: C4-C5, T6-T7, and L3 (Fig. 2.51). The variations in the amount of lordosis or kyphosis in the normal individual is considerable (81) (Fig. 2.52A-C). The Asian population seems to have slightly reduced angles. People of African descent have often been assumed to have an increased lumbar lordosis, but evidence is to the contrary. These individuals may have more protuberant buttock musculature, however (82). Clinical observations suggest that a straight spine, in the sagittal plane, is more prone to dysfunction. There is a higher incidence of Schmorl's nodes in the flat lumbar spine, because of the increased compressive loads at the central joint (83).

Figure 2.53 demonstrates reversal of the normal sagittal curves. It is probably better to have a little too much curve than too little (84). The doctor should seek to restore the normal lordosis and kyphosis if they are abnormal. This is generally achieved through the combination of spinal adjustments and exercises or postural maneuvers. Ergonomic considerations are critical. The slouching computer operator with the head bent in a forward position will have a more difficult time in returning the cervical lordosis to normal.

It is important to not isolate the various spinal regions from one another. For example, the lumbar spine and pelvis can often contribute to compensation reactions in the upper spine. The interdependence of the sagittal curves has been documented by Voutsinas and MacEwen (85).

Treatment outcomes are dependent in large part on the health of the individual motion segments. Severe disc degeneration usually represents a long term adaptation.
The possibility of improving the spinal curves is less likely in these cases, unless their presenting configurations are acute disturbances. Therapy is mainly directed at improving mobility and slowing the process of degeneration. Research is needed to determine if there is any positive influence of chiropractic care on degenerative processes.

**THE RIB CAGE**

The rib cage is an integral part of the spinal column (Fig. 2.54). It is important to recognize the tremendous biomechanical effect it has on spine function and stability. There are several biomechanical functions of the rib cage, including (2):

1. To serve as a protective barrier against lateral or anterior impacts;
2. To stiffen and strengthen the spine. Resistance to displacement is provided by two mechanisms:
   a. The costovertebral joint provides additional ligamentous structures and attachments that contribute to spinal stiffness and strength. Mobility is also reduced;
   b. An increased moment of inertia of the thoracic spine. Moment of inertia is a measure of the distribution of a material about its centroid. This distribution determines the strength in bending and torsion. The unit of measure is meters to the fourth power (Fig. 2.55). The addition of the rib cage to the thoracic spine effectively increases its cross sectional area and mass. The increased moment of inertia stiffens the spine when it is subjected to lateral bending and axial torsion. The added stiffness of the spine provided by the rib cage has been well described by Andricachi et al. (86) (Fig. 2.56). As can be seen, the results of sternum removal have as devastating an effect as removal of the entire rib cage; and
3. To add additional strength and energy absorbing capacity to the spine structure during trauma.
BIOMECHANICS OF LOCOMOTION

The classical theories of spinal biomechanics explain that locomotion is a sole consequence of leg motion. The spine is either not addressed at all, or is depicted as being part of the effort to balance the leg motion, keeping the person from falling over. Therefore, if a person has no legs, they should not be able to walk at all. The case for this theory has not been based on observations of challenged individuals who may have had amputations or developmental agenesis of the lower limbs. Gracovetsky (36) has proposed that human locomotion—from the pelvis up—has
the same features, regardless of whether or not a person has legs. To ambulate effectively, however, the spinal movement of someone without legs would be somewhat exaggerated. Gracovetsky tested an individual (CS) born with no legs and reduced upper extremities, and compared the angular movements and muscle activity with a person who had legs. The results showed similar but exaggerated activities in CS. CS had no stance phase during walking, however, which explains his abrupt transitions of lateral bending and rotation from one side to the other (36).

Toe-offs and heel-strikes during forward locomotion are near the peak of the pelvic motion for each plane of movement. This synchronization allows for a maximal stride length. The coupled motion of the lumbar spine during lateral flexion is essentially the gear-box for the spinal engine (36) (Fig. 2.57A-B). The lumbar spine is proposed as the key structure in land locomotion, the pelvis being driven by the spine (87). Lateral bending to the left
Figure 2.56. Relative stiffness of a ligamentous spine, removal of the sternum, and intact spine and rib cage. Notice that the ligamentous spine behaves similarly to a spine and rib cage that has the sternum removed. Modified from White AA, Panjabi MM. Clinical biomechanics of the spine. 2nd ed. Philadelphia: J.B. Lippincott Co., 1990:59. Based on data from Andriacchi TP, Schultz AB, Belytschko TB, Galante JO. A model for studies of mechanical interactions between the human spine and rib cage. J Biomech 1974;7:497–507.

(-θZ) is turned into axial rotation (-θY) bringing the left pelvis forward initiating the swing phase. The shoulder motion is opposite the pelvic rotation. When a neck collar was placed on CS’s neck, this made walking much more difficult (36). This implies an importance for the more cephalad structures in facilitating locomotion. When a velcro band was wrapped around his shoulders, locomotion was not possible. Unfortunately only qualitative data exist for the analysis of spinal motion during walking (88).

In patients where vertebral or sacroiliac motion is restricted in a particular plane, accommodation is required by the surrounding motion segments, thus heightening the likelihood for injury of the supporting elements. Walking has historically been considered to be a relatively benign activity for the spinal column. The erector spinae muscles provide the necessary power to facilitate forward movement. As the velocity increases (e.g., running) greater demands are placed on the ligamentous system and the powerful hip extensors. The theories on the spinal biomechanics of running are beyond the scope of this writing. The reader is referred to other sources (36).

BIOMECHANICS OF LIFTING

The cross-sectional area of the erector muscles, their attachment points, and the range of contractile forces they are able to generate are known. The maximal load supportable by the erector spinae muscles alone is approximately 500 N (112 lbs) (89). There must therefore be other mechanisms such as the ligamentous system involved in lifts of over 500 N, a common occurrence in different sporting events (e.g., powerlifting). The powerful hip extensors, primarily gluteus maximus, can provide the necessary power, but it must be channeled through the ligamentous elements such as the lumbodorsal fascia (LDF).

During forward bending to initiate a lift, the lumbar spine first flexes approximately 45–50 degrees, followed by forward rotation of the pelvis about the hip (36,90) (Fig. 2.58A-B). At maximal forward flexion the erector spinae muscles become myoelectrically silent; termed the “relaxation phenomenon” (91).

The subject may flex the knees as well to add strength to the lift by activating the thigh muscles and hip extensors. The object’s center of mass can also be brought closer to the body with the legs bent thus decreasing the amount of force needed. To bring the object from the floor, the reverse sequence applies: as the knees begin to extend, the pelvis rotates backwards because of the pull of the hip extensors followed finally by extension of the lumbar spine and activation of the erector spinae muscles.

Mathematical modeling has shown that during maximal voluntary lifts the calculated response is approximately ½ of the available resources (i.e., ligament, bone and muscle) (89). The central nervous system seems to modulate the lift thereby serving as a protective mecha-
muscle. The fascia attaches medially at the anterior surfaces of the lumbar transverse processes.

The middle layer lies behind the quadratus lumborum. Medially, it is continuous with the intertransverse ligaments. It connects laterally with the aponeurosis of the transverse abdominis (TA) and internal oblique muscles.

The posterior layer of the LDF covers the back muscles from the lumbosacral region through to the thoracic area. In the lumbar region it attaches to the tips of the spinous processes at the midline. Lateral to the erector spinae, from the twelfth rib to the iliac crest, the LDF unites with the middle layer forming a dense band known as the lateral raphae (LR). The posterior layer of the fascia has an important biomechanical role during flexed postures such as lifting.

When bending forward, the LDF is able to resist the external moment through its attachments at the internal oblique and transverse abdominis at the anterior, and to the spinal column, ribs and iliac crests at the posterior. As the spine flexes, the fascia would expectedly narrow because it is stretched. This, however, is not the case. Contraction of the internal oblique (IO) and the transverse abdominis prevents narrowing of the LDF by pulling lateralward (Fig. 2.60A-B).

The LDF thus exerts an extension bending moment and posterior shear force on the spinal column (3,18,36). This system can be activated in any spinal posture through contraction of the transverse abdominis and internal oblique muscles. The LDF has optimal efficiency, however, when the spine is flexed. The insertion points of the LDF at the posterior can be optimized with pressurization of the abdominal cavity (Fig. 2.61). This will increase the amount of extensor moment the LDF can generate.

Contraction and bulging of the erector spinae will also optimize the posteriorward pull of the LDF. In addition, the LDF also inhibits expansion of the erector spinae. This synergistic action increases the axial stress generated by the muscle, therefore optimizing its contribution to resisting the load. This effect can be used during weight-training by using an abdominal belt. When tightened snug about the waist, a weight-belt will inhibit expansion of the various trunk muscle groups thereby increasing the axial contraction they can develop.

The large bone content of the iliac crests is in direct response to the heavy tensile loads applied there by the LDF (Fig. 2.62); this is another example of Wolff’s Law in action. It is unfortunate that some surgeons consider this area to be a bone bank for different spinal surgeries. The effect of bone and ligamentous removal on the lifting capacity of the individual should always be considered before surgery (36).

If the spinous process of L5 is small, as is usually the case, the lumbodorsal fascia will exert a posterior shear force when the subject bends forward (Fig. 2.63A). Flexion radiographs will often show posterior migration of L5
during forward flexion because of this effect. This occurs only in the presence of disc injury, where the restraining elements of the annulus to posterior shear are weakened. The posteriorward pull of the fascia will counteract the increased anterior shear force that occurs as the sacral base angle increases during forward bending. If a large spinous process is present (Fig. 2.63B), the pull will change to an anterior shear force during forward bending. Interestingly, individuals with spondylolisthesis of L5 usually have a large spinous process at that level. The ineffectiveness of the fascia in creating a posterior shear force to counter the anterior shear could be one of the mechanisms in the development of a fatigue fracture of the pars interarticularis in these individuals.
Midline Ligaments

The midline ligaments consist of the supraspinous, interspinous, facet capsules, ligamentum flavum and the posterior annulus. These ligaments exert an extension bending moment when the lumbar spine is flexed. Because the amount of resistance increases with progressive forward flexion they are termed posture dependent, and are passive in their contribution to the lift. They also have time dependent characteristics such as creep. The ligaments’ contribution is minimized if the subject lifts too slowly because creep of the ligaments will reduce the amount of force that is generated by these structures.

Muscles

Muscles provide stability for the spinal column in three ways:

1. The powerful hip extensors such as gluteus maximus are used primarily in duties requiring heavy exertion;

2. The paraspinal musculature is used for lighter tasks; and

3. The abdominal muscles are used for integrating the ligamentous system with the muscular system and adjusting the entire complex to the particular task at hand (76).

Figures 2.64 and 2.65 illustrate the integration of the ligamentous and muscular systems during the lift and free fall. As can be seen, the erector spinae are relatively inactive during the lower position of the lift, in contrast to the hip extensors that are very active (93).

The “danger point” is defined as the crossover point where the individual is going from a predominantly muscular to a ligamentous strategy or vice versa. This portion of the lift must be executed with great care.

The uneven distribution of stress that occurs when an individual uses a muscle strategy during a lift results in the highest stresses at the L3-L4 intervertebral joint (76). This corresponds to the finding that Schmorl’s nodes occur with the highest frequency in the L3 vertebral body endplates (3). Figure 2.66 demonstrates integration of the muscular and ligamentous systems during backpacking.

Creep

It is important to execute a substantial lift at speed due to the creep properties of the LDF and midline ligaments. Their contribution to the lift is minimized if the subject remains in a flexed posture before initiating the lift. Rapid acceleration during the lift should be avoided, however, because this would increase the overall force required (F = MA).

Pathomechanics

The relaxation phenomenon is observed when the lumbar spine and pelvis are forwardly flexed to horizontal. In this position, the paraspinal muscles become inactive as evaluated by EMG. Freefall is prevented because of the tension in the midline ligaments and the lumbodorsal fascia.
The relaxation phenomenon also exists on maximal lateral bend (94). It is easy to see why many lumbar spine injuries occur with the spine flexed forward and laterally bent. In this posture, the ligaments take the majority of any load applied; this usually leads to failure of the system. The combined movement of flexion with axial rotation poses the greatest threat to the integrity of collagen fibers in the annulus fibrosis (3,13).

The individual should always avoid asymmetrically loading the spine because this seems to be a common injury mechanism (Fig. 2.67). Even if the lift is executed with good posture, overload situations do occur. Often, previous injury or asymmetrical motion at the FSU will precipitate injury in an otherwise benign environment.

Lifting too much weight or executing the lift at too great a speed can lead to injury. The central nervous system seems to have an innate mechanism that minimizes many potential overload situations.

**Fail-Safe Mechanism**

Mathematical modeling of the spine has determined that the maximal lift a person should be able to accomplish is roughly one-third greater than the maximal recorded effort in vivo. It is interesting to note that the relative strengths of muscle, ligament and bone are stressed equally as they approach their ultimate strength. Apparently, the organism senses impending injury and shuts
Figure 2.86. During backpacking or other activities, the individual can alternately increase and decrease the lordosis, switching from a muscle-predominant to a ligament-predominant strategy. By performing this alternating pattern it is possible to avoid loading either structure continuously, thus reducing the likelihood of fatigue. Modified from Gracovetsky S. The spinal engine. Wien: Springer-Verlag, 1988:155.

down, by refusing or aborting the task. Gracovetsky has termed this the “fail-safe mechanism” (36).

BIOMECHANICS OF THE SPINAL ADJUSTMENT

If one were to drop an object of one kilogram from a height of one meter it would exert less force on impact than if it were dropped from a height of two meters. Although both objects accelerate equally during freefall caused by gravity, and the masses of both objects are equal, the forces they exert on impact are not. The second object accelerates for a longer period of time, therefore increasing its instantaneous velocity when impact finally occurs. A greater impact velocity requires a greater rate of deceleration, assuming equal deceleration times for both objects. The force of impact is equal to the acceleration, in actuality a deceleration, multiplied by the mass of the object (F = ma).

The force received by a patient during an adjustment represents the mass of the doctor while decelerating after impact with the patient. Haas (95) states that the adjustment can be broken up into a two phase acceleration-deceleration process. In the acceleration or thrust phase, the product of the doctor’s mass and acceleration of the adjusting thrust yields the force employed by the doctor to reach the desired impact velocity. In the deceleration or impact phase, the doctor’s mass multiplied by the deceleration quantifies the actual-adjustive force produced by the doctor-patient collision.

Several other factors are at work in determining how much force the patient receives. The tissue overlying the doctor’s contact point (e.g., pisiform) as well as over the contact point of the patient (e.g., mamillary process), will contribute to the overall equation. The more soft tissue, the greater the dissipation of force and a slower transfer of energy from the doctor to the patient (96,97). The doctor attempting a specific adjustment should use doctor and patient contact points that minimize this force dampening effect, while allowing adequate comfort for the patient. For specificity, the pisiform contact is often preferred to the thenar eminence, and adjustments using the spinous process of the lumbar spine, are preferred to transverse (L5 only) process and mamillary process contacts. In patients where much tissue lies between the skin contact point and the actual segment (as in the obese, where a mamillary contact is needed), a greater amount of force is generally required, all other factors being equal. This may come at a sacrifice of specificity and patient comfort in some cases.

The patient-doctor contact point area is also important in the determination of the amount of force the patient receives. A broader contact on the vertebra will
dissipate the force over a larger area, some of which will not be acting to produce the desired bone or joint movement. It is critical for the doctor to have as specific a contact as possible and direct that force through a combination of the center of mass of the vertebra and the plane lines of the three-joint complex. The use of broader and less specific contacts (such as in long lever manipulations) will often more easily cavitate a joint. Joint cavitation is not the ultimate goal, although it does occur with a successful adjustment. Inexperienced practitioners, without proper instruction, will assume that when a “crack” is elicited, a successful adjustment has taken place. When a thrust is attempted and no movement occurs, this is rationalized as “it didn’t need to go.” There are more rational means for determining where and how to thrust into a patient’s spine.

The specificity of the adjustment, and applying it to a motion segment that needs it, is one key to limiting variables and predicting outcomes for the patient, and should not be lightly discarded as unimportant. The art of specific adjusting can be frustrating to learn at times. Understanding the biomechanics of the spine and the various pathological entities that affect it will facilitate the learning process.

**Force Measurements**

Peak force for low back adjustments is generally greater for experienced doctors than inexperienced adjusters (98). Greater grip strength, height, and weight were generally correlated with increased peak force for low back simulator adjustments (99). Wood and Adams (100) reported average force values of approximately 255 Newtons (57 lbs) for simulator posterior ilium adjustments in the prone position which is similar to values obtained on actual patients by Hessell et al. (101) using the Thompson technique.

Herzog (102) found there was a wide variation between chiropractors, and for the same chiropractor, for the peak forces used for sacroiliac adjustments. The point of application of the treatment force was applied as much as five centimeters away from the desired contact point; pretension forces and peak treatment forces were found to be positively related. Wood and Adams (100) detected slightly lower forces using the Thompson technique for simulator adjustments of the lumbar spine when compared to sacroiliac adjustments.

Herzog et al. (103) determined the forces used during a thoracic adjustment. A hypothenar contact on the transverse process of T4 was followed by a posterior to anterior thrust and the forces developed were then recorded. The preload force was approximately 150 N (34 lbs). The preload was then followed by a rapid thrust that reached a peak value of approximately 380 N (85 lbs) at 113 msec. Greater preload and greater peak force were seen with the thoracic adjustment when compared to the ilium adjustment using the Thompson technique.

Manual adjustments of the cervical spine seem to have much less force than for either the thoracic spine or the sacroiliac joint (104). There is also some evidence that cervical adjustments are applied twice as fast as those applied to the T4 area or to the sacroiliac joints (103).

**Manual vs. Instrument Procedures**

Advocates of instrument adjusting cite the relative safety of a reproducible, very controlled, predetermined force (105). Indeed, many of these advocates (106) see no situation where a manual contact procedure would be superior to an instrument. One instrument, the Activator Adjusting Instrument (AAI), has undergone some rather rigorous experimental testing with a laboratory animal. Piezoelectric accelerometers were attached to the bone of an anesthetized dog. Small, relative 1-mm translations and 0.5-degree rotations occurred during the first 19 msec after percussive thrusts at the L2-L3 motion segment (107).

There are several parameters of the adjusting process that instruments do not address. The first involves the direction of thrust. Whereas instruments are confined to a predetermined line of drive, a manual contact procedure can actually change the vector of application during the process of bone movement. To move a C7 vertebra from a fixated extended position to a neutral or flexed position, it is necessary to gradually change the direction of thrust to accommodate the pattern of motion of the vertebra. This can be termed the “pattern of thrust.” As can be seen in Figure 2.68, the pattern of thrust for a C2 vertebra has a much flatter arc than that of C4 or C7. This is due primarily to the facet angles, which are more ver-
tical in the lower cervical spine. The application of torque or screw motion towards the end of the thrust also cannot be performed with the typical adjusting instruments.

Another situation where manual adjusting procedures are preferred lies in the duration of thrust. The general approach advocated here for spinal adjustments, is to apply the force in the specified pattern of motion, and “hold” the segment contacted for 1–2 sec after the thrust. The force should then be gradually released after the thrust (Fig. 2.69) (66). In contrast, a toggle-recoil adjustment involves a rapid release of tension after the thrust (Fig. 2.70).

The “holding” after the thrust is an attempt to affect the viscoelastic tissues with a more lengthy time component, thereby increasing the effectiveness of the adjustment on these elements. It is known that viscoelastic tissues respond by lengthening to loads applied over long time durations. An adjusting instrument cannot effect the motion segment in this way.

All spines have somewhat different functional characteristics, which prohibit broad generalizations on the characteristics of an adjustment. The geriatric patient, or the patient with a severely degenerated motion segment, is adjusted much differently (i.e. generally with less amplitude) than a pediatric or young adult. Two people of similar morphological characteristics may require vastly different preloading, set-up time, relaxation, and force needed for a successful adjustment. Manual contacts help the doctor “feel” the patient’s tolerances and adjustment needs. This feedback is then used to make the next adjustment even more comfortable than the last.

Another difference between manual and instrument adjusting lies in the fact that instrument adjusting almost never results in cavitation of the articulation. This cavitation appears to increase, at least temporarily, the range of motion of the articulation.

The foregoing theoretical arguments regarding the superiority of hand versus instrument adjusting await clinical trials using various outcome measures (e.g., patient function, spine function, neurological function, etc), to determine the most effective methods for reducing vertebral dysfunction.

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This chapter explores the nature of the various aspects of the vertebral subluxation complex (VSC). It is beyond the scope of this writing to describe in detail all the possible entities included in the broad category of the VSC. The purpose of the material presented is to focus on selected aspects of the VSC relevant to chiropractic care.

Several distinct types of physical changes that occur in relation to the VSC have been described. These changes include those affecting kinesiologic, histologic, neurologic, myologic, biochemical, vascular, inflammatory, and connective tissue characteristics (1,2). This chapter will pay particular attention to the following clinical manifestations resulting from the physical changes listed above:

1. The relative positions of the vertebrae above and below an articulation involved in subluxation;
2. Interarticular motion abnormalities in any or all of the six degrees of freedom of the motion segment; and
3. Neuropathologic involvement caused by interarticular abnormalities.

Clinical presentation of a complex disorder can lead to treatment approaches that vary considerably, even within the same health field. One of the reasons for this variation results from approaching these problems from an isolated perspective of assessment. A multiparameter approach is requisite to provide for a working system of analysis and correction appropriate for each individual case presentation. One of the most important fundamentals of systematic full spine treatment is the recognition of the multiparameter nature of the VSC. The chiropractor should use examination procedures that are both sensitive and specific to all of the parameters of the VSC. Analysis procedures for the VSC will be covered in Chapters 4 and 5.

A complete understanding of normal anatomy and physiology of the structures involved is necessary to fully appreciate the clinical approach to the VSC. The subluxation is essentially an interarticular phenomenon (3). The reader is encouraged to pursue an in-depth study of normal articular structure and function and the effects of injury on the motion segment. Literature on the subject of spinal related conditions is extensive. Most research on spinal injuries has been performed on the lumbar spine. Many references for this chapter are taken from lumbar studies and may be cautiously extrapolated to other spinal regions.

POSITIONAL DYSKINESIA

Chiropractors have considered the interarticular alignment of spinal structures an important aspect of the VSC ever since the first chiropractic adjustment was given (4). The understanding of positional dyskinesia (misalignment of one vertebra on another) has evolved considerably since the original chiropractic “bone out of place” theory was formed.

The importance of the identification of positional dyskinesia is easily illustrated by the development of radiographic analysis of spinal structures. Widely taught at chiropractic colleges are literally dozens of methods of radiographic analysis (3). Positional dyskinesia is a factor in the etiology of neuropathologic disorders, especially in the cervical and lumbar areas (5–11).

Etiology

Causes of positional dyskinesia have been postulated to involve the most basic circumstances of life, such as posture, the influence of gravity and cerebral dominance. The apparently high incidence of spinal subluxation of our species, in relation to other animals may be associated with the evolutionary theory of development from the quadruped to the upright stance (3). The spine is also under constant influence of cerebral dominance. The upper thoracic spine, for example, has the tendency for a lateral deviation with the convexity towards the side of the dominant hand (12).

Clinical Considerations

Positional dyskinesia is an important aspect of the subluxation. Malalignment of contiguous vertebral structures that support weight and guide movement, alters the ability of the involved functional spinal unit (FSU) to continue normal function. It is questionable, however, that positional dyskinesia by itself can cause direct neuropathologic dysfunction. The association of positional dyskinesia with the degeneration of soft tissues and disruption of normal mechanics has been reported (13–15).

Mechanisms of Injury

It is important to recognize that positional dyskinesia can occur in any direction along the planes of possible move-