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A roentgenographic and anatomic study of lumbar facet joints

Mark J. Koruda
Yale University

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INTRODUCTION

Purpose

Low back pain is a clinical syndrome which afflicts millions of Americans. It has been estimated that 1.25 million people in the United States sustain injuries to their back or spine annually, while nearly 65,000 of those result in permanent disability (Beals and Hickman, 1972). The causes of low back pain are vast. Ghormley (1951) reviewing 2,000 patients with low back pain, reports that osteoarthritis of the spine was the cause in 25.6% of the cases, a suspected protruded disc in 22.3%, the cause was indeterminate in 19.2%, while 26 other categories were responsible for the remaining 32.9%.

Degeneration of the intervertebral disc has been recognized as a cause of low back pain for well over six decades. Mixter and Barr's (1934) contribution on the herniation of the intervertebral disc as an etiologic agent was a major advance. However, surgical treatment for a herniated disc does not achieve satisfying results in more than 30% of patients with low back and sciatic pain (Spangfort, 1972). Posterior protrusion of the nucleus pulposus as a causative agent of low back pain will be regarded as a definite factor in only a minority of patients (Badgley, 1941). Numerous authors have emphasized the importance of the posterior intervertebral articulations in the production of low back pain. In particular, the presence of asymmetrical shapes and alignments of facet joints at individual segments of the lumbar spine has been considered a prime factor producing instability in that region,

which in turn fosters susceptibility to ligamentous strain, osteoarthritis and disc degeneration (Farfan, 1969; Goldthwait, 1911; Putti, 1927; Sullivan et al., 1971; Willis, 1941).

Proper therapeutic intervention in low back pain requires an accurate determination of the cause of the syndrome. Virtually all patients with back pain undergo radiographic evaluation of the lunbosacral spine. Physicians, however, are not often able to correlate the findings on routine roentgenograms with a patient's symptoms (Togerson and Dotter, 1976). Two clinical roentgenographic studies have been reported which correlate radiographically determined asymmetry of the lumbar facets with the level and side of disc prolapse in patients with low back pain and sciatica. Farfan and Sullivan (1967) report, of the individuals who had abnormally oriented posterior intervertebral facet joints in the lower lumbar spine, 94.7% had disc disease at the level of the facet asymmetry, with disc hernation on the side whose facet was more obliquely placed versus the mid-sagital plane. Borman (1959) found a correlation at the lumbosacral level where 67% of his patients with radiographically determined facet asymmetry were found to have L5 disc prolapse on the side whose facet joint was closest to a coronal orientation.

The essence of the studies by Borman and Farfan and Sullivan hinges on the accuracy with which roentgenographs represent the form and orientation of the lumbar facet joints. The surfaces of the posterior articular processes are often found to be curved,

ammounting to nearly one half the circumference of a cylinder (Farfan et al., 1972). This curvature of the articular surfaces produces a summation of shadows on a radiograph. Since penetration of the roentgen rays parallel to the joint surfaces is impossible, false information about the alignment of the facet joint may be conveyed (Horowitz and Smith, 1940; Lewin et al., 1962; Oppenheimer, 1938a). Also, owing to the curvature of the joint surfaces, one joint could often be examined in several projections (Reichman, 1973).

The problem, then, in the radiographic evaluation of the posterior intervertebral articulations is to direct the central rays of the x-ray source on a tangent to, or parallel with the curved articular surfaces (Lewin et al., 1962). Since standard projections used in examining the lumbar spine may not adequately reflect the anatomical orientation of the facet (Reichman, 1973; Horowitz and Smith, 1940), it is essential to define the range of x-ray projections which creates radiographic images suggestive of the orientation of the facet joint.

It is the purpose of this study:

(1) to define the range of projections, angular resolution, of conventional radiography which clearly depicts the facet joint under consideration;

(2) to compare the apparent facet orientation determined with radiographs directly with their actual articular anatomy;

(3) To determine the effect of vertical displacement of the x-ray's central beam from the facet under study;

(4) to examine the ability of computerized tomography to depict lumbar facet orientation.

Historical Aspects of Lumbar Facets in Low Back Pain

Consideration of any subject with a scope so vast as that of low back pain merits an overview of the contributions of the many eminent investigators in this field, with special emphasis on the role of facets in low back pain.

Prior to 1934, it was generally accepted that low back and sciatic pain resulted from either disoreders of the spinal facets or sacroiliac joints (Fiorini and McCammond, 1976; Shealy, 1974a). As early as 1911, Goldthwait (1911) drew attention to the lumbosacral articulation in the production of sciatica. He noted that the "peculiarities in the formation of the articular processes" may result in a weaker intervertebral joint, may mechanically produce strain and cause pain, and may be so unstable as to cause irritation of the cauda equina resulting in sciatica.

Another very important contribution to the literature was that of Danforth and Wilson (1925). After completing meticulous dissections of twelve human cadavers, with special attention to the lumbar nerve roots in the intervertebral foramina, they reported that the nerve roots in the intervertebral canals between the fourth and fifth lumbar and fifth lumbar and sacrum are enclosed in bony canals and could be easily irritated or compressed by encroachment on this space from an inflammatory process of the posterior facets of an arthritic or traumatic nature.

Putti (1927) drew on the previous work of Danforth and Wilson and emphasized that variations in the size and shape of

the lumbar articular processes have a two-fold effect on the intervertebral foramen; firstly, they may alter its size and reduce its capacity; secondly, by altering the mechanics of the spinal column, may induce a localized arthritis which itself may irritate the nerve trunk or cause an effusion changing the capacity of the foramen, compressing the nerve root within it.

Ayers (1929) emphasized the close relationship of the fifth lumbar nerve and the lumbosacral articular facets stating that "any destructive process which affects the cartilage or facets may be communicated in effect to the fifth lumbar nerve." Ayers, in the same report, quotes Valls who believes "the pain of so-called essential sciatica is a symptom of vertebral arthritis." Ghormley (1933) stressed the concept of vertebral arthritis. He noted that that the articular facets were the only true joints in the spinal column and that many of the aches and pains which are known as backache are true pains of these joints. They represent the same type of pain as that seen in the arthritis of other joints and are accompanied by changes characteristic of degeneration.

The extensive consideration given to the role of the facets in the etiology of back pain became somewhat lessened with the landmark publication by Mixter and Barr (1934). In their report, these authors ascribed the herniation of the nucleus pulposus, rupture of the intervertebral disc, into the spinal canal with irritation of the nerve roots as a "not uncommon" cause of the symptoms of sciatica. Following this description most neurosurgeons and orthopedists became convinced that back and sciatic

pain must be due to either a ruptured disc or a psychosomatic disorder (Fiorini and McCammond, 1976; Shealy, 1974a). The emerging clinical experience, however, after an era of wide scale disc surgery with highly variable results, indicated that the intervertbral disc did not explain all low back and leg pain complaints and considerations of the posterior spinal structures again came to the forefront (Mooney and Robertson, 1976; Spangfort, 1972).

The Intervertebral Joint

An understanding of the significance and diagnosis of the many variations of the lumbar articular processes in the production of low back pain, sciatica and disc degeneration cannot be attained without a working knowledge of the general development, morphology and function of the intervertebral joint and foramen. The basic functional unit of the intervertebral joint consists of an articular traid: two synovial vertebral joints (the facet joints or posterior vertebral articulations) and the corresponding cartilaginous joint between the vertebral bodies, the intervertebral disc. The manner in which this articular triad functions is determined to a large degree by the anatomy of the small vertebral joints (Gardner, 1960). The main thrust of this study concerns these facet joints. Hence, this overview will emphasize the general aspects of the articular processes and the joints they form.

The Lumbar Vertebra

Each of the lumbar vertebra contains a body and the neural arch structures, namely, the pedicles, laminae, inferior and superior articular processes, maimillary processes, pars interarticularis, transverse processes, accessory processes, and spinous process (Fig. 1).

The vertebral body is a cylindrical mass of cancellous bone contained within a shell of cortical bone. The body has a larger transverse than anterposterior diameter, with their vertical height being the smallest dimension. Its upper and lower flattened surfaces are the vertebral end-plates. The end-plate is composed of a thin plate of hyaline cartilage separating the center portion of the intervertbral disc from the vertebral body. Surrounding the hyaline cartilage is a bony ossified ring epiphyseal plate. The vertebral body is waisted having a circumference in the middle less than at its superior and inferior poles (Christenson, 1977; Farfan, 1973; Hollinshead, 1974).

The pedicles are round bony cylinders that arise from the posterior aspect of the vertebral bodies. They are basically oriented in the anteroposterior plane, extending backwards to unite with the laminae. The laminae are raired, flattened bony plates fused in the posterior midline and attached to the pedicles laterally. The articular processes arise from the lateral edges of each lamina, one directed superiorly, and one inferiorly. The mamillary processes are bony enlargements located just lateral to the articulation of the superior process.

From the region of the junction of the lamina and the pedicle laterally project the transverse process. The accessory processes are small tubercles on the dorsal aspect of the transverse process. The area where the lamina and the inferior articular process join the heavy bony mass made up of the bases of the pedicle, transverse process and superior articular process is known as the pars interarticularis. The union of the vertebral body, the pedicles and the laminae create a triangular compartment, the spinal neural foramen which houses the spinal cord (Christenson, 1977; Farfan, 1973; Hollinshead, 1974; Morton, 1937).

Since the laminae of the vertbra approximate the vertical height of the vertebral body and the pedicles are much narrower that that dimension, there are notches, a shallow superior and deep inferior vertebral incisures, above and below each pedicle. Where the vertbrae are fitted together, adjacent superior and inferior incisures form an intervertebral foramen, through which the spinal nerves leave the spinal canal (Hollinshead, 1974).

The Posterior Articular Processes

The superior and inferior posterior articular processes of a vertebral segment are appendages of the osseous vertebral arch. Embryologically, neural processes grow bilaterally from the vertebral body anlage into connective tissue, unite to an osseous ring which encloses the spinal canal and in different periods of development, gives rise to the articular, spinous,

and mammillary processes (Schmorl and Junghans, 1971).

It is important to recognize that the articulations formed by the vertebral facets are true apophyseal joints. They attain functional maturity as spinal joints at the seventh to the eighth month of fetal life, 50 mm. crown-rump (CR) length (Kuhns, 1935). A joint capsule then develops and the joint cavity is complete in fetuses of 70 mm. CR-length (Reichman, 1971). Ossification then commences at the cranial portion of the spine at the end of the second embryonic month, gradually progressing in a cranio-caudal direction (Schmorl and Junghans, 1971). Clear radiographic definition of the articular margins is not commonly found before the age of eight years (Kuhns, 1935).

In general, the lumbar superior articular processes are stout, oval curved plates of bone fused in front with the roots of the laminae (Fig. 1). The articular surfaces are concave, amounting to nearly half the circumference of a cylinder and have been noted to be more often J-shaped than rounded (Fig. 2). The inferior articular processes lie on either side of the root of the spinous process supported on the inferior margin of the laminae. Their articular surfaces are generally oval in outline, convex from side to side. The inferior articular surfaces are closer together than the superior aricular processes so that when articulated, the superior processes embrace the inferior of the next highest vertebra (Badgley, 1941; Hirsch, 1963; Hadley, 1961).

The superior articular lumbar joint facet generally is

faced medially and backwards while the inferior, laterally and forwards. However, the angulation of the articular surfaces versus the mid-sagittal plane increases in the lumbar region from the first to fifth, with the upper segment most closely approaching the sagittal plane (Badgley, 1941; Reichman, 1971). This observation is exquisitly documented by Jonck (1961a) where he reports the mean inclinations of the lumbar superior articular processes of 200 Bantu skeletal remains (Table I). This turning of the articular facets away from the sagittal plane in the lower lumbar segments is only a trend, for a wide range of orientations have been observed (Badgley, 1941; Farfan et al., 1972; Willis, 1959).

In the horizontal plane the inclination of the articular processes also varies in the different lumbar segments. The processes of the sacrum and the superior articular process of the fifth lumbar vertebra are inclined forwards, those of the fourth lumbar are more or less vertcal, while those of the upper lumbar region are inclined backwards (Jonck, 1961).

Normally the articular surfaces are covered by smooth hyaline cartilage of varying thickness but unbroken continuity and enclosed in a joint capsule. The joint capsule is attached close to the dorsal and ventral margins of the articular facet joint. It allows little freedom of movement in the horizontal plane. Dorsally, the capsule is reinforced by the multifidus muscle. This muscle originates mainly from the mammillary and superior articular processes of the lumbar vertebra. As it approaches its insertion on a spinousprocess one or two levels

above, some of the multifidus fibers merge with those of the joint capsule. This muscle, in fact, covers the lumbar vertebral synovial joints on all sides except ventrally. On the ventral side, the capsule becomes very thin, consisting of a synovial stratum that is reinforced by a lateral continuation of the tough ligamentum flavum. Posteriorly, the capsule is also much thinner. It is loosely attached, not to the margins of the joint, but is reflected around to the outer surfaces of the bony articular process. The articular cartilage likewise may extend well beyond the limits of bony contact. The expanse of both the joint capsule and the articular cartilage actually continues the joint space around to the posterior surface of the articular process which has the effect of increasing the amplitude of the joint's movements. Where the joint surfaces are not completely in contact, meniscus-like tabs of mesenchymal intral-articular tissue extend into the joint's cavity from the capsule. These are regarded as true menisci whose primary function is to provide greater stability and help distribute the load over a greater articular area (Hadley, 1961 and 1964; Lewin et al., 1962).

Measurements of the area of the articular surfaces have been reported. Fiorini and McCammond (1976) report an average value of 0.15 $in.^2$ for adult lumbar vertebra. Badgley (1941) quotes Putti's comprehensive study of articular facets as there being great variation in the true articular surface with the area usually 20x18 mm. (.6 $in.^2$). Farfan and others (1972) note a range of about 0.20-0.50 $in.^2$. They also make the

observation that the area of these joint surfaces decreases as the angle of the joint processes increases so that, in general, the larger the articular process, the smaller the angle formed by the plane of the joint with the anteroposterior axis of the intervertebral joint.

At the superior and inferior poles of the lumbar vertbral joints there are two fat filled recesses. These collections of adipose tissue seem to act as a movement compensating mechanism, being easily displaced by the articular processes during sliding movements of the joint. Where these recesses communicate with the joint space, the adipose tissue terminates as a synovial fat pad, thereby providing a source for lubrication of the facet joint (Hadley 1961 and 1964; Lewin et al., 1962).

The synovial membrane of the facet joints is composed of synovial vili which vary in size, shape and appearance. These appendages contain a rich supply of blood vessels and a particularly abundant network of nerve endings (Kraft and Levinthal, 1951; Mooney and Robertson, 1976). The capsule of the articular facets and its surrounding ligaments are likewise richly innervated with sensory fibers (Gardner, 1960; Hadley, 1961; Stillwell, 1956).

The innervation of the posterior vertbral structures has been of interest to numerous investigators because of the controversial role the facets may play in relation to low back pain. The literature contains many descriptions of the course and nature of the nerve fibers innervating the posterior vertebral structures (Badgley, 1941; Gardner, 1960; Hickey, 1977; Jung and Brunschwig, 1932; Lewin et al., 1962; Pedersen et al.,

1956; Stillwell, 1956). The most recent and most descript is the report of Bogduk (1979). His dissection of human cadaver spines revealed that from the dorsal root ganglion of the lumbar nerves arises the primary dorsal ramus in association with the major branch of the ventral ramus. At the lumbar levels the dorsal rami shortly divides into medial and lateral branches. The lateral derivatives pass to the longisimus and iliocostalis muscles. The medial branches bear a constant relationship to the bony spine: each crosses the most medial aspect of the superior edge of the transverse process and then run across the root of the adjacent superior articular process. At this level fibers are given off to the facet joint. The medial branch of the dorsal ramus then continues in a caudal direction crossing the lamina embedded in the fibrous tissue of the joint. It eventually gives off muscular and cutaneous branches as well as several fine fibers to the medial aspect of the superior pole of the joint below.

In summary, each apophyseal joint is innervated by the posterior rami of two vertebral levels. The superior portion of the facet receives branches arising from the dorsal root one level higher. The inferior portion of the joint is innervated by proximal branches of the nerve root exiting through the neural foramen at that particular intervertebral segment.

Nerve ending staining techniques have shown that the facet joint capsule are innervated by the full triad of nerve endings: fine free fibers, complex unencapsulated, and small encapsulated endings. In this sense these joint capsules differ in

no remarkable manner from any other joint capsule providing the modalities of joint sense, posture control and pain conduction (Hirsch, 1963).

The Intervertebral Disc

The fibrous intervertebral joint is formed by two adjacent vertebral bodies and their intervertebral disc, the details of which have long been well known. Apart from variations in detail among the discs of each spinal region, the anatomy of each intervertebral disc is essentially the same (Inman and Saunders, 1942).

Three elements compose the intervertbral disc. The first is the annulus fibrosus, a series of concentric, circumferential fibrous lamellae. It's individual fibers pass from the vertebral body to vertebral body in an oblique or spiral course and sink into the subchondrial bony layer as the so-called fibers of Sharpey. The second element of the disc is its soft, pulpy, elastic center, the nucleus pulposus. This pulpy center is situated in a cavity in the center of the annulus fibrosus. It consists of a three-dimensional network of collagen fibrils emmeshed in a mucoprotein gel (Ayers, 1935; Coventry et al. , 1945; Hirsch, 1959 and 1963; Schmorl and Junghans, 1971). The mucoid material consists mainly of chondroiten sulfate with a dry weight of only 15 percent of its wet weight (Farfan, 1973). The percentage of water varies considerably with age and state of health of the disc, decreasing to nearly 70 per cent in the seventh decade (Inman and Saunders, 1947; Keyes

and Compere, 1932). The third element is the cartilage plates which bound the disc above and below. These plates cover the weight bearing surfaces of the contiguous vertebral bodies and are analogous to the articular cartilages of other bony joints. The cartilage plates are an integral and intimate component of the disc structure, being fastened to their apposed vertebral body plates by means of a calcium layer (Schmorl and Junghans, 1971).

The Intervertebral Ligaments

The ligaments of the vertebral bodies are the dorsal and ventral longitudinal ligaments. The annulus fibrosus is supported in front and behind by these ligaments. The ventral ligament is the more substantial of the two, consisting of dense fibrous connective tissue. It is in loose union with the annulus fibrosus while being firmly attached to the vertebral bodies. The dorsal longitudinal ligament, on the other hand, is thinner than the ventral, while it contains more elastic fibers. The dorsal ligament also differs from its ventral counterpart in that it is firmly attached to the disc structures and merely spans the slightly concave posterior surfaces of the vertebral bodies (Hadley, 1964; Inman and Saunders, 1942; Schmorl and Junghans, 1971).

The ligaments of the vertebral arches are the interspinous, the intertransverse, and the ligamentum flavum. The interspinous ligament is a true ligament and plays a conventional role in limiting the excursion of the individual vertebra during

flexion. The intertransverse ligaments appear more a part of the lumbodorsal fascia system rather than true ligaments. The ligamentum flavum also has the structure and function of a true ligament. It consists of yellow elastic tissue and joins adjacent lamina and articular processes. The fibers in the intralaminar portion are vertically disposed; whereas, those of the articular capsule course obliquely and downward. The ligamentum flavum, as previously mentioned, acts as a fibrous capsule on the ventral side of the facet joint. It is flexible enough to allow movement of the lumbar spine insuring that the spinal nerves and cord will not be compressed by displacement of the articular processes (Inman and Saunders, 1942; Jonck, 1961; Hirsch, 1963; Lewin et al., 1962).

The Intervertebral Foramen

The anatomical relationships of the lumbar nerves as they lie in the intervertebral foramina are of particular significance in this discussion. The shape of the lumbar intervertebral foramina as seen in the lateral roentgenogram is quite similiar to an inverted pear (Inman and Saunders, 1942)(Fig. 4B). The foramen is formed as follows: (Fig. 3A),above is the inferior intervertebral notch; below is the superior intervertebral notch of the subadjacent vertebra; anteriorly are portions of the posterior vertebral body above, the intervertebral disc, and the poterior vertebral body below; posteriorly is the facet articulation reaching upward toward the inferior intervertebral notch (Danforth and Wilson, 1925).

The relationship between the sizes of the intervertebral foramina and the diameters of the nerve root passing through them is interesting. (Fig. 3B) The foramen between the fifth lumbar vertebra and the sacrum is the smallest, that between the fourth and fifth lumbar vertebra is the next larger, while that between the third and fourth is larger still. Quite contrary to the size of the foramen is the diameter of the nerve root it encloses. The largest root is the fifth lumbar and it must therefore pass through the smallest foramen between L-5 and the sacrum. It frequently almost fills its canal (Danforth and Wilson,1925). The fourth root is the next largest and the third is yet smaller. the fourth and fifth lumbar roots are predisposed on anatomical grounds to be afflicted more than any other root by changes in the canals through which they pass (Putti, 1927).

Intervertebral Joint Function

There has been extensive research examining the anatomy and physiology of the intervertebral disc in spinal dynamics. While much conjecture has surfaced as to the role of the vertebral facet joints in spinal stability, documentation of the integration of the intervertebral triad for spinal support has only recently appeared.

Nachemson (1966) demonstrated that the nucleus pulposus was semiliquid and could support hydrostatic stresses only. The nucleus is confined under considerable pressure between the cartilaginous vertebral plates superiorly and inferiorly,

and circumferentially by the elastic annulus fibrosus. Because of its high water content, the nucleus pulposus is incompressible. Pressures exerted on the nucleus by the vertebral bodies are transmitted to the annulus fibrosus and other related ligaments (Jonck, 1961). The elasticity of the spine is derived not from the static structure of the nucleus pulposus, but from the elastic ligamentous structures which exercise resistance against deformation of the fluid content of the disc (Inman and Saunders, 1947; Keyes and Compere, 1924).

An examination of the vertebral structure and motion indicates that the articular facets have a geometry apparently suited for resisting forces perpendicular to the surface of the lumbar vertebra. The attachments of the joint capsule, the associated ligaments, and the angulation and curvature of the lumbar articular processes, all provide for mobility in the sagittal plane, allowing flexion and extension while in the horizontal plane, resisting rotation and antero-posterior sliding of the vertebral bodies, permitting lateral flexion (Fiorini and McCammond, 1976; Gianturco, 1944; Hadley, 1961; Keyes and Compere, 1932; Lewin et al., 1962).

The role the posterior lumbar facet joints play in protecting the spine from rotational forces was investigated by Farfan's group. Exposing cadaver lumbar spines to tortional loading he reported that the intact intervertebral joint possessed a torque strength twice as high as the strength of the isolated disc (1969). Thirty-five percent of the resistance to the torque was supplied by the intervertebral disc, twenty-

eight percent by the articular processes and their capsules and ten percent by the interspinous and supraspinous ligaments (1970). However, compression of the intact joint by the equivalent of one half the body weight increased the facet joints ability to withstand torsion by almost fifty percent, while that of the isolated disc remained virtually unchanged (1969).

Comparable studies evaluating the contribution of the individual intervertebral structures to flexion-extension forces have not been done. In vivo measurements of intradiscal pressures during various positioning and load lifting have been conducted (Nachemson, 1966). Fiorini and McCammond (1976), however, using principles of engineering statistics has supplied a calculated distribution of forces in the lumbar intervertebral structures during sitting, standing, and load lifting. His calculations demonstrate that the pressures exerted on each L-3 facet of a 170 pound person in the standing position is 32 lb./in.^{2} while that incurred on the L-3 disc is 104 lb./in.^{2}. When this person bends forward at an angle of 70° the pressure at each facet increases 1009 percent to 355 lb./in.^{2} as the disc only experiences a 255 percent increase to 369 lb./in.^{2}. While lifting a 200 pound load at 70° flexion, the pressure at each facet increases further to 1323 lb./in.^{2} as that of the disc increases to 1065 lb./in.^{2}. He concludes that the pressures on the interarticular joints can be at least as large as on the intervertebral discs when heavy objects are lifted in flexion.

While Fiorini's and Farfan's data emphasizes the impor-

tance of the facets in preventing forward and backward gliding and rotation of adjacent vertebral bodies, the contribution these joints have to spine stability under vertical loads has also been shown to be significant. Several studies evaluating the response of the lumbar vertebral facets to vertical loading have been performed (Hakim and King, 1974 and 1976; King et al., 1975; Nachemson, 1960). These investigators demonstrate that the posterior articulations indeed are capable *in vitro* of transmitting twenty to twenty-five percent of both tensile and compressive loads.

In summary, the intervertebral joints form a most complex integration of structures maintaining dynamic spinal stability. While the intervertebral disc assumes most of the responsibility for spinal support during vertical loading of the spine, the contribution of the facets during rotational and flexion movements becomes increasingly important.

Mechanisms of low back pain production by the lumbar facets

From the preceding discussion it is clear that the lumbar intervertebral discs form a sturdy union uniting the bodies of adjacent vertebrae, reinforced for further stability by the anterior and posterior longitudinal ligaments. The facet joints on the other hand are small, joined at the periphery by a very thin, delicate capsular ligament. The pressures exerted on the articular joints are as formidable as the pressures exerted on the discs. It is easy to understand how the facet joints, whose synovia, capsule, and ligaments are abun-

dantly innervated with sensory endings, are susceptible to damage and capable of producing considerable pain.

The Facet Syndrome (Ghormley, 1933; Hadley, 1935; Kraft and Levinthal, 1951; Putti, 1927) is a particular "catch-like" excruciating pain in the lower back most often diagnosed as an acute ligamentous tear. It usually results when initiating an attempt to straighten up after bending over, especially when associated with a twisting or rotary component. The laxity of the posterior capsule allows considerable range of movement. If the joint space opens enough during flexion to allow a piece of redundant synovial tissue to fill the space, upon extension the synovium will become pinched giving rise to the syndrome. Back manipulation to free the pinched synovial tissue has been the suggested treatment.

Because of the intimate relationship of the intervertebral joint triad, any alteration of one of its components will place increased stresses on the remaining structures. Compromised intervertebral disc function may increase the stress at the arthroidal joints (Hickey and Tregonning, 1977; Jonck, 1961; Keyes and Compere, 1932). Abnormal motion of the apophyseal joints has been observed radiologically when degenerated discs were present (Giantruco, 1944). The facets are thereby vulnerable to undergo pathological changes, specifically arthritis, ligamentous strain, and apophyseal subluxation (Harris and Macnab, 1954; Hirsch, 1965; Macnab, 1950).

Arthritis of the facet joint was described earlier. Key

(1924) makes note that sprains, with or without tearing of the spinal ligaments, are a frequent cause of back pain. Apophyseal subluxation is the sliding of the posterior articulations past each other. This occurs either with increased lumbar lordosis or thinning of the intervertbral discs. Thinning of the disc may result from herniation of the nucleus pulposus either into an adjacent intervertebral body or spinal canal (Keyes and Compere, 1932), mechanical trauma (Hirsch, 1959), or chemical changes resulting in fibrotic degeneration (Coventry et al., 1945; Hendry, 1958). The pain produced by subluxation is produced by either: tension upon the capsular ligaments; encroachment upon the size of the intervertebral foramen; and/or impingement of the ends of the articular processes against the non-weightbearing surfaces of the pedicle above and the lamina below (Hadley, 1935).

When encroachment on the diameter of the intervertebral foramen occurs, nerve root entrapment and a radiculitis may commence. The typical syndrome of sciatica may then follow; that is, a lower back deep ache which usually radiates down the ipsilateral extremity in a more or less continuous path corresponding to the affected sclerotome. There may then follow progressive loss of vibratory sense and tactile discrimination, hyperaesthesia, and hypalgesia over the area supplied by the related dermatone, muscle weakness and reflex changes in those structures supplied by the involved nerve root (Inman and Saunders, 1942 and 1947).

A similar radicular syndrome may develop when the L-5 or S-1 nerve root becomes entrapped in stenotic lateral recess of the vertebral canal between the superior articular facet and the intervertebral disc (Fig. 1). This etiology has been called the superior facet syndrome and relates to the inflammatory thickening of investing tissues secondary to acute or chronic trauma, hypertrophy of vertebral margins, thinning of the intervertebral disc or subluxation of the vertebral body or facets (Epstein et al., 1972).

However when sensory and reflex changes are absent from low back pain syndromes while pain radiation to the lower extremities persists, the etiology of the symptoms was less readily attributed to nerve root entrapment and was clouded. Several authors were able to reproduce a patients back pain with radiation by causing pressure changes in diseased discs by percutaneously injecting solutions into the discs (Hirsch, 1948 and 1963; Lindblom, 1951). Under these conditions the mechanism of radiation of the pain was thought not to be secondary to direct nerve root pressure but to be referred in the sclerotomal distribution of the irritated deep back structures (Inman and Saunders, 1942 and 1947). By a similar referred pain mechanism, focal areas of tenderness and inflamation of the articular capsule or bone were thought to have some responsiblity in producing low back pain symptoms (Badgley, 1937). In fact, controlled irritation of facet areas in human subjects with back pain by electrical slimulation via percutaneous electrodes (Shealy, 1974 and 1974a) or by injection of hyper-

tonic saline (Hirsch, 1963; Kellergren, 1938; Mooney and Robertson, 1976) reproduced the patients' symptoms.

The appreciation of the role the lumbar facets play in certain low back pain syndromes natrually fostered the development of possible treatment modalities. The earliest approach proposed in the 1930's was partial, hemi-, or complete surgical facetectomy (Ghormley, 1933; Mitchell, 1934; Putti, 1927; Williams and Yglesias, 1933). These procedures have been shown to insure relief from neural entrapment (Epstein et al., 1973; Jonck, 1961). In the recent decade, the illucidation of the innervation of the posterior articular joints has spawned the development of a sophisticated concept, namely, percutaneous denervation of the facet joint. On the assumption that pathological conditions affecting the facet articulations will induce pain, it was reasonable to assume that destruction of the sensory nerves to the afflicted structures by some means would alleviate pain. Percutaneous denervation has been successfully accomplished by blind percutaneous rhizotomy with a fine surgical blade (Rees, 1971), injection of anesthetic with steroids (Mooney and Robertson, 1976), radiofrequency neurolysis (Finneson, 1973; Fox and Rizzoli, 1973; Lora and Long, 1976; Oudenhoven ,1979; Shealy, 1974 and 1974a) and chemical neurocoagulation (Hickey and Tregonning, 1977). The morbidity resulting from these procedures has been reported as minimal while the initial success rate in improving certain patient's symptoms has been greater than 90 per cent (Rees, 1971; Shealy, 1974 and 1974a).

Facet Asymmetry

With the distinctive contribution that the lumbar posterior facet joints make in maintaining spinal stability and producing low back pain symptoms, asymmetrical orientations of the articular processes have been considered by many investigators as a state that predisposes to spinal instability. Goldthwait (1911) was the first to comment on the significance of asymmetrical posterior facets. He observed that when one articulation at the lumbosacral joint was placed in the transverse plane while the other was in the sagittal, bending toward the side of the sagittally oriented joint would cause that joint to act as a fulcrum, straining or weakening the opposite facet joint. Willis (1941) and others (Brailsford, 1929; Ferguson, 1941; Kuhns, 1935; von Lackum, 1924) echoed the significance of asymmetrical facets finding it reasonable to suppose that asymmetrical anchorage of the lumbar spinal column to the pelvis predisposes that part of the back to strains and sprains. Putti, in 1927, coined the term "articular tropism" for the condition of asymmetrical facet orientation.

As well can be imagined from the previous discussion of facet joint anatomy, the wide range of orientations the lumbar articular processes may assume should statistically foster a high incidence of asymmetry at a particular vertebral level. This is indeed the case. Table II summarizes the literature reporting the incidence of articular tropism. From radiographs of people with and without back pain, as well as from dissection of cadaver spines, a very wide range of asymmetries is evident.

An incidence of 23 to 25 per cent asymmetry at each lumbar level is often quoted and a reasonable extrapolation from Table II (Farfan, 1973; Pheasant and Swenson, 1942).

The etiology of the high variation in the orientation of the lumbar articulations has been historically most perplexing. Before and at birth, the lumbar joint surfaces are reportedly flat and oriented in the frontal plane. The form and orientation of the facet surfaces, therefore, change during development. It has been concluded that the development of the particular characteristics of the lumbar joints is not closely linked to the assumption of bipedalism or to the development of the lumbar lordosis. Genetic mechanisms are favored to have great importance in determining the general form and allignment of the lumbar intervertebral joint surfaces (Reichman, 1971).

Putti (1927) proposed that the best criterion for judging the probability of a relationship between articular asymmetry and the symptoms of pain, is the early evidence of degenerative arthritic changes in these joints. This is best indicated by a narrowing and irregularity of the interarticular space, by increased density of subarticular bone, and later by osteo-arthritic lipping (Putti, 1927). In examining 42 cadaver lumbosacral articulations, Pheasant and Swenson (1942) reported that the asymmetrical articulations, indeed, showed the highest incidence of arthritic involvement. This observation concurs with that of Horowitz and Smith (1940), who likewise noted the presence of advanced degenerative changes in the joints and discs when asymmetry was found.

With this historical relationship of asymmetrical facet orientation with an increased incidence of apophyseal arthritis, one might expect that people complaining of low back pain should have a higher occurance of asymmetry of lumbar facets. This association, however, is not evident from the data presented in Table II where the incidence of facet asymmetry as determined radiographically is quite similar in the populations with and without pain. In particular, Splithoff (1953), who roentgenographically compared patients with and without backache, found no difference in the incidence of asymmetry between the two groups. He excluded those from the study who had herniated discs, though. Two clinical studies, however, did report a significant correlation with radiographically determined lumbar facet asymmetry and the side of patients' low back pain as well as with the level and side of disc herniation (Borman, 1959; Farfan and Sullivan, 1967). Although there are problems inherent in the technique of determining facet orientation radiographically, which will be discussed in a later section, the results of these studies are most promising and summarized in Table III.

Borman (1959) evaluated 100 consecutive patients presenting for operation fro a herniated lumbar intervertbral disc. From preoperative lumbar x-rays, he determined the orientation of the articular facets at the L4-5 and L5-S1 level and compared the presence of asymmetry with the location of the disc pathology determined operatively. While he found the 79% of these patients had asymmetry and herniated disc at the L5-S1

level and 81% at the interspace above, correlation with the side the disc herniated and the side of the more obliquely positioned facet of the asymmetrical pair was 67% at the L5 disc and 56% at the L4 disc.

Farfan and Sullivan (1967) conducted a similar two part investigation. One study population consisted of 45 consecutive patients admitted to the hospital for conservative treatment of low back pain with sciatica. Tropism of the L3-4, L4-5, and L5-S1 posterior apophyseal joints was determined radiographically without knowledge of each patient's history. They report that 40 (89%) of these patients had definite asymmetry between the orientation of the two facets at one or more levels. Correlation between the side of the more obliquely set facet of the asymmetrical pair(s) and the side of the sciatica was correct in all 40 (100%) patients. Their other study population composed 52 consecutive patients with low back pain who ultimately came to operation. They were likewise evaluated with lumbar radiographs and the addition of myelography. Of these, 38 (73%) had definite asymmetry, 24 at one level, 7 with asymmetry at two ipsilaterally, and 7 at two levels contralaterally. In this instance, correlation with the side of the more obliquely set facet of the asymmetrical pair(s) and the side of sciatica, myelographic defect and operative findings was correct in 36 (94.7%) of the 38 patients.

These studies apparently contribute support to the contention that asymmetrical orientation of the lower lumbar apophyseal joints predispose intervertebral disc degeneration,

lateralized to the side of the more obliquely postioned facet. As noted earlier, one of the principle roles of the lumbar facet joints is to protect the intervertebral joint from rotational stresses. Upper lumbar posterior facets, generally aligned closer to the mid-sagittal plane, appear especially suited to prevent tortional strain (Farfan, 1969). As the lower lumbar posterior joints assume a more oblique orientation, they sacrifice the optimal orientation for resisting trosion. Thus, the combination of increased obliquity and asymmetry of the lower lumbar facets may explain the incidence of degenerative changes at these levels (Farfan, 1969).

Farfan's group offers further evidence to support the relation of lumbar facet tropism and degenerative disc disease. Of 100 consecutive myelograms with proven disc protrussion, it was possible to locate the protrusion to one side of the disc in 51 cases. In 49 (96%) of these, the pathology occured at the side of the more obliquely positioned facet at the particular level (Farfan, 1973).

In another study (Farfan et al., 1972), the L4-5 and L5-S1 intervertebral joints of post-mortem spines were examined by dissection. Of 71 total joints, 36 (51%) were found to have unilateral posterolateral tears in the intervertebral disc. Thirty (83%) of these specimens had differences between the angles of the posterior articular surfaces at the interspace greater than 5^{o}. Twenty-nine (80.5%) had the radial fissure tear in the disc directed toward the side where the articular process' joint surface formed the greater angle versus the

the mid-sagittal plane.

Finally, rotational spinal instability was created in rabbits by removing a single facet process of the posterior intervertebral joint complex. The pathological changes that developed in the contralateral facet joint and intervertbral disc were studied (Sullivan et al., 1971). This investigation showed that the facet joint changes that developed were typical of advancing osteoarthritis. The pathological changes of the intervertebral disc were less dramatic, but did suggest an early degenerative process, particularly at the site of facetectomy.

In summary, asymmetrical oblique posterior articular processes of lumbar vertebra probably produces spinal instability which allows abnormal rotational stresses to act on adjacent discs, producing susceptibility to early disc injury. The ability to categorize facet joint orientation may well identify a population at risk for developing low back pain syndromes.

Roentgenographic Evaluation of Lumbar Facet Joints

Information acquired by the radiological study of the spine can be gained largely from the anteroposterior, lateral, and bilateral oblique projections (Christenson, 1977). Each individual vertebra is a complex bony structure and when it unites with other vertebra above and below it to form the spinal column, a still more complex arrangement results. In Figure 5 each specific component of the vertebral complex is demonstrated in each projection in order to correlate the actual and radiographic anatomy of the lumbar spine.

The highly variable shape and orientation of the lumbar articular processes has made the radiographic evaluation of these structures difficult (Oppenheimer, 1938; Pheasant and Swenson, 1942). Anteroposterior views of the lumbar spinal column may show the facets of the upper lumbar vertebra clearly, but the facets of L4-5 and L5-S1 are usually so placed that they do not show clearly in the projection (Ghormley, 1933).

Since in the lumbar vertebra the axis of the plane of the facets is rotated backwards nearly to an angle of f0°, it was advised that a similar oblique projection would best roentgenographically visualize the facets. The "Dittmar position" (Dittmar, 1930), a 45° posterior oblique advocated by Meyer-Burgdoff (1931) in Europe and Hubeny (1931) in the U.S., offered substantial aid in studying changes in the lower lumbar articular facets. Many authors (Hadley, 1961; Morton, 1937; Oppenheimer, 1938a) likewise acclaimed the importance of the 45° oblique projection in the study of changes in the facets and apophyseal joint spaces. Ghormley (1934), however, recommended a position with the transverse axis of the pelvis at a 32° angle with the horizontal plane. The most important lesions occurring in the lumbar spine for which the oblique projection was proposed to give valuable information included separation of the neural arch, subluxation of the apophyseal joints, arthritic changes, intraspinal tumors and lumbar spine anomalies (Morton, 1937).

While the advantages of the 45° oblique projection were professed in the 1930's, controlled studies evaluating its

advantages were not conducted. Horowitz and Smith (1940) reported an evaluation of the oblique view in the roentgenography of the lumbar spine. Comparing anteroposterior, lateral, right and left 45° oblique radiographic views with the dissected anatomy of 25 male adult lumbar cadaver spines, they concluded: since in 13 of 25 normal joint specimens the 45° oblique x-ray suggested pathology, all of whose facet angulation was greater or less than 45° from the sagittal plane, facet joints of the lumbar spine whose axis are other than 45° from the sagittal plane may falsely appear pathological on routine 45° radiographs. The apophyseal joint space and the surrounding structures will be accurately visualized only if the planes of the articular facets are flat and are nearly in the same oblique projection as the roentgenogram. The articular surfaces of the lumbar facets are, however, not flat (Badgley, 1941; Farfan et al., 1972; Hadley, 1961; Hirsch, 1963) and this compounds the problem of depicting the joint spaces radiographically. Horowitz and Smith (1940) have demonstrated that the inferior facet of the L-5 vertebra was convex in 14% of 80 lumbar spines, 49% at L-4 and L-3, 79% at L-2 and 100% at L-1. Furthermore, in the 80 spines the apophyseal joint spaces would not have been accurately visualized by a 45° oblique projection in 56% of the L5-S1 facets, 34% of the L4-5, 61% of the L3-4, 89% of the L2-3, and 100% of the L1-2. A similar study of 88 human cadaver lumbar facet joints revealed that only 44 were properly depicted by a 45° oblique radiograph (Reichman, 1973).

The curvature of the articular surfaces makes penetration

of the roentgen rays in a plane parallel to the joint surfaces impossible. The result on a roentgenogram is a summation of shadows which may falsely give the impression of changes in the clarity and width of the joint space or of changes in the density of the adjacent bone (Horowitz and Smith, 1940; Lewin et al., 1962; Oppenheimer, 1938a; Pheasant and Swenson, 1942).

The unreliability of the 45^{o} oblique view for the evaluation of lumbar facet pathology is proven. In the light of the proposed relationship of lumbar facet joint asymmetry with spinal instability and the significant correlation of radiographically determined facet asymmetry with lateralizing disc herniation, the accuracy with which the radiographic prediction of facet joint orientation must be examined.

Borman (1959) in his clinical study determined the obliquity of the L4-5 and lumbosacral joints by evaluating anteroposterior (AP) radiographs of the lumbar spine using the method of Ferguson (1941). By this technique, judgement of the plane in which the articulations lie is "most simply and most accurately made by judging the amount of overlap of shadows of the superior and inferior facets as seen in the anteroposterior view" (Fig. 5). When the articulations are anteroposteriorly situated (joint space in the coronal plane), the shadows of the processes overlap throughout their entire width. With the internal-external arrangement (joint space in the sagittal plane), the amount the articular processes overlap is less than half the width of the facet. Intermediate orientations are judged by the proportionate amount of overlap between the two

extreme types. This method has been criticized in that slight variation in the plane of the roentgen ray projection would cause a sagittal portion of one articulation to stand out in relief and obscure the plane of the articulation on the opposite side. Sacral inclination may also cause the margins of the lamina and articular processes create the roentgenographic appearance of marked articular asymmetry (Pheasant and Swenson, 1942).

Farfan and Sullivan (1967) in reporting their extrordinary correlation, roentgenographically examined the L3-4, L4-5 and L5-S1 facet joints. Their criteria for determining asymmetry involved studying the anteroposterior, lateral and oblique projections of included patients. They divided the lower lumbar facets into three types: (1) vertical orientation - the joint spacewas clearly visualized on the AP projection and not the oblique; (2) oblique orientation - the space was not seen on the AP projection but visualized on the oblique; (3) equivocal orientation - the space was identified, bu not clearly, on either projection.

It is important to note that the conclusions of these investigators rest soly on the assumption that their individual criteria for evaluating the planar orientatation of the lumbar apophyseal joints from radiographs is an accurate representation of the vertbral anatomy. It is not at all proven from the review of the literature that this is indeed a valid assumption.

Investigators mentioned earlier (Horowitz and Smith, 1940; Reichman, 1973) studies the capability of selected radiographic

projections in accurately depicting the lumbar facets for the purpose of evaluating those areas for the presence of pathological changes. The key structure of the apophyseal joint is the articular cartilage which is not directly visible radiologically. When accurately depicted on the roentgenogram, the joint spaces are 1-3 mm. in width and are very sharply outlined by the facets which stand parallel with the tip of the supra-adjacent articular process exactly opposite to the base of the sub-adjacent (Oppenheimer, 1938a). When a particular joint space is not accurately depicted, the cause may be artifactual, secondary to the facet orientation, or indeed a result of pathological changes in the facet joint (Horowitz and Smith, 1940; Reichman, 1973).

Again, some facets which on roentgenograms appeared oblique were actually found to be curved (Horowitz and Smith, 1940). Also, no facet plane is purely oblique, sagittal or coronal. All have some curved component corresponding to a segment of a cylinder. The facets appear on radiographs as sagittal, frontal or oblique depending on which component is predominant in the curvature of the facet (Pheasant and Swenson, 1942). By varying the angulation of the roentgen beam within a range of 20° to 55°, one can obtain a picture through different parts of the joint's dorso-ventral curvature (Lewin et al., 1962). It cannot be said with any certainty how a radiographic facet image represents its true orientation since it is visible over such a wide range of projections. Correlation should be made with the radiographically derived joint orientation and the

actual anatomy.

The introduction of transverse axial tomography of the spine, a radiologic technique that shows a cross-section of the spine in a living patient, was a major advance in spinal imaging. The method offers a undistorted axial view of the spine that had been unsurpassed for examination of the vertbral canal and the bordering articular processes (Gargano et al., 1974; Jacobson et al., 1975). Transverse axial tomography had been shown to be of diagnostic value in lumbar stenosis, spondylosis, facetal hypertrophy and other abnormalities that can obstruct the spinal canal (Jacobson et al., 1975).

The most recent addition to the radiology armamentarium is computed tomography (CT). By computer processing, the quality of axial computed tomographic imaging has surpassed non-computed tomography because of the inherent technical limitations of the latter's instrumentation. CT has recently been shown to be an excellent means of studying facet joint disease by providing high quality transverse axial images of vertbral structures (Burton, 1979; Lee et al., 1978). With high resolution technoques, CT distinguishes not only the bony structures but also the soft tissues around the facet joints. This technique has been able to demonstrate osteophyte formation, hypertrophy of articular processes, articular cartilage thinning, vacuum joint phenomenon and calcification of the joint capsule. CT apparently can provide the radiographic detail necessary for accurate definition and diagnosis of facet abnormalities (Carrerra et al., 1980).

With this understanding of the intimate role the posterior articulations play in spinal dynamics, the potential of the ability to radiographically identify a population at risk for low back disease and the limitations of radiography in examining the facet joints, this study was undertaken. Under controlled conditions, with optimized radiologic techniques, human lumbar spines were examined in an attempt to answer the following questions:

(1) Understanding that facet joint spaces are visible radiographically over a wide range of projections, what is the relation of the projection(s) that "best depicts" the joint to the range of projections (angular resolution) that the joint is visualized?

(2) The curved character of the articular surfaces makes parallel passage of a x-ray beam through the facet joint impossible, a particular projection does not correspond to the planar orientation of the joint. What is the relationship of the best projection(s) of the facet joint to the actual anatomy of the articular processes?

(3) The primary rays produced during roentgen ray production diverge in all forward directions. The central ray is that portion of the primary rayys that leave the x-ray port at right angles to the long axis of the x-ray tube. Distortion of a radiographic image may result when the central ray is angled or when the object is not centered to the vertical central ray (Jacobi and Paris, 1977).

(4) Since computed tomography demonstrates certain pathology

of the lumbar facet joints, how well can CT define lumbar facet orientation?

MATERIALS

Spines

A total of five spines were examined in part during this study. Two (#121,#122) intact embalmed cadaver spines were obtained from the Yale School of Medicine, Department of Anatomy. One (#108) was an intact post-mortem spine obtained at autopsy (Yale School of Medicine, Department of Pathology). Whole spines were removed from the cadavera by disarticulating the sacrum from the pelvis at about the sacroiliac joint. A circumferential hole sawed through the base of the skull mobilized the cervical spine. The thoracic ribs were transected close to their vertebral articulations. The intact spines were then excised and the major muscle mass was dissected off. The embalmed spines were stored wrapped in dressings soaked with preservative while the freshh spine was sealed in double plastc bags and frozen at -20^{o}C (Panjabi et al., 1977).

Two frozen motion segments (#81,#101) were also examined. A vertebral motion segment is the basic unit of the spine consisting of two adjacent vertebra and the interconnecting soft tissue, disarticulated from the supra- and sub-adjacent vertebra (Panjabi, 1977). These segments were obtained from post-mortem spines and were likewise frozen, sealed in double plastic bags.

Specimen Mounting

A specimen holder was constructed which allowed the spines to be stabilly suspended and rotated manually along their

longitudinal axis. A clear Plexiglas cylinder, 6 in. in diameter and 36 in. in length, housed the suspended spines. A wire threaded through exposed sacral foramina securred to a Plexiglas base plate and another wire threaded through several vertbral artery foramina in the cervical area, fastened to an adjustable tension mechanism, permitted the intact whole spines to be suspended within the cylinder. The cylinder housing rested on a support which permitted free rotation of the specimen without discernable vibration, movement or contact with the sides of the cylinder. A 360° protractor afixed to the cervical cylinder's base and a pointer permanently mounted on the apparatus' support base, insured accurate determination of angular rotation.

The vertebral motion segments had been previously prepared (Panjabi et al., 1977). The lower third of the lower vertebra was fixed into quick setting polyester cast (Plastic Padding) via screws tapped axially and radially into the vertbral body. Also cast in the mould were two bolts which served to fix the motion segment to the base within the rotation cylinder. The bolts were positioned so as when mounted in the apparatus, the segment would lie in its radiographic anteroposterior orientation.

Radiographic Technique

All x-rays were taken at 95 kV with a Toshiba Mobile Diagnostic X-Ray Unit (KCD-10M-6C) on Kodak X-OMAT (XTL-2) non-screen film. X-OMAT automatic development was used throughout. Initial ffd was 116 cm with a source-specimen distance of 100 cm.

This ffd was later decreased midway through the study to 81 cm. with a source-specimen distance of 71 cm. This was done in order to decrease the exposure (mAs) needed for each radiograph. Comparable radiographic penetration was maintained with this adjustment. In so doing image magnification was maintained and the resolution was not perceptably altered among the different studies. The exposure was varied (100-200 mAs) to maintain comparable penetration.

Calibration of the x-ray machine was done. The path of the central ray generated by this unit was best adjusted to align with the cross hairs of the optical aiming system. It was then determined (see Appendix) that the cross-hair prediction of the direction of the central ray was in error of $.76^{o}$ in the longitudinal plane, while eroor in the transverse plane was immeasurable. The error in longitudinal displacement of the central ray from the desired target was then calculated to be .81 cm. at the ffd of 81 cm. and 1.2cm. at the 116 cm ffd.

All of the radiographs in this study were taken in the general posteroanterior projection which assured accurate focusing of the central ray at the facet under study

METHODS

Determination of Facet Joint Radiographic Angular Resolution

Both whole intact spines and motion segments were mounted as described earlier. The posterior articulations to be studied were exposed by dissecting away overlying soft tissue. The actual posteroanterior (PA) alignment, so as the central ray would parallel the spine's mid-sagittal plane, was determined with scout films. Here the axial orientation was varied with each scout film until the projection of the spinous processes were equidistant between the projections of the pedicles. When this was obtained, that orientatation was referenced 0^{o} or the true PA. Radiographs were then performed on the facets under study by rotating the spine in 5^{o} intervals, generally in the range of 0^{o} to 65^{o} for each specimen. Care was taken to reposition the central ray on the facet joint after each manipulation. A total of nine lumbar facet joints were examined in this way.

In addition, the two motion segment specimens underwent a further study. In order to create a clear radiographic image of the articular joints, the bony shadows overlying and obscuring the facets were removed. By transecting the vertebral body from its adjoining pedicles, the entire body of the superior vertebral and one third to one half of the inferior vertebral body with their contiguous disc, were removed, preserving the neural arch structures. This maneuver allowed production of radiographic images of the facets devoid of overlying soft tissues and bony elements (Fig. 7). Radiographs of these joints were repeated in the same manner as were the intact segments.

Evaluation of the Radiographs

Without reproducible objective criteria for evaluating the quality of the radiographs, the x-rays produced here were subjectively evaluated by the author. The entire series of films for each facet (6-9 x-rays) was examined without knowledge of the specific angular projection at which each was taken. Considering the clarity of the facet joint space, presence of overlying bony shadows obscuring the space, sharpness and contiguity of the surfaces of the articular processes and joint space width, the radiographs were classified as optimal, good, or poor (Fig. 8).

The "optimal projection" of a facet joint was selected as that radiograph which depicted the joint space most clearly. The margins of the articular processes were sharp, distinct and contiguous. The joint space was homogeneous without overlying shadows or double densities. In most series more than one radiograph were of such similar quality that a single projection that best depicted the joint could not be selected. In the cases where the observer could not tell the difference in the quality of several radiographs considered optimal, they were categorized together.

"Good projections" are those in which the joint space is only partially "optimally depicted", in comparison with the rest of the series. Either blurring of a portion of the margins of one or both articular processes' surfaces or the presence of overlying bony images in the joint space has qualitatively degraded the depiction of the facet joint.

"Poor projections" are selected as the most inferior of the series. Although a feact joint space is visible, the margins of the articular processes are not demarkated and the joint space is widened and blurred.

When the joint space was not visualized in a projection, it was recorded as such.

Vertical Displacement of the Central Ray from the Facet Joint

After completion of the angular resolution studies, the effect of vertical displacement of the central beam from the facet under study was examined (Fig. 6). The spine was mounted and oriented in the angular projection deemed optimal. The central ray was then directed at the facet as a reference point. The mounting apparatus was then shifted along the longitudinal axis of the spine to displace the central ray from the facet joint. X-rays were taken at 2 cm. intervals, up to 8 cm., of cephalad and caudad longitudinal displacement. These radiographs were compared blindly to the optimal projection(s).

Comparison of Radiographic Images with Facet Anatomy

After completion of the afore mentioned studies, three pairs of posterior intervertbral articulations were examined in order to correlate the anatomical construction of the articular processes with their radiographic images. The two mounted motion segments were used. Also, the most superior portion of the sacrum of spine #122 was cast and mounted as previously described for the motion segments in preparation for this study.

Visualization of facet anatomy was obtained by cutting

serial horizontal sections through the intervertebral joints. The motion segments were manipulated in the frozen state. In order to preserve the orientation of the articular processes while being sawed, threaded Kirschner wires (K-wire, Type F, 0.062 in. dia.) were manually drilled through the inferior and superior articular processes near the lower pole of the joint approximately perpendicular to the joint space. The location of the K-wires was ascertained radiographically. Each specimen was then horizontally, serially sectioned, beginning at the superior pole of the joint, in 2-3 mm. intervals. The approximate location of each transverse cut was determined by oblique radiographs taken after each slice.

As the vertebral motion segments and sacral spine were cast mounted with the support bolts aligned to permanently direct them in their anteroposterior orientation when attached to the apparatus' base, the mid-sagittal plane could readily be identified. This was accomplished by construction of a Plexiglas base with two support posts permanently fixed along opposite edges. Matching holes were drilled at 5 mm. intervals in each post. When the spinal segments were placed on the base, wires thread through the support posts would overlie the vertebra in its mid-sagittal plane. The facet joint anatomy exposed with each transverse section was photographed with the overlaid sagittal plane reference in place.

The approximate angulation of the superior articular processes of the joint versus the mid-sagittal plane was determined for each photograph. A line drawn across the joint concavity

connecting the most posterolateral point of the superior articular process with its most anteromedial extent. Continuing this line to its intersection with the mid-sagittal plane reference created an angle used to approximate the angulation of the facet joint (Fig. 9).

Computed Tomography

Before the casted spine #122 was horizontally sectioned, its L4-5 posterior articulations were examined with computed transverse axial tomography. Scans were done by a Pfizer 0200 FS Computerized Tomographic Scanner. The spine was mounted in the rotation apparatus and aligned in its PA postion within the scanner. The level of the initial scan was determined with the scanners laser indicator. One millimeter thick, 90 kV, 40 sec. duration, transverse scans were completed at 2 mm. intervals throughout the joint space. The axial images were recorded on x-ray film and compared with photographs of the actual transverse anatomy.

RESULTS

Angular Resolution

The results of the categorization of the radiographs are presented in Table IV. The lumbar facet joints are radiographically visible over a wide range of angular projections. In only two instances (#101, #108) could a single projection be considered of optimal quality. For one specimen (#122-T12-L1) no radiograph was considered to optimally depict the facet joint. In the remaining cases two radiographs were of such similar quality that distinction between them could not be made. In these instances the two optimal projections were sequentially related except for one (#101-L) where thirty degrees separated the best projections. Similarly, for each specimen, two or more projections depicted the joint less adequately and are termed "good". The majority of the projections done for each specimen depicted the joint poorly or not at all. The facet joints of the upper lumbar vertbra (T12-L1, L1-L2) were visualized over the largest range of projections. None of the facets examined were visualized on the 90° projection.

Table V compares the results of the angular resolution of the in situ vertebral joints with the angular resolution of the same joints isolated, radiographically, by removing the overlying bony shadows. The evaluation of the projections remained quite similar under both conditions, except: (1) for spine #81, the 30° and 35° projections were downgraded while the 40°, 45° and 50° projections were all upgraded one category; (2) for spine #101-R, the 50° projection was improved with isolation;

(3) for spine #101-L, the 40° and 10° projections were down graded with the result that no single projection was optimal.

Vertical Displacement of the Roentgen Beam

The displacement of the central ray along the longitudinal axis of the L4-5 facet (#122), up to 8 cm. above and below the joint, reulted in no appreciable change in the quality of the image produced. The T12-L1 joint (#122) was also examined. No change in the radiographic resolution of the joint occurred up to 6 cm. of longitudinal displacement. At 8 cm. displacement there did appear slight blurring of the surfaces of the articular processes and joint space.

Comparison of Radiographic Images with Facet Anatomy

Table VI presents the angular orientation of the facet joints for each horizontal cross-section. The table also summarizes the data presented in Tables IV and V. It is evident that the serial horizontal sections reveal varied orientation of the articular processes for each facet joint. Generally, sections near the superior pole of the facet joint space expose the articular processes oriented nearer the mid-sagittal plane than the sections made at the mid-point of the joint space. Closest correlation of the optimal radiographic projections with the orientation of the articular processes occurs when the facet angulation is determined from the horizontal sections made through the central half of the joint space, joint fraction 0.25 to 0.75.

Computed Tomography

Computed tomographic images of the L4-5 facets proved to be of exquisite quality in depicting the anatomy of the articular processes. Unfortunately, the quality of the black and white photographs of the horizontal serial sections for this embalmed specimen did not permit optimal comparison of the axial anatomy with its corresponding CT image. Figure 10 depicts two CT axial images of the L4-5 facet with photos of the actual cross-sectional anatomy at approximately corresponding levels. Evidence for osteophyte formation at the articular process edges and hypertrophy of the articular facet is contained in the CT images and confirmed in the anatomical cross-section. Osteophyte formation is defined as excrescent new bone, lacking a medullary space and arises from the margin of the joint. Hypertrophy is enlargement of the articular process with normal proportions of medullary cavity and cortex (Carrerra et al., 1980). Possible calcification of the ligamentum flavum on the left is also suggested. The L-4 nerve root ganglia are observed by CT in the L4-5 intervertebral canals. Poor preservation of the articular cartilage in this embalmed spine is noted as the moth-eaten joint space photographed in Fig. 10 is compared with the pristeen, smooth articular cartilage in Fig. 9. This preservative artifact may explain the apparent widening of the facet joint space observed in the CT images.

DISCUSSION

The possible role the lumbar posterior spinal articulations play in low back pain syndromes has been well documented. Mechanisms by which facet arthropathies cause back pain and sciatica are postulated and not completely understood. The complex integration of the intervertebral joint structures focuses increased importance on the articular facets in maintaining dynamic spinal stability. The contention is that asymmetrical oblique posterior articular processes of the lumbar spine produces spinal instability. This allows abnormal rotational stresses to act on adjacent discs, producing susceptability to early disc injury. Borman's (1959) and Farfan and Sullivan's (1967) clinical correlation of radiographically determined lumbar articular tropism with the level and side of disc herniation, not only offers support to this postulate but also suggests that a population for developing low back symptoms may be identifiable.

The curvature of the articular surfaces makes penetration of the roentgen rays in a plane parallel to the facet joint impossible allowing the joint to be visible over a wide range of angular projections. Also, in routine clinical radiographic examinations of the lumbar spine, the variabilities of patient positioning and direction of the roentgen beams are vast. The confidence with which precise information as facet orientation gained from routine radiographic studies has to be proven.

In order to investigate the ability of planar radiographs to predict facet orientation, roentgenographic conditions were optimized and clinical variables minimized. Whole spines or spinal segments were precisely positioned both longitudinally and axially in relation to the x-ray beam. Overlying soft tissues and organ densities were negated as the spines were extracted from their cadavers. The use of high resolution film also improved the technique. However, routine spine radiographs are conducted in the general anteroposterior projection with the film cassette at the patient's back, minimizing the radiographic magnification of the posteriorly situated facet joint structures. The posteroanterior projections used in this study permitted accurate direction of the central roentgen ray at the facet joint. In so doing, the x-ray film is placed nearer the anterior vertebral body incruing slightly more magnification and distortion to the facet image than would be observed with radiographs done in the AP projection.

Although the number of lumbar facet joints examined is small due to the combination of availability of specimens and the cost of x-ray film, several observations can be made after evaluating the extensive series of roentgenograms. In agreement with previous investigators, each posterior lumbar articulation was radiographically visible over a wide range of angular projections (Lewin et al.,1962; Reichman, 1973). Of significance is the observation that for the majority of the facets, two projections were considered to optimally depict the joint; but more importantly, for all but one facet joint,

the two optimal projections were sequentially related. This strongly infers that there is a small range of angular projections which will produce similar highest quality radiographic images depicting the lumbar facet joints.

Ordinarilly, the less optimal, "good" projections might be expected to bracket the optimal projections, and likewise, the "poor" projections bracket the good. That is, as a spine is rotated along its logitudinal axis and the orientation of the articular processes versus the roentgen beam circumvolves, initial poor visualizations give rise to good images which, in turn, progress to optimal depictions. This sequence then reverses as rotation continues through the angular orientation of the facet joint. This progression in the quality of the radiographs was observed for four facet joints, while two joints (#108,#81) had shown optimal projections bounded sequentially by a poor projection image. An explanation for this finding lies in an understanding of the morphology of these articular processes which limits the angular range for each joint image classification. If the window of angular projections which will depict the joint in each classification is less than five degrees, each categorization may not be captured by the five degree intervals used here.

A pattern surfaces from the evaluation of the serial rotational radiographs of the lower lumbar posterior facets (L3-4, 14-5). Under these experimental conditions, there is a 10^{o} projection range where the qualitative resolution of the

lower lumbar facet joints is optimally depicted according to the criteria set forth in this investigation. A projection directed fifteen or more degrees in either direction from the optimal range, will create a poor representation of the facet.

After gaining familiarity with the anatomy and radiographic representation of the facet joints, the series of roentgenograms for each lower lumbar joint was again examined. This was done with the intention of deriving criteria from these films, usuing the method of Ferguson (1941), that would perhaps indicate the direction and magnitude which a less than optimal projection is from the optimal orientation of the facet. After close scrutiny of the progressive changes in the facet joint space and the articular processes, no reproducible index could be ascertained that would serve to gain further insight in to interpretation of less than optimal facet depictions.

As Figure 7 illustrates, the most unobstructive radiographic view of the lumbar facet joint is obtained by removing the overlying bony images of adjacent vertebral bodies. Neglecting any alteration of facet position which may have resulted secondary to the process of removing the vertebral bodies, the resolution of several projections had changed when the original radiographs were compared to those made of the isolated joint. The sample size is small and firm conclusions cannot be drawn from these observations. Since some resolutions improved while others worsened, emphasis is placed on the

effect that the overlying densities of the vertebral bodies can have in altering the depction and interpretation of facet radiographs.

The photographs of the cross-sectional anatomy of the intervertebral facet joints add considerable insight into the relation the radiographic projections have with facet morphology. The method used in this investigation to determine the orientation of the articular processes is novel. In previous studies where facet orientation was measured, intact articular processes of macerated vertebral segments were examined. By lying an instrument across the concavity of the articular surfaces, a single approximate angulation for the entire process was derived. The plane of reference was either perpendicular to the posterior surface of the vertebral body (Badgley, 1941; Jonck, 1961a; Willis, 1959) or a line constructed from the base of the spinous process through the center of area of the intervertebral disc (Farfan,1973). While these studies focused on the accurate determination of the average orientation of a facet, this investigation was intended to compare the orientation of lumbar articular processes versus a radiographically derived reference plane. By selecting the true PA orientation as the alignment where, on radiograph, the image of the spinous process is equidistant between its two pedicles, the mid-sagittal plane reference then became, in fact, the line bisecting the neural arch structures. Since both the vertebral body and neural arch, themselves, may

be asymmetrical in construct (Farfan, 1973), the measurements obtained in this study will not give a true picture of the vertebra as a whole. The angulations are useful since they are referenced to the only mid-sagittal plane approximation that can be reproducibly derived from planar radiographs. This technique also differs from the earlier studies in that the angulation of serial aspects of the articular processes were obtained by horizontal cross-sectioning rather than the single value reported when the entire articular process was considered as a whole.

If the form of the articular processes did indeed resemble one half of the circumference of a cylinder as described (Farfan et al., 1972), then the angles defined by the points at each horizontal plane of the process will all be the same. This was not observed, however. As indicated in Table VI and illustrated in Figure 11, horizontal cross-sections through different aspects of the facet joint reveals marked variation in the form and orientation of the individual facet processes. The quite straight joint space pictured in 11-A has become significantly curved in the cross-section, 11-B, made somewhat more inferior to 11-A. The variable form at each individual articular process compounds the difficulty of representing the lumbar facets on planar radiographs.

Only a joint space formed by the apposition of straight articular surfaces (Fig. 11-A) can be characterized by a single angular orientation. The curved posterior intervertebral

articulations are best depicted radiographically by central rays directed tangent to or parallel with the articular surface (Lewin et al., 1962). There are, however, an infinite number of tangents to the curved articular surfaces which results in the range of projections which visualize a particular facet joint. Therefore, the angular orientation assigned to the exposed cross-section of the articular processes can only be a reduction or approximation of the facet form. The question addressed in this investigation concerns the relation of the radiographic angular resolution of the lumbar facet joints with the approximation of facet orientation.

By comparing the projections thought to optimally depict a facet with its cross-sectional anatomy, best agreement is found when the superior articular process' angulation had been derived from the cross-sections made through the central two quarters (underlined in Table VI) of the joint space. The form of the articular processes is oval yet curved (Badgley, 1941; Hirsch, 1963; Hadley, 1961) (Fig. 1), so the central half of the joint space is composed of the widest cross-sectional diameter of the facet process. In general, an optimal image results when the overprojections of adjacent vertebral and articular components created by a central ray tangent to the joint space are such that the facet space is homogenous and the articular surfaces are sharp and complete. The data outlined here suggests that the orientation which fits the conditions for optimal facet depiction results when the central ray is aligned along the approximate angulation of the central

portion of its superior articular process. The derived angulation of the central portion of the superior articular process is therefore a close approximation of the radiographic orientation of the entire facet joint. Under the experimental conditions set forth in this investigation, central rays directed along the approximate orientation of the superior articular process (defined as the angle that the plane that the most posterolateral and anteromedial aspects of the central half of the superior articular process makes with the radiographic mid-sagittal plane) will create radiographic images that optimally depict the facet joint.

Therefore, a radiographic projection which optimally depicts the facet joint offers accurate information as to the orientation of the articular process. A less than optimal radiograph can only suggest that the actual orientation of the articular process lies at a minimum of positive or negative fifteen degrees from the optimal projection.

The nature of the curvature of each facet joint determines the range of projections in which the joint space will be visualized. As observed here, the orientation of the larger central portions of the articular processes influences the optimal angular projection to a greater extent than do the extreme poles of the facet. This is illustrated by the 30^0 separation of optimal projections for, and the large range of visualization of, the *in situ* left facet of spine #101. As evident in Figure 11, the left superior articular process

is oriented at 45° and 11° planes in these cross-sections taken through 0.71 and 0.50 fractions of the joint, respectively. Simplistically and conveniently these values correspond quite well to the joint's optimal depiction at 40° and 10°. However, the smooth, symmetric curvature of the superior articular process exposed by the section mid-way (0.50) through the joint contributes more insight into its radiographic images. Figure 12 illustrates the path of the central roentgen beam through the facet joint at projections of 10°, 40° and -5°. At each projection the beam is tangent to a portion of the joint curvature and radiographically visualized (Table VI). The curvature of the joint permits it to be visualized over a wide range of projections while its smooth contour effects a gradual progression of poor to good optimal projections as the x-ray angle circumvolves. A facet with a more severe, abrupt contour (Fig. 11-B, Right facet) may serve to disrupt the gradual progression of its radiographic images and limit the angular resolution of the facet. The contribution that the overprojected bony densities have in the overall interpretation of the facet space cannot be overlooked. This is emphasized by the 40° and 10° projections (101-L) considered optimal for the <u>in situ</u> specimen, were thought to be not dissimilar from the wide range of good projections in the facet-isolated specimen.

Since the central rays of the three projections in Fig. 12 transverse different portions of the vertebral body, posterior

ariculations, joint space and other structures, the resultant images of each will depend on the overprojections which shadow the joint space.

Caution must be exercised when the observations arrived in this study are applied to interpretation of lumbar radiographs obtained clinically. The clinical variables related to imprecise patient positioning and direction of the roentgen beam were tightly controlled. The observation that the resolution of a facet joint remained unchanged with longitudinal displacement of the central ray, up to 8 cm. superiorly and inferiorly at the L4-5 level and 6 cm. at the T12-L1 level, suggests that all the lumbar facet spaces can be confidently examined by a radiograph taken with the central ray directed at the mid-lumbar region. The effect of lateral displacement of the central ray from the facet joint must be addressed before a single roentgenogram of the lumbar spine can be reliably interpreted.

It must be kept in mind that the radiographs taken in this study were evaluated solely to determine the angular resolution of the lumbar facet joints. No inferences were made as to the presence of any pathology within the articular processes and the effect of facet pathology on the resolution was not addressed. The inadequacies of planar radiographs in diagnosing facet arthropathy is well reported (Horowitz and Smith, 1940; Reichman, 1973; Rhea, 1980).

The computed tomographic images presented here, as well as those reported earlier, are of such high resolution that subltles of the cross-sectional articular process anatomy are readily evaluated non-invasively. While CT has been able to demonstrate

osteophyte formation, hypertrophy of articular processes, articular cartilage thinning, vacuum joint phenomenon and calcification of vertebral ligaments (Carrerra et al., 1980), the insight it provides into facet orientation is of equal importance.

In certain cases, the articular processes at a vertebral level may be asymmetrical in form and yet have the same angulation versus the mid-sagittal plane when measured across the joint concavity (Willis, 1959). Figure 11-A demonstrates this concept. The right and left facets are quite dissimilar in shape while their orientations are only five degrees apart. Conventional radiography may not detect this relationship as both joints may project equally well on routine films. The effect of this alignment on spinal stability and disc diseasy may then go unnoticed. The transverse axial images provided by CT would readily identify this facet relationship.

As the conclusions formed by this investigation reflect the radiographic study of the lumbar facet joints under near optimal conditions, the images produced are considered of similar quality, if not better than, those obtained clinically. Further efforts need to be directed in correlating the findings presented here with those clinically oblainable. In particular, precise reproducible positioning of the patient and calibration of the x-ray units' central beam direction should be accomplished before correlation is made between clinicaaly produced lumbar roentgenographs and either operative or post-mortem anatomy. High resolution computed tomography, on the other hand, appears to be a medium immediately accessible for clinical investigation

of the lumbar facet joints.

of the lumbar facet joints.

CONCLUSIONS

Several observations can be made from this radiographic, anatomic and computed tomographic evaluation of the nine lumbar facet joints:

(1)Under conditions which optimized the radiographic representation of the lumbar facet joints:

(a) the lumbar facet joints were visualized over a wide range of angular projections

(b) the individual radiographs for each facet could be reproducibly categorized according to the depiction of each joint

(c)for the L3-4-5 facets there was observed a 10° projection range within which radiographs were of indistinguishable optimal quality

(d)projections taken fifteen degrees from the optimal range uniformly depicted the L3-4 and L4-5 facets poorly

(e)the angular resolution of the upper lumbar facets (T12-L1, L1-2) were not as clearly defined as for the lower lumbar region;

(2)Overprojections of the bony vertebral body over the facet joint space affects interpretation of the joint image;

(3)Displacement of the central beam did not affect the angular resolution of the L4-5 facet up to 8 cm. of cephalad and caudad displacement and up to 6 cm. for the T12-L1 facet;

(4)The angular orientation of the lower lumbar facets versus the radiologic mid-sagittal plane may be approximated as the line across the concavity of the superior articular

process in the central half of the facet;

(6) Radiographic projections along the angular orientation of the facet, plus or minus five degrees, depict the facet optimally;

(7) Computed tomography provides accurate, high resolution axial images of the lumbar facet joints.

APPENDIX

The accuracy that which the optical aiming device of the x-ray unit predicted the true focus of the roentgen central ray was determined. The aiming mechanism consists of cross-hairs etched on a Plexiglas plate attached to the housing of the x-ray port. When illuminated by a bulb within the housing, an image of the cross-hairs is projected which putatively corresponds to the focus of the central beam. The cross hairs were adjusted so as to coincide with the central ray as nearly as possible. The error with which the central ray was not alligned with the cross-hairs was calculated as follows.

The actual projection of the central beam was determined. The x-ray tube, x-ray port, and x-ray film were all leveled. Two rulers with radio-opaque markings were situated, overlying each other, six inches apart, in register. These rulers were positioned over the x-ray film. Since the primary rays generated by the x-ray source diverge in all directions, only the rays perpendicular to the rulers will penetrate the same point of each and hence will superimpose the image of the ruler marker at that point on the film. Divergent rays will penetrate each ruler at different points and the superimposed markings on the fim will not coincide. By exposing the film with the rulers in the vertical, and then horizontal planes, the central ray's projection (B) was extrapolated. The location of the optical projected cross-hairs (C) was recorded on the same film by afixing a steel ball-bearing (0.125 in. diameter) to the film's

cover at the point where the cross-hairs were projected. Measurement of the distance between points C and B on the exposed film (1.16 cm.) along with the information that the x-ray port to film distance was 88 cm., facilitated calculation of the angular deviation of the central beam from the optically aimed path. This error was derived to be $.76^{\circ}$ in the longitudinal plane, while the deviation in the transverse plane plane was immeasurable.

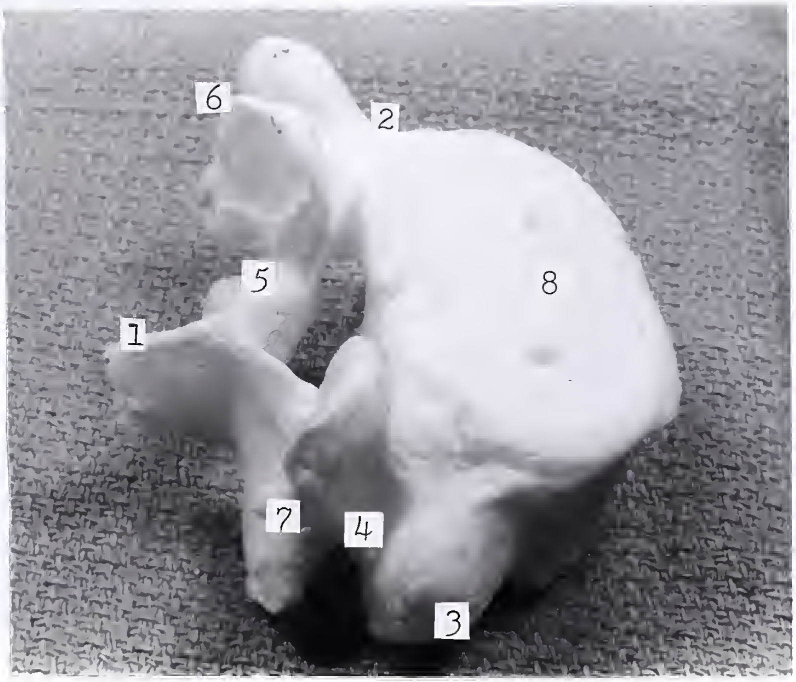


Figure 1. Fifth Lumbar Vertebra

1. Spinous Process
2. Pedicle
3. Transverse Process
4. Pars interarticularis
5. Lamina
6. Superior articular process
7. Inferior articular process
8. Body

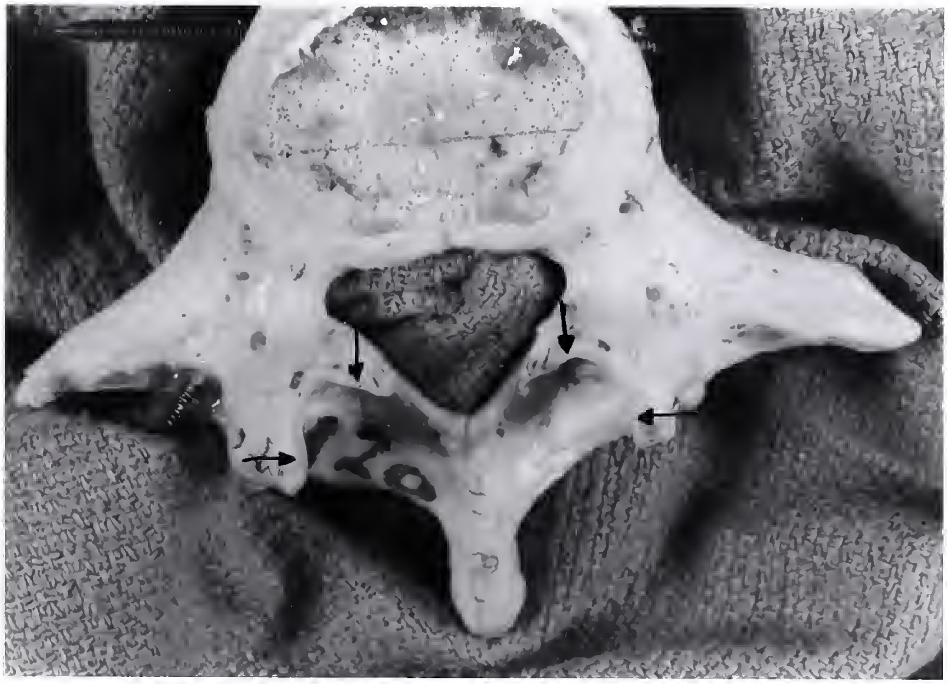


Figure 2. Superior Aspect of a L-4 Vertebra

Note the J-shaped curvature of the superior articular processes (arrows).

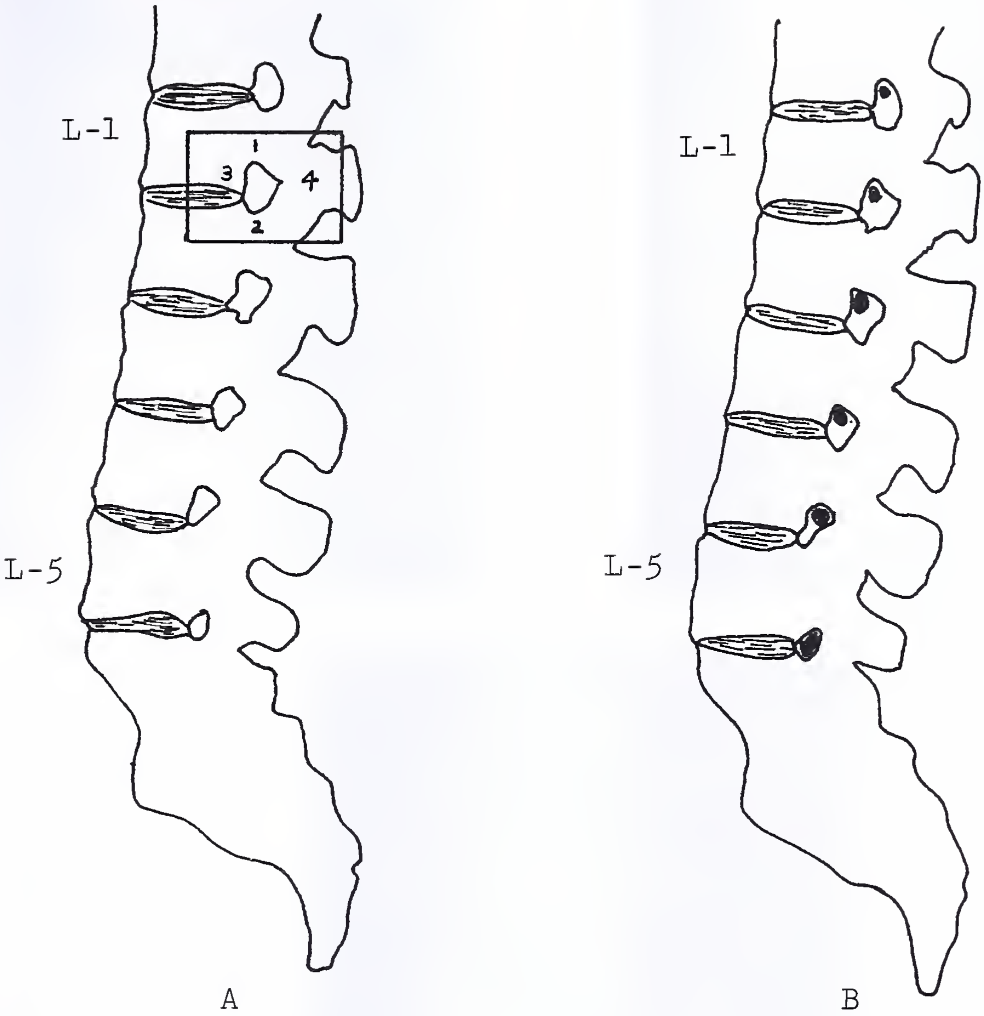


Figure 3. Drawings illustrating the relative sizes of the intervertbral foramina of the lumbar spine, viewed laterally. A - without and B - with the sizes of the corresponding nerve roots. (Danforth and Wilson, 1925)

Intervertebral foramen boundries (box):

1. Inferior vertebral notch (incisure)
2. Superior vertebral notch (incisure)
3. Posterior surfaces of the lower body of L-1, intervertebral disc, and upper body of L-2
4. Facet articulation

AP

Lateral

Oblique

Figure 4.

1. Spinous process
2. Pedicle
3. Transverse process
4. Pars interarticularis
5. Lamina
6. Superior articular process
7. Inferior articular process
8. Body

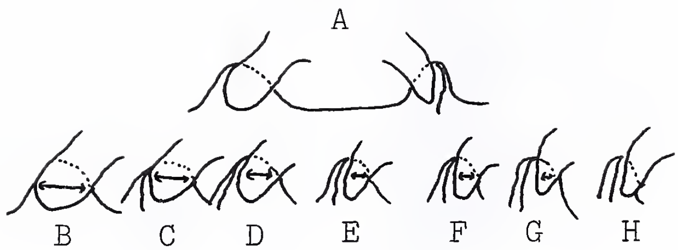


Figure 5. Anteroposterior projection for the estimation of the obliquity of the facets (Ferguson, 1941)

A. Severe asymmetry
B. Anteroposterior facets - coronal joint space
C. Facets nearly anteroposterior
D. Oblique facets tending toward anteroposterior
E. Oblique facets
F. Oblique facets tending toward internal-external
G-H. Internal-external facet - sagittal joint space

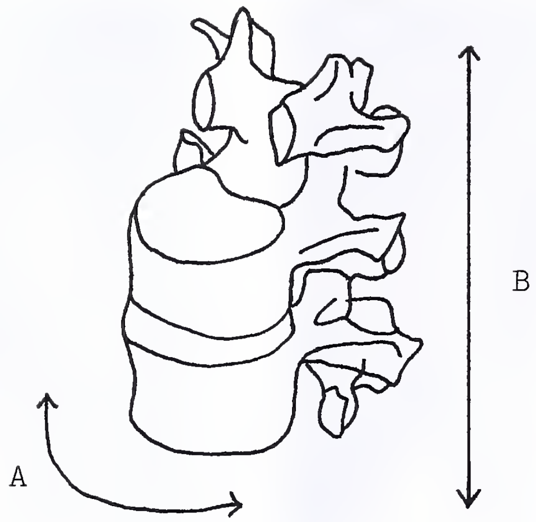


Figure 6. Displacement Parameters of Roentgen Central Ray

A. Angular Displacement
B. Longitudinal Displacement

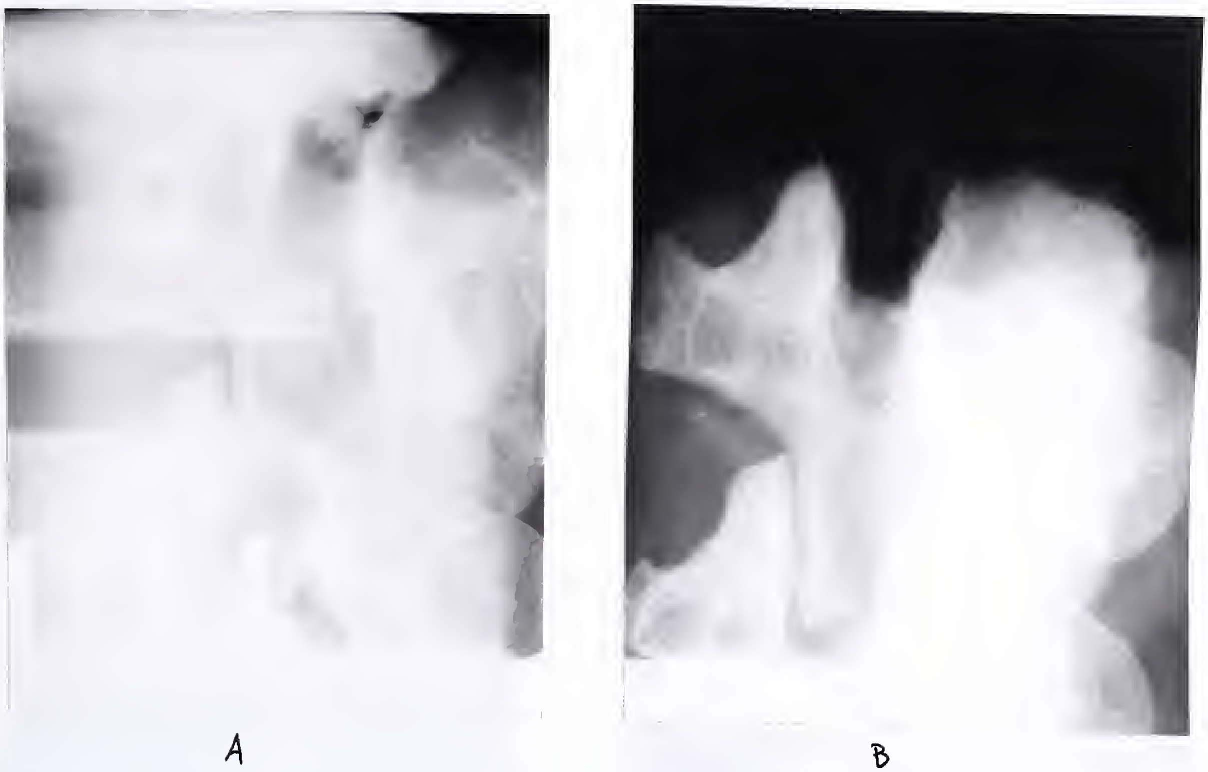


Figure 7. Forty-five degree oblique radiographs of the L3-4 motion segment (spine #81)

A. Intact - Graded Good
B. After L3 body, L3-4 disc and a portion of the L4 body have been removed to radiographically expose the facet joint - Graded Optimal

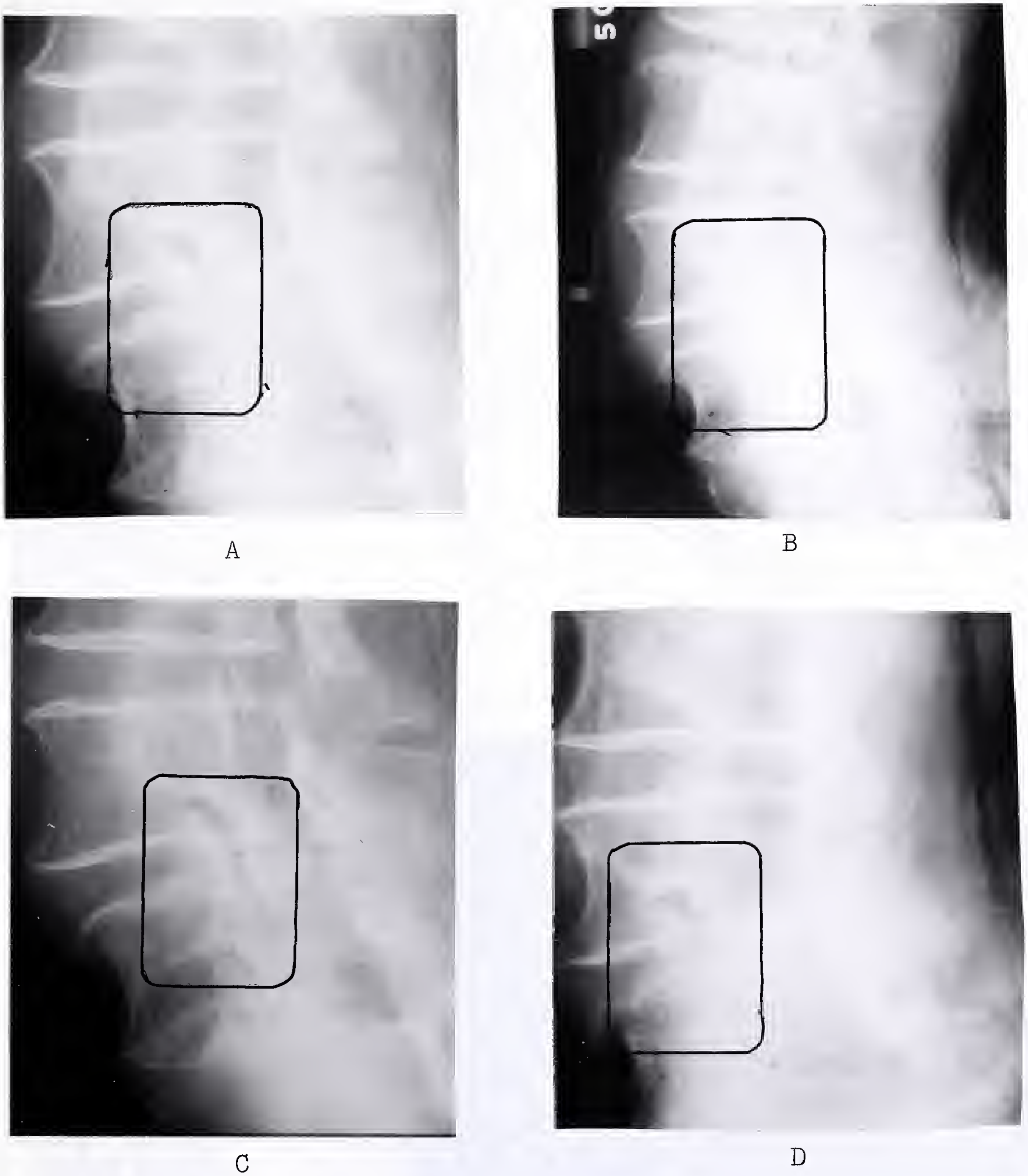


Figure 8. Photoradiographs of four projections of the L4-5 facet (encircled; spine #122)

A-40° and B-45° - OPTIMAL projections - The entire joint space is clear and homogeneous; articular surfaces are smooth, sharp and continuous.
C-50° - GOOD projection - Although the entire joint space visible, the articular surfaces are blurred.
D-30° - POOR projection - The joint space is only partially visualized and is not homogeneous, but narrowed by double density bony overprojections.

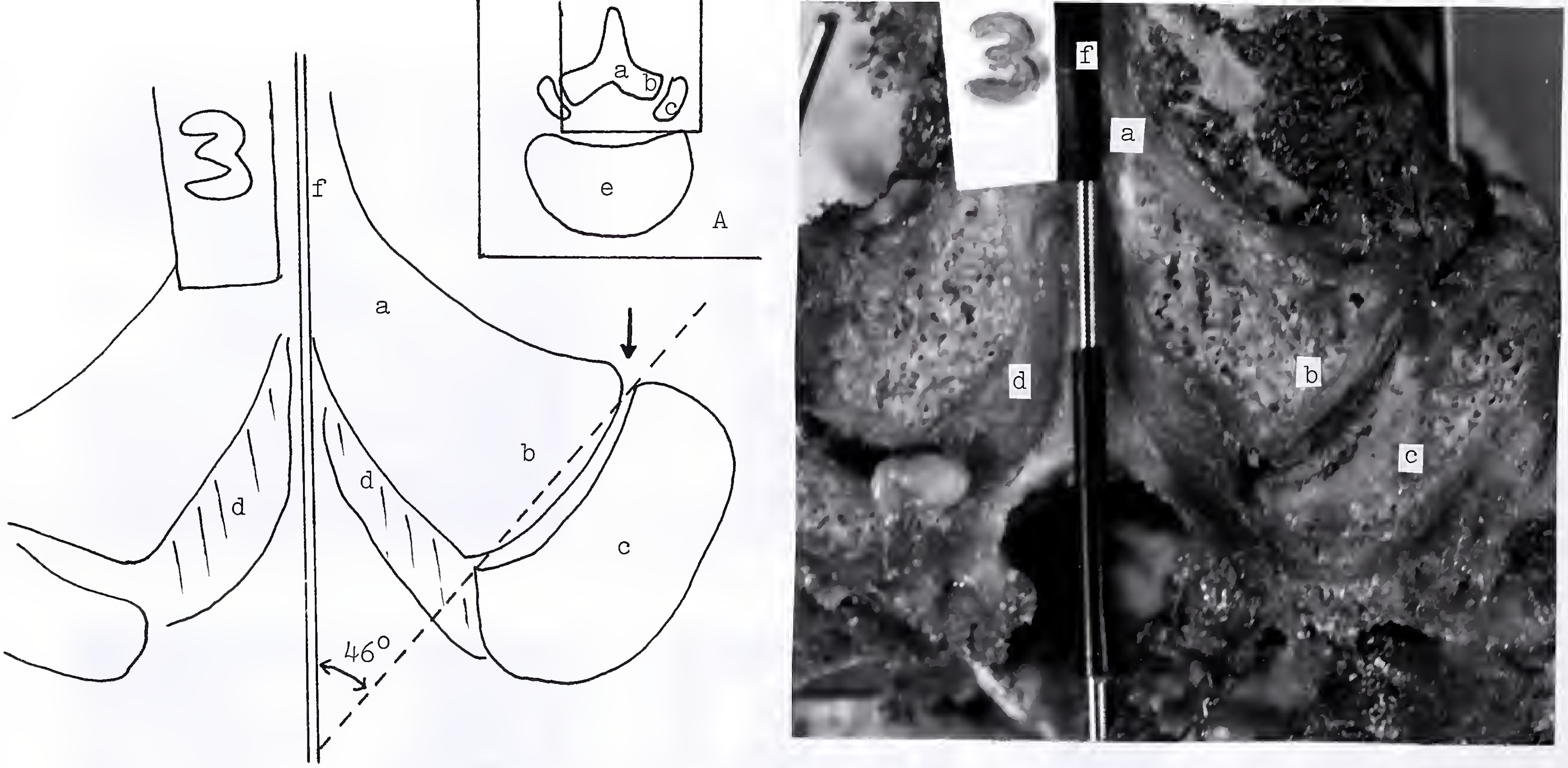


Figure 9. Cross-sectional anatomy of L3-4 (spine #81)

Diagram (A) and photograph (C) of cross-section through the L3-4 intervertebral disc and posterior articulations. The tracing (B) of the photograph corresponds to the boxed area of A. The dashed line connects the posterolateral with the anteromedial aspects of the left superior articular process and is continued to its intersection with the mid-sagittal plane which creates an angle used to approximate the facet orientation. a-left lamina L-3; b-left inferior articular process L-3; c-left superior articular process L-4; d-ligamentum flavum; e-L3-4 intervertebral disc; f-overlaid wire indicating the mid-sagittal plane; arrow-facet joint space

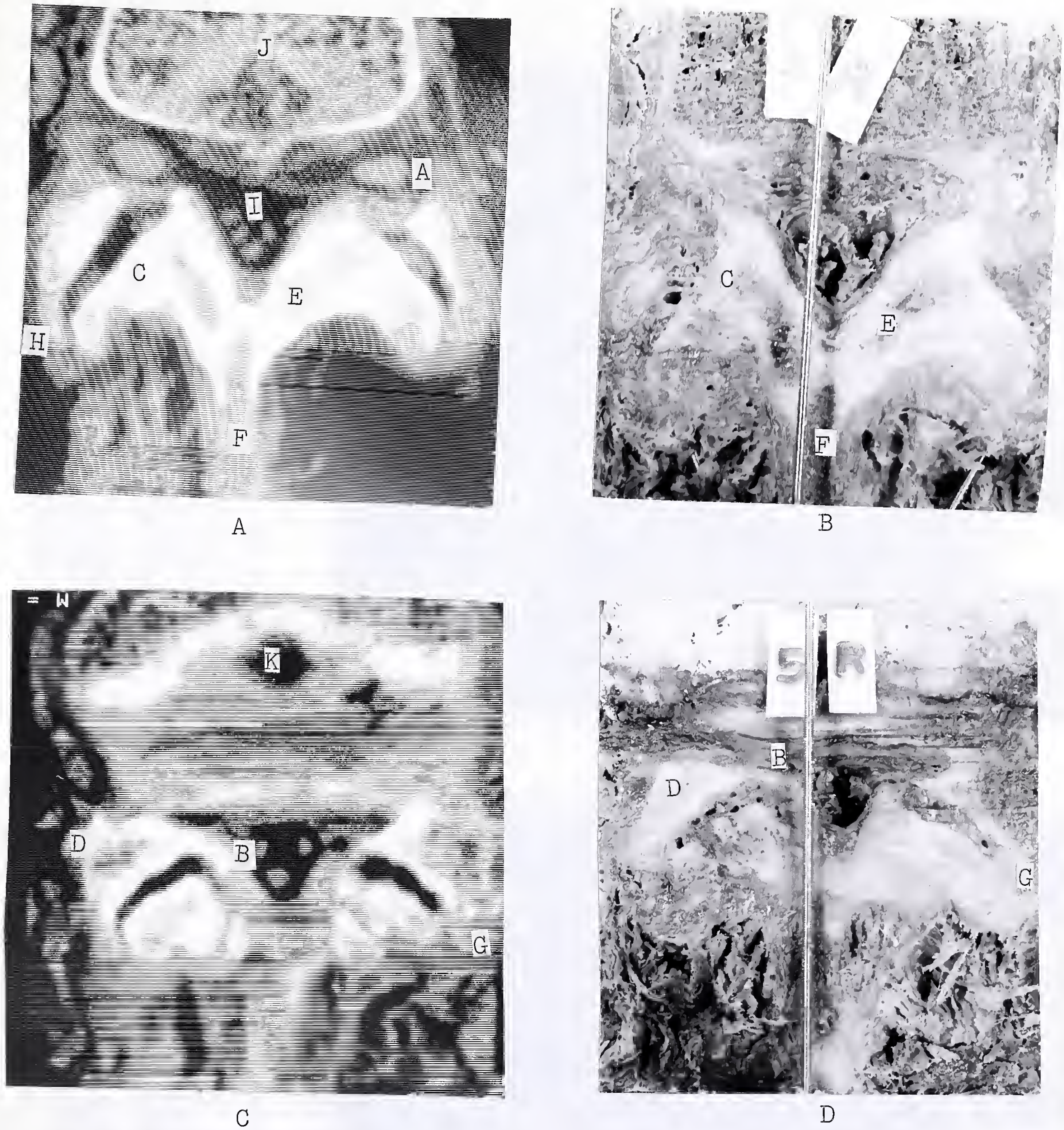
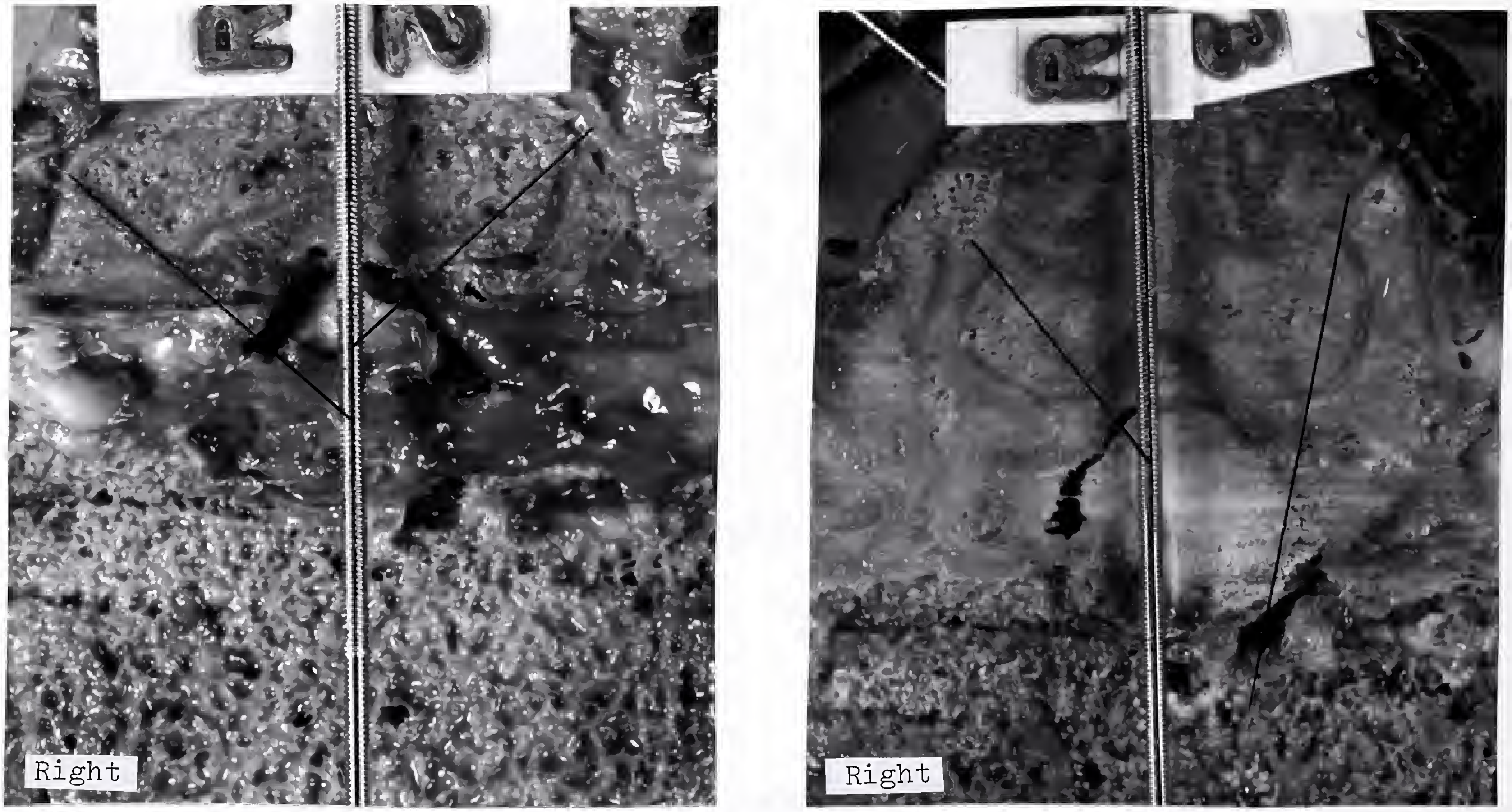


Figure 10. Computed tomographic (CT) images and photographed cross-sectional anatomy of the L4-5 facet (spine #122)

The cross-section in B is slightly superior to the CT image A, while the cross-sections of C and D are nearly through the same level of the facet joint.

A-L4 nerve root ganglion; B-calcification of the left ligamentum flavum; C-left inferior articular process L4; D-left superior articular process L5; E-right lamina L4; F-spinous process L4; G-hypertrophy superior articular process; H-osteophyte; I-cauda equina; J-body L4; K-L4-5 intervertebral disc; arrow-joint space



A. B.

Figure 11. Photographs of the cross-sections through the T12-L1 facet (spine #101)

A-Right superior articular process (SAP) angle is 50° through the .64 portion of the joint. Left SAP angle is 45° through the .71 portion of the joint. Note the marked difference in shape of the two SAP, yet they have similar angulations.

B-Right SAP angle is 35° through the .29 portion of the joint. Left SAP angle is 11° through the .50 portion of the joint. Note the difference in shape and orientations of each SAP in the subsequent cross-section.

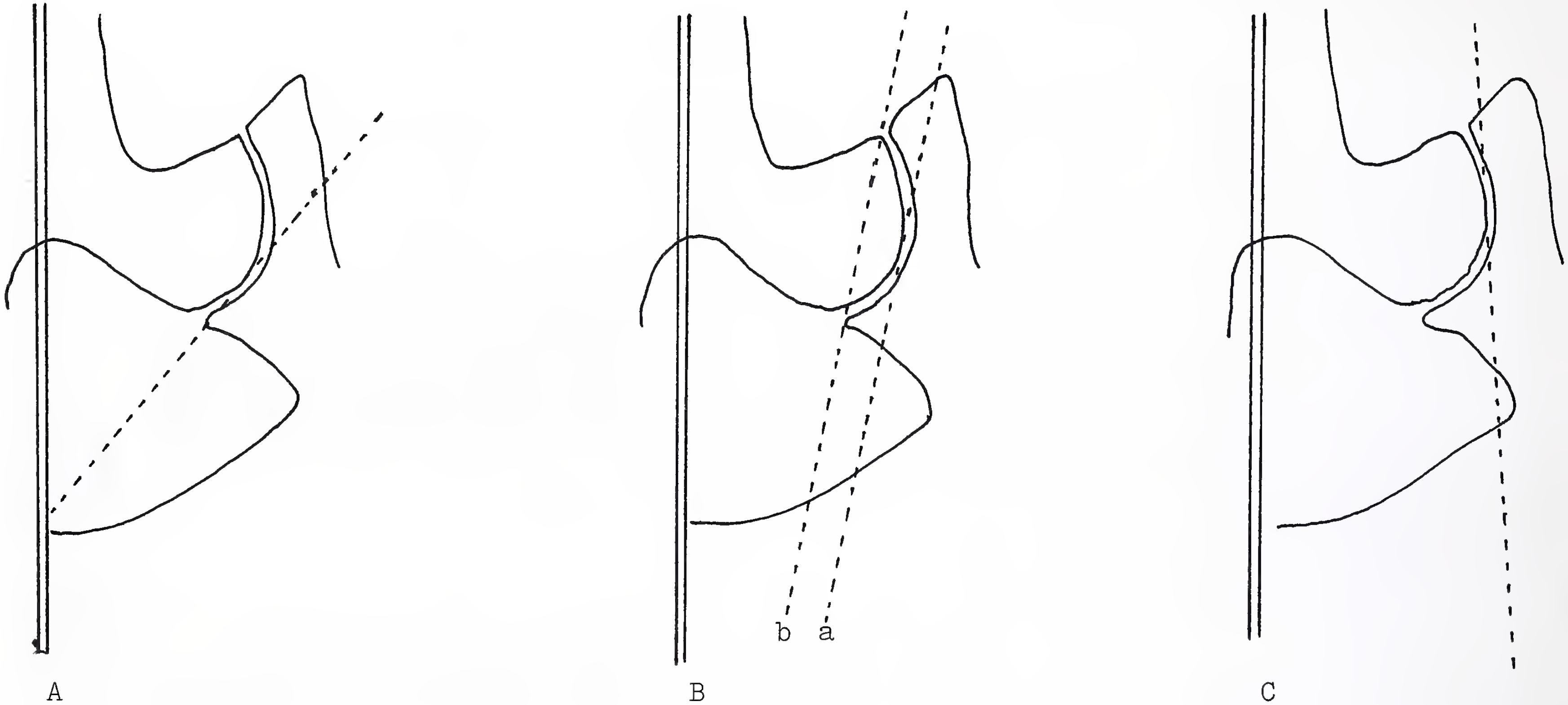


Figure 12. Illustrations of the path of the central ray for three radiographic projections tangent to the facet joint

The diagrams are tracings of the left T12-L1 facet photographed (Fig. 11-B)
Double line - Mid-sagittal plane; Dashed line - path of the central x-ray beam

A-40^{o} projection
B-10^{o} projection showing not only the ray tangent to the joint space (a) but also its path across the joint concavity corresponding to the angulation of the superior articular process (b)
C- -5^{o} projection

TABLE I

MEAN INCLINATION OF THE SUPERIOR ARTICULAR PROCESS VS. THE MID-SAGITTAL PLANE*

	MALE (L/R)	FEMALE (L/R)
S-1	48.4/46.3	48.1/47.5
L-5	46.3/45.4	44.9/43.9
L-4	35.4/34.7	35.7/34.4
L-3	27.0/26.0	27.7/25.1
L-2	22.0/22.1	23.8/21.2
L-1	34.0/34.0	35.2/33.1
T-12	84.7/86.0	83.8/81.4

*Jonck, 1961a

TABLE II

PREVIOUS INVESTIGATIONS CONCERNING FACET ORIENTATION

METHOD	ASYMMETRICAL FACETS (%) LUMBOSACRAL	EACH LUMBAR LEVEL	NO. SPINES
Radiographic* (without pain)			
Brailsford (1929)	31		3000
Farfan (1967)		23	200
Horowitz (1940)	10		80
Kuhns (1935)		10	500
Splithoff (1953)	24		100
Radiographic* (with pain)			
Ford (1966)	6.6	11	1616
Willis (1941)	14		79
Badgley (1937)	22		447
Splithoff (1953)	26		100
Dissection			
Badgley (1941)	21		100
Putti (1927)	8		75
von Lackum (1924)	60		30
Jonck (1961a)		14	200
Willis (1959)	52		100

*Asymmetry was determined after examining lumbar radiographs of patients either complaining of low back pain or without pain.

TABLE III

CORRELATION OF RADIOGRAPHIC FACET ASYMMETRY WITH INTERVERTEBRAL DISC HERNIATION

	Borman (1959)	Farfan and Sullivan (1967) Operative	Farfan and Sullivan (1967) Non-operative
Radiographic Projections	AP	AP, Lateral, Obliques	
Levels Studied	L4-L5 L5-S1	L3-L4 L4-L5 L5-S1	
Asymmetry			
L4-L5	81/100(81)*		
L5-S1	79/100(79)		
Lumbar		38/52(73)	40/45(89)
Correlations Asymmetry...			
Side of pain			40/40(100)
Level of disc pathology			
L4	55/81(68)		
L5	60/79(76)		
Side of disc lesion			
L4	31/55(56)		
L5	42/63(67)		
Total	73/118(62)	36/38(95)	

*Values within the parentheses indicate percentages

TABLE IV

SUMMARY OF THE GRADED RADIOGRAPHIC PROJECTIONS FOR EACH FACET JOINT

Vertebral Level	Spine	Type[1]	Grade[2] Optimal	Good	Poor	N.V.[3]
L4-5(L)[4]	122	E.W.	40,45	35,50	0,30,55,60	90
L4-5(R)	122	E.W.	45,50	40,55	0,25,30,35 60	90
L4-5(L)	108	F.W.	50	40,45	30,35,55,60	0,90
L3-4(L)	81	MS.F.	30,35	40,45	20,25,50	0,90
L1-2(L)[5]	121	E.W.	25,30	20,40	0,5,10,15, 45,50	60,80,90 100
T12-L1(L)	122	E.W.	---	15,20, 25,30	35,40,45,50	55,90
T12-L1(R)	101	MS.F.	55	50,60	35,40,45, 65,70	20,25,90
T12-L1(L)	101	MS.F.	40,10	5,15,20, 25,30, 35,45	0,50,55,-5, -10,-15, -20,-25	-30,90

[1] E-Embalmed; W-Whole spine; MS-Motion segment; F-Frozen

[2] Values, in degrees, are the posteroanterior projections from the mid-sagittal plane

[3] N.V.-Facet not visualized

[4] (L)-Left; (R)-Right facet examined

[5] 35^{o} projection not available

TABLE V

COMPARISON OF RADIOGRAPHIC FACET QUALITY OF *IN SITU* JOINTS WITH THEIR FACETS ISOLATED FROM OVERLYING BONY SHADOWS

Level	Spine	Grade[1]	Angular Projection[2] In Situ	Angular Projection[2] Isolated
L3-4	81	O	30,35	40,45
		G	40,45	30,35,50
		P	20,25,50	20,25
		N	0	0
T12-L1 (R)	101	O	55	50,55
		G	50,60	60
		P	35,40,45,65,70	30,35,40,45,65,70
		N	20,25	20,25
T12-L1 (L)	101	O	40,10	--
		G	5,15,20,25, 30,35,45	5,10,15,20,25, 30,35,40,45
		P	0,50,55,-5,-10 -15,-20,-25	0,50,55,-5,-10 -15,-20,-25
		N	-30	-30

[1] O-Optimal; G-Good; P-Poor; N-Not visualized

[2] Values, in degrees, are the posteroanterior projections from the mid-sagittal plane.

TABLE VI

COMPARISON OF CROSS-SECTIONAL FACET ANATOMY WITH RADIOGRAPHIC ANGULAR PROJECTIONS

Level	Spine	Grade[1]	Projections In Situ	Projections Isolated	Joint Fraction[2]	Angle[3]
L4-5(R)	122	O	45,50		.89	*
		G	40,55		.79	35
		P	0,25,30 35,60		.42	50
		N	90			
L4-5(L)	122	O	40,45		1.00	30
		G	35,50,55		.89	25
		P	0,30,60		.42	49
		N	90			
L3-4(L)	81	O	30,35	40,45	.88	34
		G	40,45	30,35,50	.71	41
		P	20,25,50	20,25	.58	46
		N	0	0	.46	50
T12-L1 (R)	101	O	55	50,55	.79	52
		G	50,60	60	.64	50
		P	30,35,40 45,65,70	30,35,40 45,65,70	.29	35
		N	20,25	20,25		
T12-L1 (L)	101	O	40,10	--	.86	*
		G	5,15,20 25,30,35 45	5,10,15 20,25,30 35,40,45	.71 .50 .20	45 11 13
		P	0,50,55 -5,-10 -15,-20 -25	0,50,55,-5 -10,-15 -20,-25		
		N	-30	-30		

[1] O-Optimal; G-Good; P-Poor; N-Not visualized

[2] Aspect of facet joint exposed by horizontal section expressed as the ratio of joint length vs. the intact joint, determined radiographically

[3] Determined from photographs of the cross-sectional facet anatomy exposed by the horizontal sectioning. Values are degrees vs. the mid-sagittal plane (Fig. 9). Underlined angles were obtained from joint fractions between .25 and .75.

*Photographic quality did not permit angular measurement.

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