THE UNIVERSITY OF MANITOBA

AN ELECTROMYOGRAPHIC AND ELECTROGONIOMETRIC ANALYSIS OF THE ROLE OF THE LATERAL ABDOMINAL MUSCULATURE AND THE ERECTOR SPINAE MUSCLE DURING THORACOLUMBAR ROTATION

by

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ABSTRACT

The techniques of electromyography and electrogoniometry were used to analyze the activity of the anterolateral abdominal muscles and the erector spinae muscles of 20 normal female subjects during axial rotation of the trunk in the sitting position.

A cadaver survey and a pilot study were carried out to determine the most appropriate location for surface electrodes on the abdominal musculature. An electrogoniometer capable of measuring thoracolumbar rotation was developed, calibrated and tested for accuracy. The raw electromyographic signals were full wave rectified and low pass filtered to give a linear envelope configuration. The myoelectric signals and the tracing from the electrogoniometer were recorded simultaneously on a moving chart recorder.

Each subject performed a defined rotation exercise five times. The average amount of integrated electrical activity generated by each muscle over the five trials was measured and expressed as a percentage of a maximum voluntary contraction. The positions of average onset and peak of muscle activity were correlated with specific points on the goniometer tracing and were ultimately expressed as percentages of the rotation cycle. The normalized values for the data were compared between muscles and between subjects.

The contralateral upper lateral oblique and the ipsilateral lower lateral oblique muscles showed the greatest amount of integrated electrical activity and were considered to be prime movers. The ipsilateral erector spinae also appeared to rotate the trunk and the activity

pattern of the lower lateral oblique indicated that one of its functions was to pull the trunk back toward midline from the position of extreme opposite rotation. The lower lateral oblique and the erector spinae of one side worked together as synergists to stabilize the upper trunk as it rotated toward the opposite side. The erector spinae muscles also were active bilaterally to prevent trunk flexion that might otherwise result from unopposed activity of the abdominal muscles during rotation. The ipsilateral upper lateral oblique muscle was consistently active during rotation and may have acted to stabilize the aponeurotic sheath of rectus abdominis and the linea alba in order to allow the contralateral upper lateral oblique to contract with reverse origin and insertion to bring about trunk rotation.

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CHAPTER I

INTRODUCTION

Few investigators have examined the activity of the abdominal or of the back musculature during axial rotation of the vertebral column. Fewer still have analyzed the simultaneous activity of the two groups of muscles in this motion; none has attempted to correlate muscle activity with measured axial rotation of the trunk.

Motion of the vertebral column is the result of the sum of movements taking place at the individual joints between adjacent vertebrae (Cailliet, 1962; Farfan, 1973; Kapandji, 1974; Panjabi, 1977; White and Panjabi, 1978). Because vertebral motion is the result of this composite movement, it has been difficult to quantify by other than radiographic or invasive techniques (Matteri et al., 1976). These techniques are, however, impractical for clinical studies and there is a need for non-invasive methods by which vertebral motion can be measured accurately.

Movement at the individual joints of the vertebral column is the result of the combined effect of the activity of the trunk musculature and gravity. It is well established that the erector spinae muscles are active to control trunk flexion from the erect position and to extend the trunk from the forward flexed position (Floyd and Silver, 1951, 1955). However, the role of the abdominal muscles in trunk movements is not clear and recent advances in the understanding and quantification of the electromyographic signal have cast doubt on the results of the previously reported electromyographic studies of the abdominal musculature.

The present study was conducted to clarify the function of the abdominal and erector spinae muscles during thoracolumbar rotation in normal individuals and consisted of three phases. In the first phase a literature review, cadaver survey and pilot study were conducted to determine the specific placement of electrodes on the abdominal muscles. In the second phase an electrogoniometer capable of measuring thoracolumbar rotation was developed, calibrated and tested for accuracy. In the third and final phase, electromyography and electrogoniometry were used simultaneously to analyze the activity of the anterolateral abdominal and erector spinae muscles during thoracolumbar rotation. The parameters of muscle activity used in the analysis were the amount of integrated electrical activity expressed as a percentage of a maximum voluntary contraction, and the onset and peak of muscle activity, each of which was correlated to a specific amount of trunk rotation and ultimately expressed as a percentage of a total rotation cycle.

The data on muscle activity in normal individuals resulting from this study can serve as a baseline for investigation into the activity of the anterolateral abdominal and erector spinae muscles in individuals with adolescent idiopathic scoliosis. Scoliosis is a rotational defect of the spine (Cailliet, 1975; Riseborough and Herndon, 1975; Keim, 1978) and, as both abdominal and back muscles are active in rotation of the thoracolumbar spine, their pattern of activity in scoliotic individuals should be investigated.

Data on muscle function in normal individuals may also be applied to a variety of clinical conditions and the methodology and techniques developed for this study might be used to examine other aspects of normal muscle function and movement.

CHAPTER II

REVIEW OF THE LITERATURE

EMBRYOLOGY

FORMATION AND DIFFERENTIATION OF SOMITES

At the end of the second week of intrauterine development the inner cell mass of the human embryo has differentiated into a bilaminar germ disc which consists of an endodermal and an ectodermal germ layer. As the third week begins, the primitive streak appears on the surface of the ectoderm and ectodermal cells start to migrate toward it. These cells invaginate the primitive streak and spread out between the ectoderm and endoderm to form the mesodermal germ layer. Initially the cells in this layer form a thin sheet on each side of the midline, however as the notochord and neural tube develop, the cells adjacent to these structures proliferate to form a longitudinal column of paraxial mesoderm. By the end of the third week this paraxial mesoderm begins to divide into paired segmental blocks or somites. The first pair of somites develops adjacent to the cranial area of the notochord and new pairs develop in an uninterrupted craniocaudal sequence until, by the end of the fifth week, there are 42 to 44 pairs of somites (Hamilton et al., 1972; Gray's Anatomy, 1973; Moore, 1977; Langman, 1981).

Each somite consists of tightly packed epithelioid cells which, by the end of the fourth week, begin to differentiate. Those cells in the ventral and medial area of the somite become polymorphous and migrate toward the notochord and developing neural tube to become arranged in a loosely woven tissue--mesenchyme. This area of cells is known as the sclerotome and will give rise to connective tissue, cartilage and bone of the axial skeleton. The dorsal wall of the somite constitutes the dermomyotome. Cells proliferate from its medial aspect to form a closely packed mass, the myotome, which will ultimately form much of the striated musculature of the body. The remaining cells in this section of the somite spread out beneath the overlying ectoderm and give rise to the dermis and subcutaneous tissues of the skin (Hamilton et al., 1972; Gray's Anatomy, 1973; Moore, 1977; Langman, 1981).

DEVELOPMENT OF THE AXIAL SKELETON

The notochord is the primitive axis of the embryo. However, because it is a flexible cellular rod, it is inadequate as a supporting structure and is retained only as a central axis about which the sclerotomes will organize to form the vertebral column (Sensenig, 1949; Gray's Anatomy, 1973; Moore, 1977).

Sclerotomal cells proliferate and migrate ventromedially to enclose the notochord, separating it from the gut and neural tube. As well, these cells proliferate and condense around the notochord in such a way that the sclerotome becomes divided into a more dense caudal portion and a less dense cranial portion, both areas being briefly separated by a sclerotomic fissure. The cells in the caudal portion continue to proliferate and spread into the intersegmental tissue until eventually the caudal portion of one somite fuses with the cranial portion of the adjacent somite to form the precartilaginous vertebral body. The mesoderm adjacent to the sclerotomic fissure condenses to form the perichordal disc which will give rise to the intervertebral disc (Hamilton et al., 1972; Gray's Anatomy, 1973; Langebartel, 1977; Langman, 1981).

The notochord degenerates and disappears from the area of the vertebral bodies but, in the area of the intervertebral disc, it enlarges and persists as the nucleus pulposus. The anulus fibrosus and intervertebral ligaments develop from portions of sclerotomic tissue that do not chondrify (Hamilton et al., 1972).

Some sclerotomic cells also migrate dorsally to enclose the neural tube and thus form the neural arch of the primitive vertebra; others migrate ventrolaterally into the body wall to form the costal processes. In the thoracic region these processes will extend ventrally in the body wall to meet the sternal plates, forming the ribs (Gray's Anatomy, 1973; Moore, 1977).

During the sixth week, centres of chondrification appear first in the primitive vertebral body, forming the cartilaginous centrum. Centres then appear in the neural arch and extend ventrally to unite with the centrum, dorsally to fuse behind the neural tube forming the laminae and spinous processes, and laterally between the myotomes to form the transverse processes (Hamilton et al., 1972).

Ossification occurs in approximately the same sequence, beginning during the embryonic period and ending at approximately the twenty-fifth year (Hamilton et al., 1972; Langebartel, 1977; Moore, 1977).

DEVELOPMENT OF THE MUSCLES OF THE TRUNK

All trunk musculature is derived from myotomes, with the exception of certain head and neck muscles that develop from branchial arch mesenchyme. Because of the fusion of adjacent sclerotomes, the centre of each myotome lies opposite an intervertebral disc. This position will allow the muscles derived from the myotome to move adjacent vertebral bodies (Gray's Anatomy, 1973; Langebartel, 1977; Moore, 1977; Langman, 1981).

During the fifth week of development there is rapid growth of the myotome such that it comes to lie adjacent to the neural tube dorsally and extends into the somatopleure ventrally. Axons from the ventral roots of the developing spinal nerves reach their respective myotomes at this time. Between weeks five and six a longitudinal constriction develops in the myotome, dividing it into a small dorsal, or epaxial, portion, and a large ventral, or hypaxial, portion. These will later be permanently separated by the developing transverse process. The spinal nerve also divides into a dorsal primary ramus to the epaxial region and a ventral primary ramus to the hypaxial region (Hamilton et al., 1972; Moore, 1977).

The epaxial portion of the myotome will form the deep muscles of the back. It splits into a medial division, from which will develop semispinalis, multifidus, rotatores and spinalis, and a lateral division from which will develop longissimus and iliocostalis (Hamilton et al., 1972).

The hypaxial portions of the thoracic and first lumbar myotomes extend ventrally into the somatopleure to form a continuous muscular sheet. In the abdominal region this sheet has a narrow ventral subdivision that will form rectus abdominis and a broad lateral subdivision that will ultimately split into three layers to form obliquus externus abdominis, obliquus internus abdominis and transversus abdominis (Hamilton et al., 1972; Moore, 1977).

DEVELOPMENT AND CLOSURE OF THE BODY WALL

During the fourth week the embryo folds in the transverse plane and the body wall thus formed consists of a thin layer of somatopleure (Moore, 1977). Myoblasts from the hypaxial division of the myotomes invade the somatopleure to cause an advancing thickening of the primitive body wall. By the late embryonic period this muscular thickening has advanced to the point that only a broad, diamond-shaped area of somatopleure remains around the attachment of the umbilical cord. Fusion of the edges of the muscular body wall first begins in the upper thoracic region of the embryo, then in the suprapubic region and from these two areas fusion extends toward the umbilicus, the line of fusion being the linea alba. By week twelve the fusion of the definitive body wall is usually complete (Hamilton et al., 1972).

NORMAL ANATOMY

VERTEBRAL COLUMN

The vertebral column forms the axis of the body and is the central pillar of the trunk (Kapandji, 1974). It is a strong yet flexible bony and ligamentous structure comprised of 33 vertebrae and intervening intervertebral discs (Last, 1978). The vertebrae show regional variation and are differentiated into seven cervical, twelve thoracic, five lumbar, five sacral and four coccygeal. By approximately age 23 the five sacral vertebrae have fused to form a single mass and therefore there are 24 presacral vertebrae (Grant's Method, 1980).

Because of its rigidity, the vertebral column gives static support to the head and trunk, attachment to the ribs, and protects the neuraxis (Cailliet, 1962; Last, 1978). Since it is also a flexible structure, it permits locomotion and purposeful movement (Cailliet, 1962; Kapandji, 1974).

Cailliet (1962) considers the vertebral column to be an aggregate of superimposed segments, each being a self-contained functional unit. The functional unit itself consists of an anterior element containing two vertebral bodies separated by an intervening intervertebral disc, and a posterior element which contains two synovial articulations. The function of the anterior element is to support, bear weight and absorb shocks while that of the posterior element is to guide and limit movement between two adjacent vertebrae (White and Hirsch, 1971).

During fetal life the vertebral column is curved into one continuous anterior concavity which is designated the primary curvature (Gray's Anatomy, 1973). As fetal development proceeds the lumbosacral angle appears. After birth, as the child raises and balances its head, the cervical part of the vertebral column becomes concave posteriorly. Kapandji (1974) states that during evolutionary development the transition from quadrupedal to bipedal stance led first to straightening and then to inversion of the lumbar curvature and that similar changes are recapitulated during ontogeny. Therefore, at birth the lumbar column is convex in its posterior aspect, but by 13 months the convexity disappears and from three years of age onward the posterior concavity is evident.

By early childhood the vertebral column has two primary curvatures, in the thoracic and sacral regions, and two secondary curvatures, in the cervical and lumbar regions (Gray's Anatomy, 1973; Grant's Method, 1980). The cervical curve is considered to extend from the first cervical to the second thoracic vertebra, the thoracic curve from the second to the twelfth thoracic vertebra, the lumbar curve from the twelfth thoracic vertebra to the lumbosacral angle and the sacral curve from the lumbosacral angle to the apex of the coccyx (Gray's Anatomy, 1973).

The spinal curvatures that result from normal development are termed "physiological" and are produced partly by the wedge-shape of the vertebral bodies, but chiefly by the intervertebral discs (Last, 1978). In the cervical and lumbar areas the discs grow unequally such that they are thicker anteriorly than they are posteriorly. In late childhood it is quite common to find that a minor lateral curvature has developed in the thoracic region of the vertebral column. This is usually due to the predominant use of one of the upper limbs, and slight compensatory curves are always present above and below such a curvature (Gray's Anatomy, 1973). Scoliosis is the term applied to an abnormal lateral curvature of the vertebral column (Riseborough and Herndon, 1975; Keim, 1978; Moe et al., 1978). It has recently been proposed that all lateral curvatures greater than 11^{o} be considered abnormal (Brooks, 1980).

VERTEBRAE

Each of the 24 presacral vertebrae has certain common elements which vary somewhat in specific regions according to function. A typical vertebra has a cylindrical body which consists of a dense bony cortex surrounding a spongy medulla. The cortex of the superior and inferior aspects is thickened at the periphery to form a distinct rim which is derived from the epiphyseal plate and fuses to the vertebral body at age 14 to 15 (Kapandji, 1974). Attached to the posterior aspect of the body is the vertebral arch, composed of a pair of cylindrical pedicles laterally and a pair of flattened laminae which fuse in midline to complete the arch posteriorly. Seven bony processes take origin from the vertebral arch. The single spinous process arises from the junction of the two laminae and is directed backwards. The two transverse processes originate at the junction of laminae and pedicles and are directed laterally, while the four articular processes arise from the same region with two directed superiorly and two inferiorly. In addition, each vertebral arch has associated with it costal elements which become independent units, the ribs, only in the thoracic region. In the other divisions of the vertebral column the costal elements remain undeveloped and fuse with the vertebrae (Gray's Anatomy, 1973).

A typical cervical vertebra has a small body which displays prominent upturned rims laterally and an overhanging lip in midline inferiorly. Its spinous process is bifid and the transverse processes are distinguished by foramina transversaria. The short articular processes form a bony column cut obliquely into segments such that the facets on the superior processes face upward and backward while those of the inferior processes face downward and forward (Gray's Anatomy, 1973; Last, 1978; Grant's Method, 1980).

The body of a typical thoracic vertebra is characterized by bilateral upper and lower demifacets for articulation with the heads of ribs. Costal facets are also found at the tips of the transverse processes. The spinous processes are long, slant backwards and down, and overlap.

The articular surfaces of the superior articular processes lie on an arc of a circle whose centre lies approximately at the centre of the vertebral body, and these face posteriorly, slightly laterally and upward. Those of the inferior articular processes face forward and slightly medially (Gray's Anatomy, 1973; Kapandji, 1974; Cunningham, 1977; Last, 1978).

Attached to the thoracic vertebrae are the expanded costal elements of the vertebral arch, the 12 pairs of costae, each costa consisting of rib bone and costal cartilage (Gray's Anatomy, 1973; Grant's Method, 1980). The head of each rib is shaped like a blunt arrowhead and articulates via synovial joints with its numerically corresponding vertebral body and that of the vertebra immediately above. The apex of the head is bound to the disc between the two vertebrae by a transversely-placed intra-articular ligament. The tubercle of the rib articulates with the transverse process of its numerically corresponding vertebra and is strongly attached to it by costotransverse ligaments. By means of the superior costotransverse ligament, the tubercle of the rib is bound to the transverse process of the vertebra next above. Anteriorly, the costae articulate directly and indirectly with the sternum. These articulations are all synovial except for those of the first rib which are synchondroses. Therefore, in the thoracic region a semi-rigid cage of bone is formed by the vertebral column posteriorly, the ribs laterally and the sternum anteriorly (Hollinshead, 1976; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

In the lumbar region a typical vertebra has a stout, massive body which is slightly higher anteriorly than posteriorly and thus is wedge-shaped. The spinous process is short, thick and quadrangular while the transverse processes are thin and long. The facets of the articular processes are oriented vertically; those of the superior processes face medially and backward while those of the inferior processes face laterally and forward (Gray's Anatomy, 1973; Last, 1978; Grant's Method, 1980).

The sacrum, composed of five fused vertebrae, is the foundation platform upon which is balanced the superincumbent spinal column and thus it bears the weight of the head, trunk and upper extremities (Cailliet, 1962; Last 1978). It is triangular in outline, concave anteriorly, convex posteriorly with a large auricular surface on either side for articulation with the hip bones. Superiorly, the base presents all the features of a typical vertebra in a slightly modified form. The upper surface articulates with the fifth lumbar vertebra and slopes downward and forward. Any tendency for the lumbar vertebra to slide forward on the sacrum is prevented in part by the large, upward projecting superior articular processes of the sacrum. These are directed medially and backward to articulate with the inferior proceses of the fifth lumbar vertebra (Gray's Anatomy, 1973; Hollinshead, 1976; Cunningham, 1977; Grant's Method, 1980).

JOINTS OF THE VERTEBRAL COLUMN

In the anterior elements of the vertebral column, the joint between two adjacent vertebral bodies is classified as a symphysis, the two vertebral plateaus being joined by a fibrocartilaginous intervertebral disc (Gray's Anatomy, 1973; Kapandji, 1974). The intervertebral disc has two component parts--the peripheral anulus fibrosus and the central nucleus pulposus. The anulus fibrosus consists of concentric lamellae of dense fibrous tissue and fibrocartilage, each lamella being oriented obliquely to the one adjacent to it. The lamellae are firmly attached to the vertebral bodies (Hollinshead, 1976; Cunningham, 1977; Ghadially, 1978; Stockwell, 1979). The nucleus pulposus is a strongly hydrophilic gelatinous pulp that is confined and held under pressure by the anulus fibrosus. It consists of approximately 88 percent water and is therefore essentially incompressible although its fluid nature allows it to change shape easily (Cailliet, 1962; Hollinshead, 1976; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

The two vertebral bodies are also linked by ligaments. The anterior longitudinal ligament extends from occiput to sacrum on the anterior aspect of the vertebral column and is thicker and narrower in the thoracic region than in the cervical or lumbar regions. It is firmly attached to the anterior surface of the intervertebral discs and to the margins of the vertebral bodies, but is rather loosely attached to the middle of the bodies. The posterior longitudinal ligament also extends the length of the vertebral column. It is located on the posterior aspect of the vertebral bodies, inside the vertebral canal. The margins of the ligament appear serrated as its fibres extend laterally to bind closely to the intervertebral disc and the edges of the vertebral bodies but those fibres in the middle of the vertebral body form a narrow band that is not attached to bone (Gray's Anatomy, 1973; Cunningham, 1977; Last, 1978). These ligaments also reinforce the anulus fibrosus of the intervertebral disc and hold the disc under tension (Kazarian, 1975; Hollinshead, 1976; Stockwell, 1979).

The posterior elements of the vertebral column are united by synovial joints between the superior and inferior articular processes of adjacent vertebrae. They have all the features of a typical synovial articulation. Ligaments join the vertebral arches, spinous and transverse processes. The laminae of adjacent vertebrae are united by the strong ligamentum flavum while the spinous processes are joined by the thin, weak interspinous ligament and by the more superficial and strong supraspinous ligament. Adjacent transverse processes are connected by the intertransverse ligaments which form rounded cords in the thoracic region but are thin and membranous in the cervical and lumbar regions (Gray's Anatomy, 1973; Kapandji, 1974; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

The articulation of the fifth lumbar vertebra with the base of the sacrum is very similar to that of the joints between the lumbar vertebrae. However, the lumbosacral intervertebral disc is very thick and is more wedge-shaped than the lumbar discs in order to accommodate the considerable angulation between the two bones. Stability is enhanced by the widely spaced sacral superior articular processes and by the strong iliolumbar ligaments (Gray's Anatomy, 1973; Cunningham, 1977; Grant's Method, 1980).

At the bilateral synovial sacroiliac joints the sacrum is firmly wedged between the iliac bones and is held in position by the strong sacroiliac, sacrospinous and sacrotuberous ligaments. The weight of the superimposed vertebral column tends to push the sacrum down and rotate its base forward. This is prevented by tension in the ligaments. The sacroiliac joint transmits the weight of the body through the hip bones to the lower extremities and prevents the direct transmission to the vertebral column of forces applied to the feet (Gray's Anatomy, 1973; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

MOVEMENTS OF THE VERTEBRAL COLUMN

Two adjacent vertebrae and their adjoining soft tissues constitute a motion segment (White and Hirsch, 1971). Each motion segment has three degrees of freedom, the movements possible being flexion and extension, abduction and adduction, and axial rotation. In addition, translation can occur in three planes resulting in anteroposterior translation, lateral translation and vertical translation (Farfan, 1973; Panjabi, 1977).

Pure movement in any of the three planes rarely, if ever, occurs; rather, vertebral motion is the result of coupling in which rotation about one axis is consistently associated with rotation about a second axis (White, 1971; Farfan, 1973; Pope et al., 1977; Frymoyer et al., 1979). Because of coupling, axial rotation is always accompanied by lateral bending and some degree of flexion (Arkin, 1950; Farfan, 1973; Weis, 1975; Koreska et al., 1977; Pope et al., 1977; Gracovetsky et al., 1981).

All movements are possible in the cervical region, however most of the movement occurs in the upper portion of the spine between the skull and the atlas and axis vertebrae. Below this area the orientation of the articular facets allows extensive flexion and free lateral flexion, but only slight rotation. Lateral flexion is enhanced by the lateral convexity of the inferior surface of the vertebral bodies and the corresponding concavity of the superior surface. Because of short spinous processes, free extension is possible. The relative thickness of the cervical intervertebral discs also contributes to freedom of movement in this region (Cailliet, 1962; Gray's Anatomy, 1973; Hollinshead, 1976; Cunningham, 1977).

Range of movement is least in the thoracic region. The orientation of the articular facets allows rotation and lateral flexion, but restricts flexion and extension (Gray's Anatomy, 1973; Cunningham, 1977; Last, 1978). There is relatively more flexion than extension in this region, flexion being limited by the ligamentum flavum and extension by the overlapping spinous processes. The ligamentum flavum also restricts axial rotation (White, 1971; Hollinshead, 1976). All movement is severely restricted by the ribs and sternum and also by the thin intervertebral discs (Gray's Anatomy, 1973; Weis, 1975; Last, 1978). Although the intersegmental movement in the thoracic spine is limited, the cumulative motion for the entire region is substantial (White and Panjabi, 1978).

The intervertebral discs in the lumbar region are large and allow free flexion and extension as well as lateral flexion. The short spinous processes present no impediment to extension. Rotation is severely limited by locking of the articular processes (Gray's Anatomy, 1973, Cunningham, 1977; Last, 1978).

The intervertebral disc between the fifth lumbar and first sacral vertebrae is the thickest in the vertebral column, allowing free flexion, extension and lateral flexion. However, the widely spaced articular processes at the lumbosacral joint and the strong iliolumbar ligament effectively limit axial rotation. Because of its shape and strong ligaments, movement at the sacroiliac joints is very slight and is limited to minimal rotation about a coronal axis (Gray's Anatomy, 1973; Cunningham, 1977; Grant's Method, 1980).

ABDOMINAL MUSCLES

Four large, flat muscles constitute the anterolateral abdominal wall--rectus abdominis, obliquus externus abdominis, obliquus internus abdominis and transversus abdominis.

Rectus abdominis is a long strap muscle extending from the crest of the pubis to the front of the xiphoid process and neighboring costal cartilages of ribs five to seven. It is separated from its fellow by the fibrous linea alba and is enclosed in a sheath formed by the aponeuroses of the other flat muscles (Gray's Anatomy, 1973; Grant's Method, 1980).

The external and internal oblique muscles extend diagonally across the abdomen, the middle fibres of one muscle running at right angles to those of the other. External oblique takes origin from the external surface of the lower eight ribs and radiates downward and medially to attach to the anterior half of the outer lip of the iliac crest. The posterior border is free. The middle and upper fibres end in a sheet-like aponeurosis that is attached to the pubic tubercle and the length of the linea alba. Muscle fibres rarely descend beyond a line from the anterior superior iliac spine to the umbilicus (Gray's Anatomy, 1973; Cunningham, 1977; Grant's Method, 1980). The internal oblique muscle arises from the lumbosacral fascia, anterior two-thirds of the iliac crest and lateral two-thirds of the inguinal ligament. Its fibres fan upward and medially, the posterior fibres are almost vertical and unite the iliac crest and the rib cage while the uppermost fibres form a short, free superomedial border. The fibres arising from the inguinal ligament arch downward and medially to attach to the medial part of the pecten pubis while the middle fibres end in an aponeurosis that splits at the lateral border of rectus abdominis, forms its sheath, and ends in the linea alba (Gray's Anatomy, 1973; Cunningham, 1977; Grant's Method, 1980).

The transversus abdominis is a thin muscle that takes origin from the lumbodorsal fascia, the anterior two-thirds of the iliac crest and the lateral third of the inguinal ligament. Its fibres run horizontally and also end in an aponeurosis which superiorly blends with the linea alba and inferiorly inserts into the pecten pubis with the tendinous fibres of internal oblique. This aponeurosis forms part of the posterior aspect of the rectus sheath (Gray's Anatomy, 1973; Last, 1978).

The abdominal muscles are innervated by the ventral rami of the lower six thoracic spinal nerves and, with the exception of rectus abdominis, by the ilioinguinal and iliohypogastric branches of the first lumbar spinal nerve. The blood supply to the lateral abdominal wall is from the musculophrenic, lumbar, iliolumbar, deep circumflex iliac and inferior epigastric vessels. The upper part of rectus abdominis is supplied by the superior epigastric vessels, the lower by the inferior epigastric (Gray's Anatomy, 1973; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

Electromyographic studies of the abdominal musculature have been summarized in the major anatomy textbooks. The abdominal musculature supports the abdominal viscera during sitting and standing, the internal oblique being continuously active during standing, presumably to protect the inguinal region. Contraction of the abdominal muscles raises the intra-abdominal pressure, converting the trunk into a rigid pillar and thus protecting the lumbar spine during weight lifting. This raising of the intra-abdominal pressure is also required during forced expiration and expulsion of abdominal contents (Gray's Anatomy, 1973; Kapandji, 1974).

In movements of the trunk, head raising and trunk flexion from the supine position are brought about by contraction of rectus abdominis assisted by the obliques while during lateral flexion from this position, all muscles are active. During extension of the trunk from the orthograde position all muscles contract to prevent loss of equilibrium. Trunk rotation is brought about by contraction of the ipsilateral internal oblique and the contralateral external oblique (Gray's Anatomy, 1973; Hollinshead, 1976; Cunningham, 1977; Last, 1978; Grant's Method, 1980).

The abdominal muscles also play a role in stabilization of the pelvis during movement in the supine position and of the trunk as a whole during gait (Floyd and Silver, 1950; Flint and Gudgell, 1965; Lipetz and Gutin, 1970; Fitzgerald, 1971; Waters and Morris, 1970).

DEEP MUSCLES OF THE BACK

On either side of the vertebral spinous processes in the thoracic and lumbar areas, the deep back muscles are arranged in two columns, superficial and deep, each consisting of a number of constituent muscle bundles (Grant's Method, 1980).

The most superficial column, the erector spinae, has an extensive origin from the spinous processes of the last two thoracic and all lumbar vertebrae, the median and lateral sacral crests and the posterior aspect of the iliac crest. In the lower lumbar area it forms one muscle mass and in the upper lumbar area it divides into three bundles which ascend to insert into vertebrae, ribs, and skull. Spinalis, the most medial bundle, extends between the upper lumbar and upper thoracic vertebral spines. The intermediate bundle, longissimus, attaches to the tips of the thoracic transverse processes while the lateral bundle, iliocostalis, inserts into the angles of the ribs (Gray's Anatomy, 1973; Hollinshead, 1976; Grant's Method, 1980).

The deeper column, the transversospinalis, is made up of three constituent muscle bundles which run obliquely upward and medially from transverse processes to vertebral spines. The most superficial muscle bundle is semispinalis, which, in the thoracic region, arises from the transverse processes of the sixth to twelfth thoracic vertebrae and is inserted into the spinous processes of the upper four thoracic and lower two cervical vertebrae. Semispinalis cervicis arises from upper thoracic vertebrae to insert into upper cervical spines while semispinalis capitis also arises from upper thoracic vertebrae and inserts into the occipital bone. The intermediate bundle, multifidus, is the largest and has an extensive origin from the dorsal aspect of the sacrum, the aponeurosis of the overlying erector spinae, medial surface of the posterior superior iliac spine and lumbar and thoracic transverse processes. It attaches, by way of fascicles, to the spinous processes of vertebrae two to three levels above. The deepest layer, rotatores, is only represented well in the thoracic region. Its fascicles run from a transverse process to the spinous process of the vertebra next above (Gray's Anatomy, 1973; Hollinshead, 1976; Last, 1978; Grant's Method, 1980).

Both deep muscle masses are innervated by dorsal rami of thoracic and lumbar spinal nerves. Blood supply is from the posterior intercostal, subcostal and lumbar vessels (Gray's Anatomy, 1973; Grant's Method, 1980).

The specific action and function of the deep back muscles is not yet clear. However, it is generally held that both groups of muscles control trunk flexion from the orthograde position. Erector spinae is considered to be the chief extensor of the spine. Rotation to the ipsilateral side would seem to be a function of erector spinae while transversospinalis, acting unilaterally, is theoretically capable of rotating the vertebral column to the contralateral side although its detailed pattern of action is unknown (Gray's Anatomy, 1973; Gardner et al, 1975). Both erector spinae and transversospinalis are active during ambulation, possibly to prevent forward flexion of the trunk (Waters and Morris, 1970).

THORACOLUMBAR ROTATION

INTRODUCTION

The point about which motion occurs is defined as the centre of rotation (Farfan, 1973). The theoretical centre of axial rotation in a vertebra is defined as the intersection of two lines passing through the centres of the surfaces of the articular facets and drawn perpendicular to the plane of the facets. The centre of rotation of a thoracic vertebra will lie within the area of or anterior to the body of the vertebra, while the centre of rotation of a lumbar vertebra will lie posterior to the body. Rotation in the thoracic spine will therefore be relatively free and will be of a twisting nature; in the lumbar spine rotation is restricted it is of a shearing nature (Gregersen and Lucas, 1967).

As described previously, movement in the spinal column is the cumulative result of a possible six excursions at each motion segment. Pure axial rotation does not occur in the thoracolumbar spine because rotation is inevitably accompanied by coupled motion (Farfan, 1973; Panjabi et al., 1976; White and Panjabi, 1978). This coupled motion was demonstrated by Lumsden and Morris (1968) who found that axial rotation in the thoracolumbar spine had a component of flexion which could not be eradicated, even by conscious effort on the part of the subject.

TECHNIQUES FOR MEASUREMENT

According to Matteri et al. (1976), direct physical and kinematic analysis of the intact human spine *in vivo* is notoriously difficult. Consequently, the majority of studies of thoracolumbar rotation have been carried out on autopsy specimens and, during postmortem investigations, motion segments or larger portions of spines have been subjected to a variety of experimental techniques.

In one approach, a vertebral body is fixed rigidly while steel rods, nails or wires are threaded through the body of the vertebra next above. Torque can then be applied to the upper vertebra and relative movement can be measured by displacement gauges (White and Hirsch, 1971; Panjabi et al., 1976; Panjabi, 1977; Pope et al., 1977).

Radiography, either in one or two planes has also been used to study rotation in postmortem specimens. Nash and Moe (1969) attempted to determine the relative effectiveness of the Cobb method versus the pedicle shadow method of measuring rotation. White (1971) inserted steel balls into the body of the upper vertebra of a motion segment, applied torque and used radiography to measure the change in position of the balls. Matteri et al. (1976) and Koreska et al. (1977) used biplanar radiography to measure axial rotation in segments of spines.

Photography was used by Cossette et al. (1971). Two wires were embedded in the free vertebral body of an embedded spinal segment, torque was applied and multiple exposure photographs were taken of the excursion of the wires at defined increments of torque. Measurements were then made from the changes of position of the wires in the photographs.

Based on the findings of postmortem experiments, mathematical models of vertebral rotation have been developed by Panjabi et al. (1976) and by Rab et al. (1977).

Few *in vivo* studies of thoracolumbar rotation have been carried out. Gregersen and Lucas (1967) inserted Steinmann pins into vertebral spinous processes from the first thoracic to the fifth lumbar vertebra of male volunteers. No subject had less than two pins and the maximum number inserted per subject was eight. The position of the pins was confirmed by roentgenogram. A sacral belt with a horizontal rod mounted at the level of the second sacral vertebra was used and, by means of a relative rotation transducer, the amount of rotation between the thoracic and lumbar pins and the mounted sacral pin was measured.

The same approach was used by Lumsden and Morris (1968) who confined their investigation to the spinal segment between the fourth lumbar vertebra and the sacrum. Steinmann pins were inserted into the spinous processes of the fourth and fifth lumbar vertebrae and also into the two posterior superior iliac spines. The latter two pins were joined by a cross bar and rotation of the fourth and fifth lumbar vertebrae relative to the cross bar was measured.

Loebl (1973) used a pendulum goniometer to measure spinal rotation. The subject was placed on his side, lying with hips and knees flexed to 90°. The subject moved his shoulders to the prone position and his head was rotated to face in the opposite direction. The goniometer was placed across the forehead and then at the first thoracic, twelfth thoracic and sacral levels to record the surface inclination from the vertical.

Pope et al. (1977) and Frymoyer et al. (1979) used biplanar radiography to study spinal rotation *in vivo*. Subjects were attached to a movable frame by way of two plaster half shell casts, one molded to the anterior superior iliac spines and greater trochanters, the other molded to the sternum and rib cage between ribs eight and eleven. This fixation allowed controlled input of movement to the subject via the frame. Radiographs were taken in the resting position and at the end of the range of movement. Pope et al. (1977) felt, however, that reflex muscle activity influenced the measurement of range while Frymoyer et al. (1979) stated that errors in the radiographic technique are in the order of two to three degrees, although behavior of spinal segments in cadavers and the human subject was similar.

Routine clinical measurement of spinal rotation usually takes two forms--radiography and direct observation. While radiography is widely used, Stoddard (1959), Nash and Moe (1969) and Koreska et al. (1977) contend that it does not give an accurate measurement of rotation and Kapandji (1974) states that axial tomography lacks the definition required for the study of vertebral rotation. Measurement of axial rotation by direct observation is imprecise. The American Academy of Orthopaedic Surgeons (1965) advocates estimating the degree of spinal rotation by comparing a patient's range of motion to that of an individual of similar age and physical build and expressing the result in degrees or percentage of full range. Kapandji (1974) recommends viewing the patient from above and measuring the angle made by a line joining the scapulae and a line in the frontal plane, running through the vertex of the skull.

Values for rotation at defined levels of the thoracolumbar spine have been established by the postmortem and *in vivo* studies and are presented in Table I.

The figures cited by White and Panjabi (1978) were compiled from a review of the literature and were derived from a weighting which considered the nature of the experiments that generated them as well as their congruence with the overall knowledge of the subject. The studies of Gregersen and Lucas (1967) and Lumsden and Morris (1978) were not included in their review.

MUSCLES CONSIDERED RESPONSIBLE FOR MOVEMENT

Electromyography has been used extensively over the past 30 years to study muscle activity during movements of the trunk, however comparatively few studies have included thoracolumbar rotation and, of those, most of the investigation has focused on muscles of the back.

Portnoy and Morin (1956) found the erector spinae muscles to be active bilaterally during trunk rotation and that the muscle of either side could predominate regardless of the direction of rotation. The ipsilateral erector spinae was found to be active by Morris et al. (1961), but they proposed that it acts more to stabilize the trunk than it does to initiate rotation, an opinion that was shared by Waters and Morris (1970). Jonsson (1970) investigated the activity of both erector spinae and transversospinalis during trunk rotation in sitting and discovered that, in the lumbar area, the contralateral multifidi and ipsilateral iliocostalis showed marked activity. In addition, longissimus was active ipsilaterally at the first lumbar (L_1) level and

TABLE 1. EXPERIMENTAL VALUES FOR THORACOLUMBAR ROTATION*

SPINAL LEVEL	STUDY 1	STUDY 2	STUDY 3	STUDY 4
T_1-T_2	87			87
T_2-T_3	70			78
T_3-T_4	74			70
T_4-T_5	83			62
T_5-T_6			67	54
T_6-T_7	57			46
T_7-T_8	48			38
T_8-T_9	34			30
T_9-T_{10}	44			23
T_{10}-T_{11}				19
T_{11}-T_{12}	29			17
T_{12}-L_1	15			15
L_1-L_2	11			13
L_2-L_3			25	11
L_3-L_4				9
L_4-L_5		10.7		7
L_5-S_1	3.	7.0		5

STUDY 1 = Gregersen and Lucas, 1967. All values are in relation to the fixed pelvis, sitting position.

STUDY 2 = Lumsden and Morris, 1968. All values are in relation to the fixed pelvis, straddling position.

STUDY 3 = Loebl, 1973.

STUDY 4 = White and Panjabi, 1978. All values are in relation to the fixed pelvis and are derived from the literature.

*All figures are for total rotation, i.e., left plus right.

contralaterally at the fourth and fifth lumbar (L_4, L_5) levels. Donisch and Basmajian (1972) studied the deep back muscles and their findings indicated that the muscles in the thoracic region were always slightly to moderately active during trunk rotation in sitting while the activity of the lumbar muscles was less than that of the thoracic muscles. When the specific activity of the thoracic muscles was investigated, they found them to be active contralaterally in 44% of the subjects and ipsilaterally in 20% of the subjects while activity could not be related to direction of rotation in 36% of the subjects. Similar scrutiny of lumbar muscles revealed them to be active contralaterally in 56% of the subjects, and ipsilaterally in 12% of the subjects while in 28% of the subjects activity could not be related to direction of rotation. Furthermore, the activity was even more inconsistent when the subjects returned to the starting position from the rotated position. A further study of back muscles in the thoracic and lumbar areas was conducted by Afanasiev (1980) and his findings showed that only in the thoracic area was there a difference in activity between the right and left muscle groups with the ipsilateral muscles predominating in trunk rotation.

Few studies have been conducted on the role of the abdominal muscles during trunk rotation. Walters and Partridge (1957) and Partridge and Walters (1959) found that rotation of the trunk in the sitting position was executed almost entirely by internal oblique with little participation from external oblique. Flint (1965b) found that during the combination of trunk flexion and rotation from the supine position, external oblique was moderately active. Carman et al. (1971)

in their study of external and internal oblique muscles, found that the contralateral external oblique was the most active muscle during trunk rotation. Farfan (1975) states that the oblique abdominal muscles are chiefly responsible for producing a torque on the lumbar spine. Halpern and Bleck (1979) had subjects flex and rotate the trunk from the supine position. While the side to which the rotation occurred was not indicated, they found that the right oblique muscles were active 21% of the time and the left oblique muscles were active 19% of the time.

Carlsöö (1961) studied the deep back and abdominal muscles simultaneously. He proposed that the deep back muscles initiated rotation with the lateral abdominal muscles being mobilized secondarily. Rab et al. (1977) also considered both groups of muscles and stated that, during trunk rotation, the contralateral external oblique and quadratus lumborum plus the ipsilateral internal oblique and erector spinae were active.

Overall, the results of the studies of erector spinae activity during thoracolumbar rotation are very variable with no clear function for the muscle evident. Findings from investigations of abdominal muscle activity indicate that the contralateral external oblique and the ipsilateral internal oblique are active during thoracolumbar rotation, however the opinion about the relative roles of these muscles is inconclusive.

TECHNIQUES FOR MOTION ANALYSIS

INTRODUCTION

The systematic study of muscle action in the living person was begun in the late 19th century by Duchenne, who stimulated muscles with electricity and noted the action produced on the joint or joints that the muscles crossed (Basmajian, 1978). In the early 20th century, Beevor (1903) used visual inspection and palpation as the means of determining the action of muscles.

Today, many approaches are taken to study muscle action *in vivo*. In the kinematic approach, the time and space characteristics of motion resulting from muscle action are investigated (Kelley, 1971; Le Veau, 1977). These parameters can be measured using a variety of techniques such as motion picture analysis, electromyography and electrogoniometry, all of which can be used alone or in combination (Gowitzke and Milner, 1980).

Because electromyography and electrogoniometry were used in this investigation, further description of these techniques will be given.

ELECTROMYOGRAPHY

The Motor Unit Action Potential

The structural unit of a muscle is the individual muscle cell or fibre, while the functional unit of a muscle is the motor unit. The motor unit consists of an alpha motor neuron located in the ventral horn of the spinal cord, plus all the muscle fibres that it innervates.

Muscle fibres from adjacent motor units are not arranged in discrete bundles, but rather interdigitate. Motor units vary in size depending on the function of a particular muscle. Small muscles responsible for fine movements have few muscle fibres per axon and are said to have a low innervation ratio while muscles responsible for gross movement have many muscle fibres per axon and are said to have a high innervation ratio (Guyton, 1976; Basmajian, 1978).

Excitation of the alpha motor neuron leads to depolarization of the sarcolemma of each of the muscle fibres in the motor unit, resulting in multiple individual muscle action potentials and muscle fibre twitches. During the twitch a minute electrical potential is generated that lasts one to two milliseconds and dissipates into the surrounding tissue. All the muscle fibres in the motor unit do not contract simultaneously and therefore the electrical potential generated by the contraction of the motor unit has a median duration of nine milliseconds and an amplitude of approximately 500 microvolts. The frequency of firing of motor units depends upon the force of contraction but the normal upper limit of activation is considered by Basmajian (1978) to be 50 Hertz (Hz) while Hayes et al. (undated) state that some motor units may discharge at rates as high as 100 Hz.

The Myoelectric Signal

Electrodes placed within a muscle or on the surface of the body over a muscle will record the sum of the electrical activity produced by the contraction of all the motor units in the immediate vicinity of the electrodes at a specific point in time. The myoelectric (EMG) interference pattern consists of positive and negative spikes of varying amplitude representing the superimposed activity of the motor units in the area. Because of dissipation into the tissues, the action potentials from motor units far away from the electrodes will be smaller than those from motor units in close proximity to the electrodes.

As the level of muscle contraction increases, more and more motor units are recruited and these fire more frequently. This results in an increasingly complex myoelectric signal pattern. While a pure linear relationship between muscle tension and the various parameters of the myoelectric signal has not been found, there is consensus that a functional relationship does exist (Hayes et al., undated; Basmajian et al., 1975; Ortengren and Andersson, 1977; Magora and Gonen, 1978).

The electromyographic (EMG) spectrum ranges from 5 to 2000 Hz with most of the signal concentrated in the band between 20 and 200 Hz. Sources other than contracting muscle generate frequencies within the EMG spectrum and therefore are capable of distorting the EMG signal. The most common distortions or artifacts arise from the heart muscle (EKG signal) which can have frequencies up to 100 Hz, movement of electrodes or cables generating frequencies in the 0 to 10 Hz range and 60 Hz interference from power mains or nearly electrical equipment (Hayes et al., undated; O'Connell and Gardner, 1963; Grossman and Weiner, 1966; McLeod, 1973).

Acquisition of the EMG Signal

Because of its very small amplitude, the electrical signal from contracting muscle must be received, amplified, processed and recorded before it can be studied and quantified.

The EMG signal is received by electrodes. Two basic types are used in kinesiological studies--fine wire indwelling and surface electrodes. While the use of one type over the other is controversial, the choice depends upon the experimental problem and an understanding of the advantages and limitations of each type.

At the present time indwelling electrodes most frequently consist of fine wires inserted into the muscle by a fine bore hypodermic needle. According to Basmajian (1978), they are easily implanted and withdrawn, are relatively painless, give clear signals and are broad in their pick-up. However, Ortengren and Andersson (1977) state that indwelling electrodes have a limited pick-up area and therefore do not always give a representation of activity in the whole muscle. Indwelling electrodes are subject to dislocation, kinking and displacement during muscle contraction (Jonsson, 1968; Jonsson and Komi, 1973; Ortengren and Andersson, 1977). In addition, their reliability in day to day application is poor and therefore they are considered inappropriate for long term studies (Komi and Buskirk, 1970). However, these are the electrodes of choice when precision of measurement is required or when studying deep or closely placed muscles (O'Connell and Gardner, 1963; Basmajian, 1973; Letts and Quanbury, 1978; Perry et al., 1981).

Surface electrodes usually consist of recessed discs of a metal and one of its salts, most commonly silver-silver chloride. Their chief advantages are that they are easy to obtain, easy to apply and cause no discomfort to the subject as they are attached by double sided adhesive cuffs (Ortengren and Andersson, 1977; Basmajian, 1978). Because they pick up electrical activity from a relatively large volume of underlying muscle, the signal they transmit is considered representative of the whole muscle (Close et al., 1960; Jonsson, 1968; Ortengren and Andersson, 1977). Komi and Buskirk (1970) found that their reliability in day to day application was good. The chief disadvantage of surface electrodes is that their use should be restricted to superficial muscles because the signals from these muscles will mask the attenuated signals from the deeper muscles. Also, surface electrodes may pick up the signals from muscles adjacent to the one being studied. If these muscles are antagonists, the signal would be contaminated (Ortengren and Andersson, 1977; Perry et al., 1981). Consequently, surface electrodes should be used only when simultaneous activity or interplay of activity are being studied in fairly large, superficial groups of muscles, where global pick-up is desired or when the overlap in muscle function is inconsequential (Basmajian, 1978; Perry et al., 1981).

Placement of surface electrodes must be done with care. Zuniga et al. (1970) found that the average amplitude of myoelectric potentials recorded by surface electrodes was greatest at the middle of the muscle belly and decreased when the position of the electrodes was moved toward the ends or sides of the muscle. In addition, they found that surface electrodes can pick up myoelectric signals from quite distant muscles and Perry et al. (1981) state that localization of the myoelectric signal decreases as spacing between the electrodes increases leading to contamination of the signal by other muscles. Therefore, to improve localization of pick up, surface electrodes should be placed close together over the belly of the muscle in line with the muscle fibres (Waterland and Shambes, 1969; Zuniga et al., 1970; Basmajian, 1978; Perry et al., 1981).

The myoelectric signal can be affected by the contact between the surface electrodes and the skin and also by the resistance offered by the skin itself. Contact can be improved by interposing a saline paste between the skin and the active surface of the electrode, and by securing the electrodes with adhesive collars and tape. Skin resistance can be reduced to practical levels by rubbing the skin with alcohol to remove protective oils and the dead layer of cells (Basmajian, 1978).

Because the amplitude of the myoelectric signal is low and ranges from 100 microvolts (μV) to 5 millivolts (mV), it must be amplified and the amplifier used must be capable of augmenting the signal without distorting either amplitude or frequency. For amplitude, the amplifier should have a range of gains (ratio of output voltage to input voltage) from 100 to 10,000 (Hayes et al., undated). Also, to avoid attenuation of the signal due to voltage drop across resistances, Winter et al. (1979) advocate that the input impedance of the amplifier be at least 100 times greater than the electrode/skin impedance with 1 megohm usually adequate for surface electrodes. The amplifier must be capable of responding without attenuation to frequences in the range of 10 to 1000 Hz for surface EMG and 20 to 2000 Hz for indwelling EMG. As most of the myoelectric signal is concentrated in the band between 20 and 200 Hz filters may be used to remove some of the low or high frequencies and thus eliminate amplifier noise, tissue noise and movement artifact (Hayes et al., undated; Basmajian, 1978).

External interference from machinery and power lines may distort the myoelectric signal and therefore a differential amplifier is used which subtracts the signal from one electrode from that of the other electrode. If a signal that is common to both electrodes (common mode input) is applied, the output will be zero and the interference will be eliminated. However, perfect subtraction does not occur and the ability of the amplifier to suppress common mode signals is the common mode rejection ratio (CMRR), usually expressed in decibels (dB) (Hayes et al., undated; McLeod, 1973). Winter et al. (1979) recommend a CMRR of 80 dB or higher, that is, at 80 dB all but one ten thousandth of the common mode signal is rejected. Movement artifact due to the motion of electrodes and/or cables may be reduced by using small pre-amplifiers close to the electrode site (Milner et al., 1971; McLeod, 1973).

The amplified raw EMG signal is difficult to quantify and cannot be faithfully reproduced on pen recorders as the inertia of the pens prevents them from responding to the very rapid changes in the signal beyond 60 Hz. Therefore the signal is usually processed with three common forms used: full wave rectification, full wave rectification plus low pass filtering (linear envelope detector) and integration (Hayes et al., undated).

In full wave rectification the signal has positive polarity, does not cross the baseline and fluctuates with the strength of the muscle contraction. The amplitude of the spikes can be measured or the change in muscle activity over time can be evaluated, but the chief use of the full wave rectified signal is as an input to other processing techniques (Hayes et al., undated; Winter et al., 1980).

The full wave rectified signal can be low pass filtered to remove all the rapidly changing components of the wave form, leaving an indication of the intensity of the activity at a specified instant in time or a moving average. The wave form thus generated is called a linear envelope and it is far easier to quantify than the raw or full wave rectified signal (Hayes et al., undated; Winter et al., 1980).

Integration processing techniques use the signal parameters of amplitude and time. Therefore measurements are expressed in millivolt-seconds (MV.s). Three methods of integration are in common use: integration starts at a preset time and continues during the total time of muscle contraction, the integrated signal can be reset to zero at regular intervals of time (usually 40 to 200 ms), or the integrated signal can be reset to zero at a specified voltage level (Hayes et al., undated; Winter et al., 1980).

The selection of the proper processing technique depends upon the problem being investigated. The raw EMG signal may be most appropriate when small magnitudes of muscle activity are being studied (Kelley, 1971). Because there is a time lag between the raw and filtered signal in the linear envelope, this technique should be used with caution if precise measurement of the timing of the signal is required. If measurement of the level of muscle activity is required, integration may be a useful processing technique (Hayes et al., undated; Winter et al., 1980).

The EMG signal must be recorded in order for it to be studied and measured. Again, there is a wide variety of recording techniques and selection of the most appropriate one depends upon the nature of the experimental problem. The raw EMG signal contains high frequency components, therefore it is best recorded on a cathode ray oscilloscope and later photographed, by a light beam recorder with a high frequency response or by magnetic tape (Kelley, 1971; McLeod, 1973). For processed signals, pen writers are inexpensive and easily serviced, their chief limitation being a relatively low frequency response (Grossman and Weiner, 1966; McLeod, 1973; Basmajian, 1978). Perhaps the most accurate method of recording is on magnetic tape. Data thus recorded can be stored in raw or processed form and later replayed to processor or directly to pen writer, light beam recorder or to computer for automatic data processing (Bamsjian, 1978; Gowitzke and Milner, 1980).

Evaluation of the EMG Signal

According to Basmajian (1978), the evaluation of recordings is the most abused part of electromyography. Indeed, to date there is no universally approved method of analysis and scoring of the EMG signal and, as with all other aspects of EMG, the evaluation method depends upon the experimental problem. Analysis can be subjective or objective although both methods should be used for most EMG records (Kelley, 1971).

Subjective analysis involves careful visual inspection of the EMG record and uses a system of classification that assigns symbols and descriptors to represent different levels of magnitude of electrical activity. The investigator who uses this approach should be well trained and have a great deal of experience (Kelley, 1971). Hirose et al. (1974) and Ortengren and Andersson (1977) state that, with this method, it is difficult to distinguish between levels of activity or to compare levels of high activity while Magora and Gonen (1978) point out that visual analysis of the EMG record is time consuming and often inaccurate.

Objective analysis involves a variety of techniques: measurement of temporal or positional events, amplitude, frequency or electrical activity over a defined period of time (Willison, 1963; Kelley, 1971; Hirose et al., 1974; Ortengren and Andersson, 1977). Events such as onset peak and cessation of muscle activity can be quantified by comparing them to an external standard for example, an electrogoniometer tracing, cinefilm, footswitch tracing or event markers on a pen recorder (O'Connell and Gardner, 1963; Peat, 1976; Tata, 1980; Quanbury, 1981). Measurements of amplitude, frequency or total electrical activity cannot be compared directly between muscles of the same subject or between subjects because of the uncontrolled variation in motor unit sampling, but rather the activity levels of a muscle must only be compared to a standard for that muscle (Grossman and Weiner, 1966; Basmajian, 1978; Perry et al., 1981). To do this, a maximum voluntary contraction is recorded for each muscle under investigation to determine the maximum amount of activity that the muscle is capable of producing. This then serves as a standard against which all subsequent activity of the muscle is compared and is expressed as a ratio of the maximum voluntary contraction. This EMG ratio allows comparison of the activity between muscles in the same or different subjects (Basmajian et al., 1975; Basmajian, 1978; Letts and Quanbury, 1978; Perry et al., 1981).

As with subjective analysis, manual measurement of the various parameters of the EMG signal is time consuming and may be inaccurate, therefore researchers are now using various forms of computer analysis with increasing frequency (Basmajian et al., 1975).

ELECTROGONIOMETRY

A goniometer is a device used to measure the angle produced between two bony segments when motion occurs in a particular plane. For clinical purposes a simple device is used to measure joint movement; it consists of a protractor to which has been attached two arms, one stationary and one movable. The stationary arm extends from the axis of the protractor while the movable arm is riveted to the axis of the protractor and thus is free to move through 360°. The axis of the goniometer is placed over the axis of joint motion and a reading of the joint angle can be taken (Esch and Lepley, 1971; Trombly and Scott, 1977).

In an electrogoniometer, a potentiometer is substituted for the protractor. There is a linear relationship between the shaft angle of the potentiometer and its electrical resistance, therefore, if the device is mounted such that joint movement causes movement of the shaft of the potentiometer, a voltage applied across the potentiometer will be varied. Changes in joint angle will result in changes in the output voltage of the circuit containing the potentiometer (Liberson, 1965; Brown et al., 1979). The output voltage can be fed to an oscilloscope, voltmeter or pen recorder for quantification (Tipton and Karpovich, 1965; Morris and Brown, 1976; Gowitzke and Milner, 1980; Quanbury, 1981).

CHAPTER III

MATERIALS AND METHODS

INTRODUCTION

The purpose of this study was two-fold: first, to develop a non-invasive technique to measure objectively thoracolumbar rotation of the spine; second, to investigate, using surface electrodes, the electrical activity of the anterolateral abdominal and erector spinae muscles during thoracolumbar rotation in order to establish normal baseline data for a subsequent study of females with idiopathic scoliosis.

The equipment and facilities of the Locomotion Laboratory, Rehabilitation Centre for Children, Winnipeg, Manitoba were used for this investigation.

ELECTROMYOGRAPHY

CHOICE OF ELECTRODES

Fifteen studies on abdominal electromyography were reviewed; only the most relevant will be cited. Eleven investigations used surface electrodes and four used indwelling electrodes; not all investigators gave reasons for their choice of one type over another. Surface electrodes were chosen by Campbell and Green (1953) and Ono (1958) because they are painless to apply, while Klausen (1965) chose this type because of ease of application. Floyd and Silver (1950) used surface electrodes to study the oblique abdominal muscles and elected not to investigate transversus abdominis as this would have meant using indwelling electrodes with the attendant risk of penetrating the peritoneum. The fact that surface electrodes sample a large volume of muscle was cited as the reason for choice by Campbell and Green (1953), Ono (1958), Carlsöö (1961) and Hatami (1961a).

Twenty-two EMG studies of erector spinae were reviewed; again, only the most relevant are cited. Fourteen investigations were carried out with surface electrodes, six with indwelling electrodes and two with both surface and indwelling electrodes. Again, reason for choice was not always given. Ease of application, lack of discomfort for the subject and sampling from a large volume of muscle were reasons for selection of surface electrodes in the studies of Klausen (1965) and Andersson et al. (1977). Floyd and Silver (1951) and Golding (1952) used surface electrodes as, in their opinion, these gave findings similar to those from indwelling electrodes. Pauly (1966) and Pauly and Steele (1966) chose indwelling electrodes because they allow study of deep as well as superficial muscles and also allow study of individual muscles without interference from adjacent muscles. Letts and Quanbury (1978) used surface and also indwelling electrodes because of the possibility of signal contamination by the activity of multiple overlying paraspinal muscles.

In the present study, it was decided that surface rather than indwelling electrodes would be used for two reasons. First, it would be very difficult to judge the depth at which a particular lateral abdominal muscle could be isolated during insertion of indwelling electrodes and second, insertion of indwelling electrodes might result in penetration of the peritoneum with the risk of intra-abdominal infection plus the risk of pain because of the rich sensory innervation of the parietal peritoneum. Indeed, Koepke et al. (1955), in their study of the thin, three-layered intercostal muscles using indwelling electrodes, penetrated the pleura in two of 33 subjects with a resultant minimum pneumothorax.

POSITION OF ELECTRODES

To establish precisely where surface electrodes should be placed on abdominal and erector spinae muscles, a review was carried out of major anatomy textbooks and of relevant literature, followed by a study of anatomical specimens. The findings are outlined in the following paragraphs.

Abdominal Muscles

Initially it was thought that the external and internal abdominal oblique muscles could be isolated for electrode placement. According to major anatomy texts, muscle fibres of external oblique rarely descend beyond a line joining the anterior superior iliac spine to the umbilicus, and the fibres of internal oblique that originate from the inguinal ligament arch downward and medially to attach to the pecten pubis (Gray's Anatomy, 1973; Cunningham, 1977; Grant's Method, 1980). Thus the fibres of internal oblique are covered only by the aponeurosis of external oblique in a triangular area bounded by: the lateral border of rectus abdominis, a line from the anterior superior iliac spine to the umbilicus, and a line from the anterior superior iliac spine to the public tubercle. It was proposed that electrodes to sample internal oblique activity be placed within this triangle, while those for external oblique would be placed in the upper lateral area of the abdominal wall, below the costal margin.

A review of the literature on abdominal muscle EMG studies showed lack of consistency in the placement of surface and indwelling electrodes among those investigators, such as Floyd and Silver (1950) and Godfrey et al. (1977), who did report details of placement (some investigators did not define electrode location). Because of this inconsistency, electrodes may not always have been located over or inside the muscle selected for investigation and this might account for conflicting results.

Some investigators have considered external oblique and internal oblique muscles separately, while others have considered the lateral abdominal muscles as a group. Electrodes for external oblique have been positioned above the anterior half of the iliac crest (Floyd and Silver, 1950; Ono, 1958; Klausen, 1965), on the anterior axillary line midway between the iliac crest and costal margin (Campbell, 1952; Campbell and Green, 1953), just below the angle of the costal margin at the end of the ninth rib (Flint, 1965a; Flint and Gudgell, 1965; Godfrey et al., 1977), or along the costal margin between axillary and midclavicular lines (Waters and Morris, 1970). For internal oblique, Floyd and Silver (1950) and Ono (1958) placed electrodes over the triangular area bounded by the lateral edge of rectus abdominis, the inguinal ligament and a line joining the anterior superior iliac spine to the umbilicus, while Waters and Morris (1970) placed electrodes halfway between the pubis and the anterior superior iliac spine about three centimeters (cm) above and perpendicular to the inginal ligament.

Diagrams were used by Walters and Partridge (1957), Partridge and Walters (1959) and by Hatami (1961a, 1961b) to show electrode placement; positioning was similar to that cited in the studies above.

Although the possibility of interference from adjacent muscles was raised by Floyd and Silver (1950), Klausen (1965) and Battye and Joseph (1966), only Waters and Morris (1970) state that a cadaver study was conducted to confirm electrode placement.

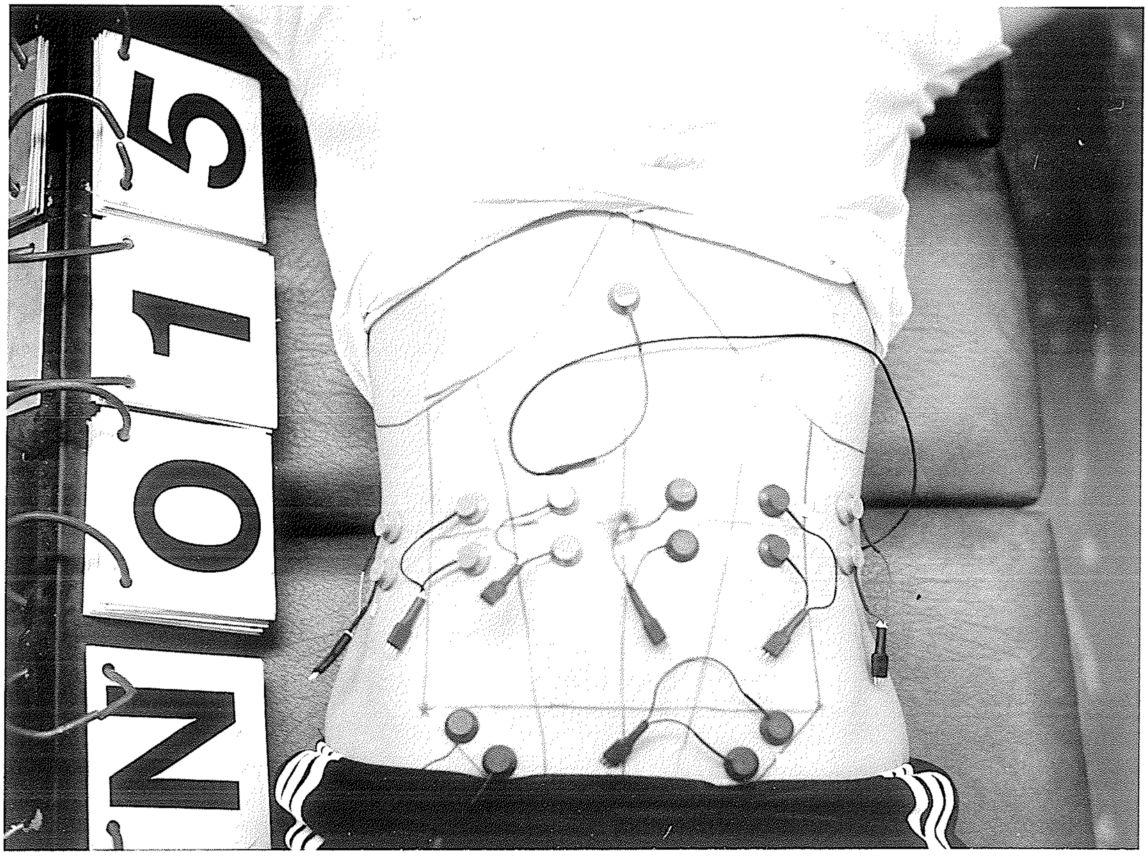
The lateral abdominal muscles were studied as a group by Carlsöö (1961) and by Morris et al. (1961). In the former study, electrodes were placed in the upper central and lower lateral parts of the abdomen, while in the latter study, electrodes were situated in the upper and lower quadrants of the abdomen.

To confirm textbook accounts of the muscles and to determine if internal oblique could be isolated in the lower lateral abdominal area, 10 cadavers were examined for the present study. It was found that in a triangle bounded by the lateral border of rectus abdominis, the inguinal ligament and a line joining the anterior superior iliac spine with the umbilicus, the fibres of internal oblique were covered only by external oblique aponeurosis. However, the size of the triangle varied greatly. In two specimens, fibres from external oblique were found inferior to the level of the anterior superior iliac spine, contrary to statements in major anatomy texts. Also, the lateral border of rectus abdominis was found, in some specimens, to extend laterally so as to encroach upon the triangle of interest. Because of this variation in size of the triangle, electrodes placed here to monitor internal oblique activity might instead pick up interference from external oblique and/or rectus abdominis.

Several preliminary runs were carried out with electrodes placed over external oblique, over internal oblique within the triangle mentioned above, and over rectus abdominis. When subjects performed a variety of trunk movements it was noted that the ipsilateral muscles became active at similar times. While it might be interpreted that the three ipsilateral muscles did, in fact, become active simultaneously, it was also possible that the electrodes were picking up interference signals from adjacent muscles. Because of this and of the results of the cadaver survey, a pilot study was conducted to attempt to locate interference-free areas for electrode placement for external oblique and internal oblique muscles.

Ten female subjects were chosen from a convenience sample (Currier, 1979). Their ages ranged from 11.9 to 38.8 years with a mean age of 23.8 years. All subjects were in good health, none had had abdominal surgery. Surface electrodes were placed over the abdominal muscles as follows (Fig. 1): for external oblique--one pair placed halfway along a vertical line joining the anterior superior iliac spine to the costal margin and another pair placed halfway between this line and the lateral border of rectus abdominis at the same level as the first pair, that is, over the lateral and medial fibres of the muscle; for internal oblique--within a triangle bounded by the lateral border of rectus abdominis, a line joining the two anterior superior iliac spines and a line joining the anterior superior iliac spine to the pubic tubercle; for rectus abdominis--halfway between the linea alba and the lateral border of the muscle at the level of the external

FIGURE 1. Pilot study: placement of electrodes on abdominal musculature.



oblique electrodes. The electrodes for external oblique were placed below the costal margin to avoid interference from serratus anterior and intercostal muscles.

In order to isolate the actions of rectus abdominis, external oblique and internal oblique muscles, the movements outlined in the manual muscle testing procedures of Daniels and Worthingham (1980) were used. It is their opinion that rectus abdominis is the prime mover in trunk flexion from supine and is not active during trunk rotation in sitting; external and internal obliques are prime movers in trunk rotation in sitting and are accessory muscles during trunk flexion from supine.

Two movements were chosen for analysis: trunk flexion from supine and trunk rotation to the right in sitting.

Because the trunk constitutes a long lever arm, considerable resistance must be overcome by the trunk flexors during trunk flexion from supine. Therefore, it would be likely that both prime movers and accessory muscles would work to overcome the large resistance (Gowitzke and Milner, 1980) and that they would become active at approximately the same time. Consequently, it was predicted that there would be no significant difference in the time of onset of activity of rectus abdominis, external oblique and internal oblique muscles during trunk flexion from supine. In the sitting position the lever arm is very short and thus relatively little resistance must be overcome during trunk rotation. As a result, only the prime movers for rotation, the contralateral external oblique and ipsilateral internal oblique, would likely be active (Gowitzke and Milner, 1980). Therefore, it was predicted that, during trunk rotation in the sitting position, there would be a significant difference between the onset time of the prime movers and of any other abdominal muscles that might be active. If the electrodes on the right side of the trunk were placed such that the signals received from the right rectus abdominis, external oblique and internal oblique were separate and distinct, no difference in onset times could be expected during trunk flexion from supine, but a significant difference in onset times might be expected between all muscles during trunk rotation in sitting.

During the experiment the beginning and end of each movement were indicated by a marker on the moving chart, and the time interval between the beginning marker and the onset of muscle activity was calculated for each muscle and expressed as a percentage of the total time between beginning and end marks on the chart. The data for the onset times of the muscles on the right side of the trunk were compared using a two-tailed paired t test with alpha set at .05. Summaries of the statistical tests are presented in Tables 2 and 3 . All muscles were active during the two movements. It can be seen that during trunk flexion from supine, the mean difference in onset times was significantly different from zero in only one instance--that of the right rectus abdominis when compared to the right lateral oblique; in all other instances the muscles became active at the same time. These findings support the prediction that all muscles would become active at approximately the same time. During trunk rotation in sitting, the mean difference in onset times was significantly different from zero in all instances except one--that of the right medial oblique compared to the right internal oblique. These

TABLE 2. COMPARISON OF THE DIFFERENCE IN MEAN ONSET TIMES BETWEEN RIGHT ABDOMINAL MUSCLES DURING TRUNK FLEXION FROM SUPINE.

MUSCLE vs	MUSCLE	MEAN DIFFERENCE IN ONSET TIME	STANDARD ERROR OF MEAN	P
RRA	RLO	-4	1	.05
RRA	RMO	-1	1	NS*
RRA	RIO	-5	2	NS
RLO	RMO	4	2	NS
RLI	RIO	-1	3	NS
RMO	RIO	-4	2	NS

*Not Significant. The difference in means does not differ from zero.

The mean differences were due to chance variations.

$$SEM = \frac{S}{\sqrt{N}}$$

KEY: RRA = Right Rectus Abdominis.

RLO = Right Lateral Oblique.

RMO = Right Medial Oblique.

RIO = Right Inferior Oblique.

TABLE 3. COMPARISON OF THE DIFFERENCE IN MEAN ONSET TIMES BETWEEN RIGHT ABDOMINAL MUSCLES DURING TRUNK ROTATION IN SITTING.

MUSCLE vs	MUSCLE	MEAN DIFFERENCE IN ONSET TIME	STANDARD ERROR OF MEAN	P
RRA	RLO	9	3	.01
RRA	RMO	12	3	.01
RRA	RIO	13	3	.01
RLO	RMO	3	1	.05
RLO	RIO	4	1	.01
RMO	RIO	1	1	NS

KEY: RRA = Right Rectus Abdominis.

RLO = Right Lateral Oblique.

RMO = Right Medial Oblique.

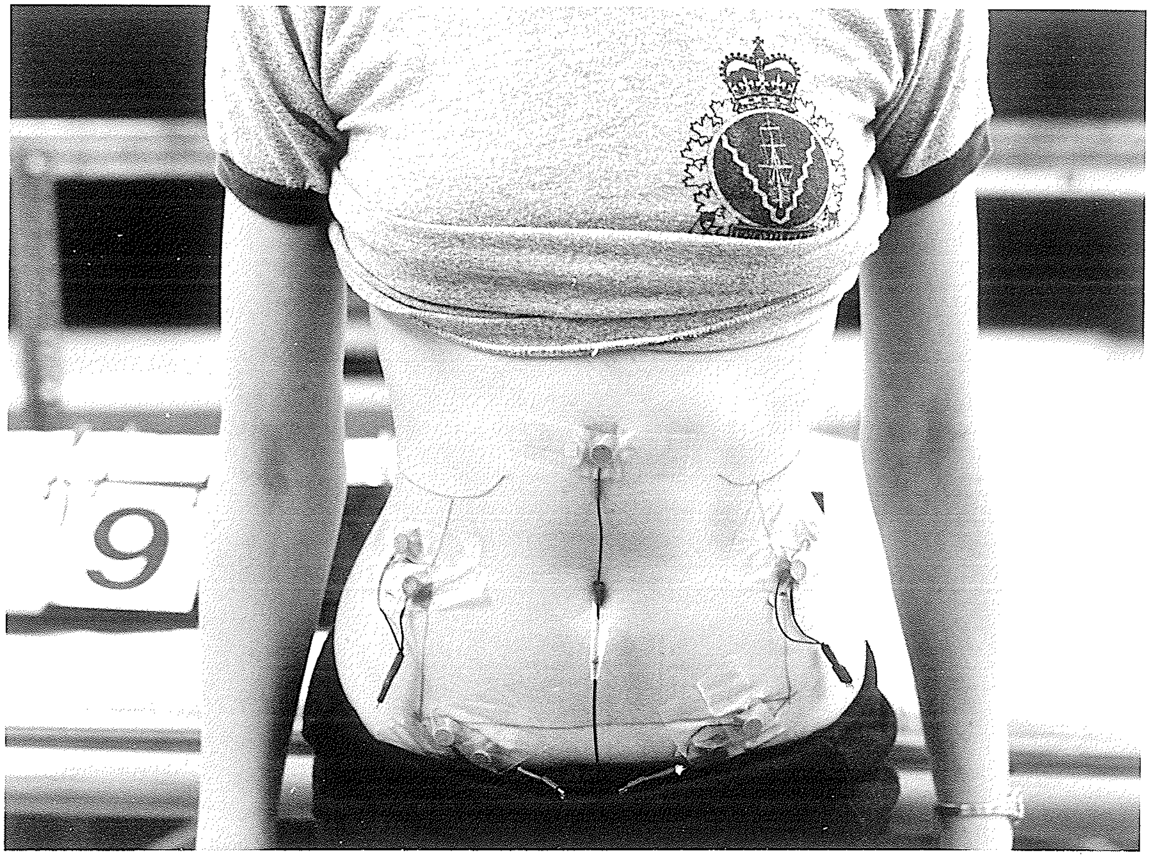
RIO = Right Inferior Oblique.

findings suggest that there is no interference from rectus abdominis in the signals received from the oblique muscles. However, the similar onset times of the right medial external oblique and the right internal oblique indicate two possibilities: the two muscles may have analogous functions or the electrodes placed over the inferior oblique may have picked up and transmitted the signal from the medial external oblique. When these findings are coupled with the results of the cadaver survey, the latter possibility appeared to be the more likely explanation of the apparent similarity in muscle activity.

It was concluded that the electrode placement was such that there was no cross-talk from rectus abdominis to the electrodes over the oblique muscles, however, it was impossible to state with certainty that separate output from external oblique and internal oblique could be monitored. Therefore, it was decided to consider the muscles of the anterolateral abdominal wall as a group and to investigate their activity in the upper and lower quadrants of the abdomen.

In the final placement of electrodes, bony landmarks were used to standardize electrode location in all subjects: the anterior superior iliac spines, pubic tubercles and costal margins. Guidelines were drawn between the landmarks with water-soluble ink as follows (Fig. 2): from anterior superior iliac spine to ipsilateral pubic tubercle, from one anterior superior iliac spine to the other, from each anterior superior iliac spine vertically to the costal margin and a lateral extension was drawn from a point halfway along and perpendicular to this last line. The upper lateral electrodes were placed in line with

FIGURE 2. Placement of electrodes on abdominal musculature.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the muscle fibres of external oblique while the lower lateral electrodes were placed in line with those muscle fibres of internal oblique that arch downward and medially from the inguinal ligament toward the pecten pubis. The reference electrode was located on the upper abdomen, immediately inferior to the xiphoid process.

Erector Spinae Muscle

As with the abdominal muscles, specific electrode placement in EMG studies of erector spinae muscle, when given, has varied greatly. Researchers have placed electrodes in lumbar areas, thoracic areas and in both lumbar and thoracic areas.

Morris et al. (1962) and Waters and Morris (1970) sampled erector spinae activity in the lower thoracic region by inserting indwelling electrodes into the muscle over the posterior aspect of the lower ribs medial to their angle. Other investigators have applied electrodes to erector spinae in the thoracic area at a variety of levels from the ninth to the twelfth thoracic spines (Floyd and Silver, 1951; Joseph and McColl, 1961; De Vries, 1965; Pauly, 1966; Pauly and Steele, 1966; Letts and Quanbury, 1978).

In the lumbar area researchers have sampled muscle activity simultaneously at various levels (Floyd and Silver, 1951: Golding, 1952; Portnoy and Morin, 1956; Joseph and McColl, 1961; Andersson et al., 1977), while others have confined their investigations to one specific level. For example, De Vries (1965) placed electrodes at the first lumbar level, Chapman and Troup (1969) at the second lumbar level, Morris et al. (1961) and Afanasiev (1980) placed electrodes between the second and third vertebral levels, Floyd and Silver (1955), Donisch and Basmajian (1972) and Blackburn and Portney (1981) located electrodes at the third lumbar level, Klausen (1965) and Battye and Joseph (1966) placed electrodes between the third and four lumbar level, and finally, Letts and Quanbury (1978) at the fourth lumbar level.

Centering of the electrodes has also varied. Battye and Joseph (1966) placed electrodes along the lateral border of the muscle while specific distances measured in inches or centimeters were used by Joseph and McColl (1961), Andersson et al. (1977), Letts and Quanbury (1978), Afanasiev (1980) and Blackburn and Portney (1981). Rather than use specific measurements, Pauly (1966) and Pauly and Steele (1966) placed electrodes halfway between the vertebral spine and the lateral border of the muscle.

Floyd and Silver (1955), Portnoy and Morin (1956) and Battye and Joseph (1966) stated that a check was done to rule out interference from other muscles, however only Morris et al. (1962) reported that cadaver specimens had been studied to verify electrode placement.

Following the review of the major anatomy textbooks and of the reports in the literature, it was proposed that electrodes be situated over erector spinae at the level of the third lumbar spinous process. At this level the erector spinae forms a large prominent, fleshy mass and is covered only by the posterior layer of the thoracolumbar fascia. This was verified by examination of three prosected cadavers and, in preliminary runs with electrodes placed at this level, there was no indication of interference from adjacent muscles.

The landmarks used in the study were the third lumbar spinous process and the lateral border of erector spinae. These points were marked with water-soluble ink and the electrodes were placed halfway between the two points, parallel to the muscle fibres (Fig. 3).

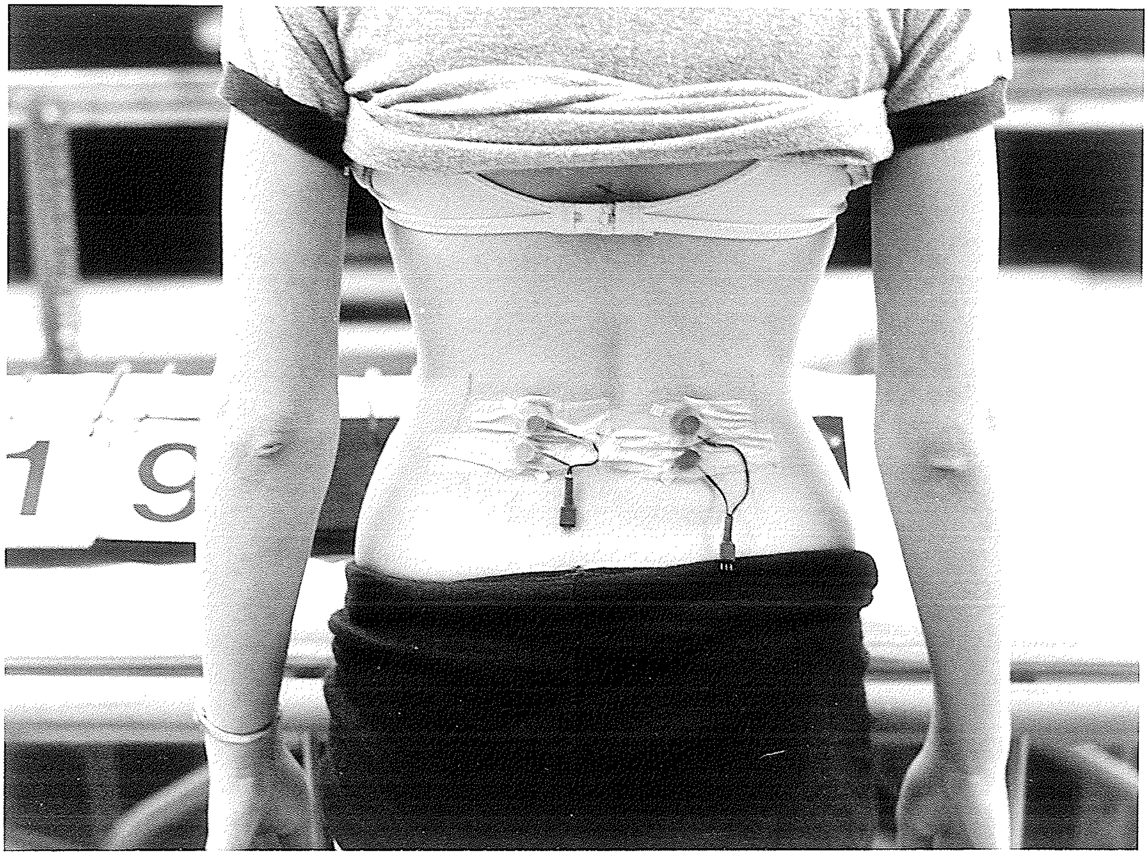
INSTRUMENTATION

Paired Beckman silver-silver chloride surface electrodes were used. These had an overall diameter of 14 millimeters (mm) with an active surface of 5 mm^2. By using adhesive cuffs as a guide, spacing between the electrodes of each pair was kept constant at 10 mm, 19 mm between active surfaces. The hollow portions of the electrodes were filled with Beckman electrode electrolyte gel and electrodes were fastened to the skin by double-sided adhesive cuffs and Millipore brand surgical tape.

In order to minimize motion artifacts, each pair of electrodes was attached at the electrode site to a preamplifier with an input impedance of 2.2 megohms. Wires from the preamplifiers were conveyed to a junction box located beside the subject and this, in turn, was connected to the amplifier by a single multiconductor cable.

The amplifier was designed and constructed by the Biomedical Engineering Department, Rehabilitation Centre for Children. It has a bandwidth of 50 to 300 Hz with an input impedance of 2.2 megohms and

FIGURE 3. Placement of electrodes on erector spinae muscle.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a common mode rejection ratio (CMRR) of 90 dB. The signal was full wave rectified and low pass filtered to produce a linear envelope. A first order low pass filter was used with a time constant of 45 milliseconds and a frequency cutoff of 35 Hz.

The analog signal from the muscles was recorded by a Gould Brush 8 channel ink chart recorder (Model 481) with a bandwidth frequency response of 50 divisions ± 1 division dc to 40 Hz, 10 divisions ± 1 division dc to 100 Hz. A rectilinear trace presentation was given with each channel measuring 40 mm in width, marked off into 50 divisions. The sensitivity of the recorder was adjustable from 1 millivolt/division to 500 volts/division.

Throughout the experiment the chart speed was kept constant at 25 mm/sec. Accuracy was ±.25%.

ELECTROGONIOMETER

DESIGN

The electrogoniometer used in this study was designed by A.O. Quanbury, Head, Biomedical Engineering Services Department, Rehabilitation Centre for Children, Winnipeg, Manitoba, and was adapted from a photograph of an instrument developed at the Ontario Crippled Children's Centre, Toronto, Ontario. It was constructed by the Biomedical Engineering Services Department.

The goniometer consisted of two potentiometers capable of 360° rotation, connected in series (Fig. 4). Attached to the shaft of one of the potentiometers was a removable rod, square in cross-section. The rod was fitted into a square-bore hollow metal shaft which was attached to a rectangular thermoplastic base.

The instrument was designed to adjust to the flexion that accompanies axial rotation because coupled motion invariably occurs in the vertebral column (Lumsden and Morris, 1968; Farfan, 1973; Panjabi et al., 1976; White and Panjabi, 1978). The square rod was free to slide in and out of the shaft, however movement in the horizontal plane between rod and shaft was prevented by the square configuration and was instead transmitted directly as torque to the shaft of the potentiometer. In addition, a section of plastic bellows connected the rod to a cuff which fitted over the potentiometer shaft, and another section of bellows joined the hollow shaft to its thermoplastic base. These bellows allowed a small amount of movement in sagittal and coronal planes, but transmitted rotation in the horizontal plane to the potentiometer. Thus

FIGURE 4. Electrogoniometer.

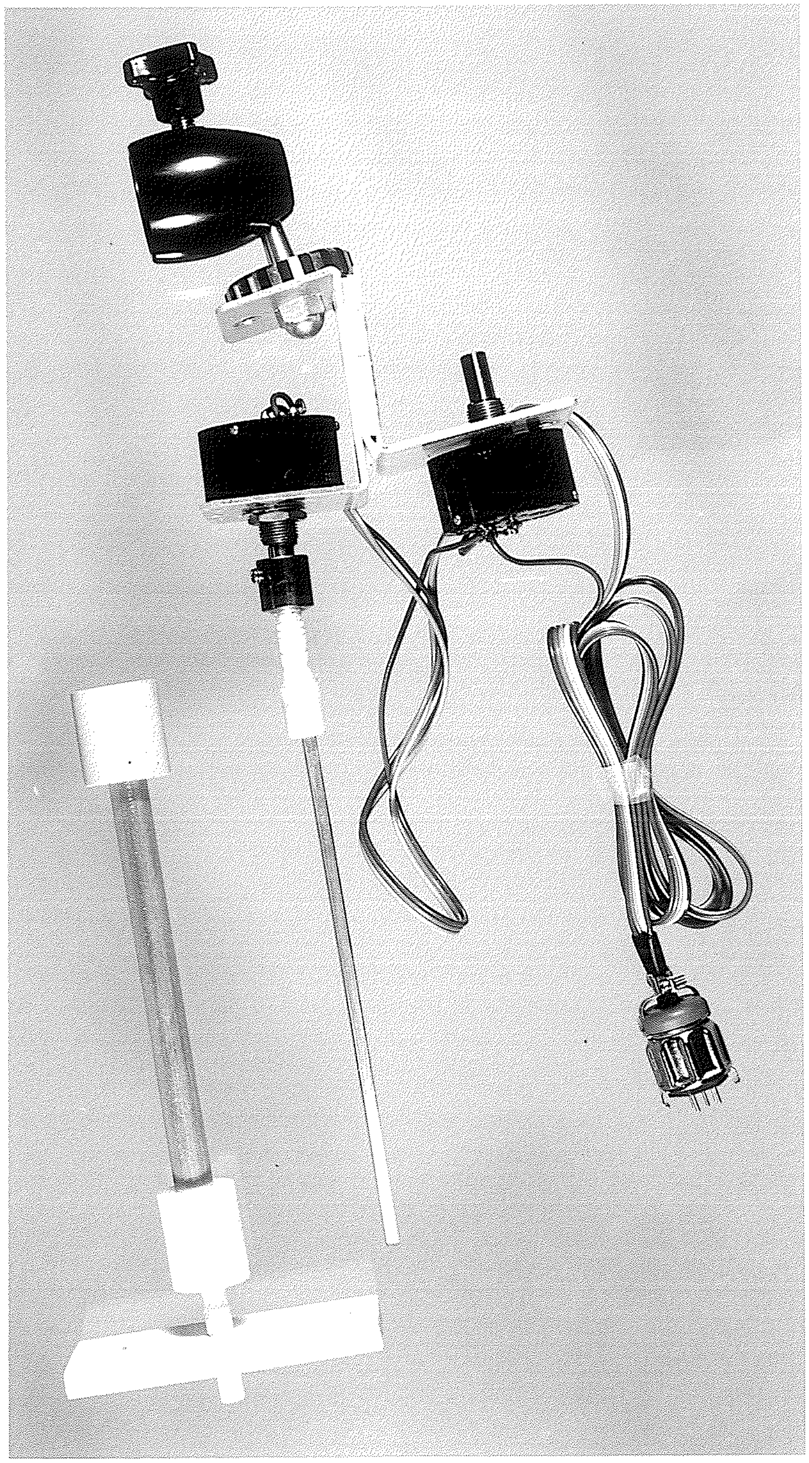


FIGURE 5. Electrogoniometer circuit.

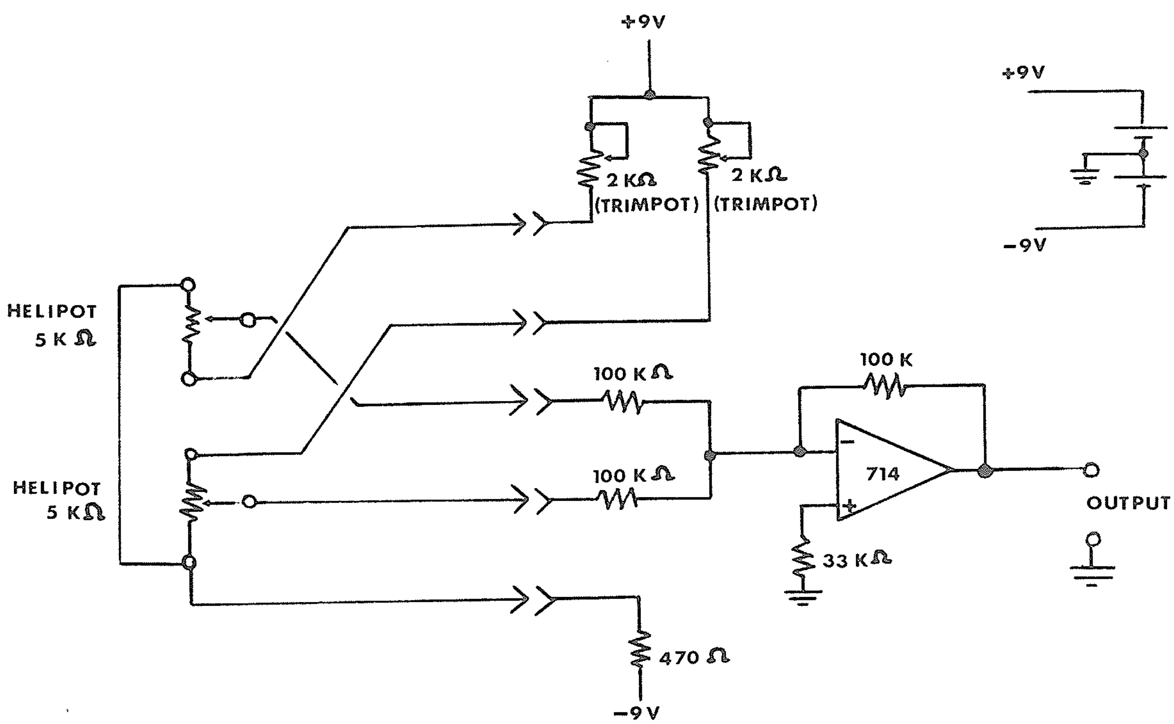


Fig. 5 Electrogoniometer Circuit

the rod-shaft arrangement limited input to the potentiometer to axial rotation, but could adjust to other movements of the body.

CIRCUITRY

Figure 5 represents a diagram of the goniometer circuit. Input to the circuit was provided by two 9 volt (V) nicad batteries. The constant voltage from the batteries could be modified by two 5 kilohm potentiometers (Helipot-Beckman Instruments) capable of 360° rotation with a linearity of output of ±.5%. The output of each potentiometer could be adjusted to OV by a 2 kilohm trimpot. The shaft of one of the potentiometers was attached to the rod of the goniometer, while the shaft of the other was used to adjust the output of the circuit as a whole to OV. The summing and balancing circuit was housed in a small plastic box attached to the plastic pelvic girdle worn by the subject, and was connected to the potentiometers by flexible multiconductor cable. Output from the summing and balancing circuit was passed via cable to the chart recorder for analog display simultaneously with the EMG recording.

Figure 6 shows the arrangement of the instrumentation used to acquire the data on EMG and rotation.

ATTACHMENT TO THE BODY

The electrogoniometer was developed to measure the relative rotation between the thoracolumbar vertebrae and the sacrum. To do this, it had to be attached to the body of the subject in such a way that full range trunk rotation could occur with minimum discrepancy

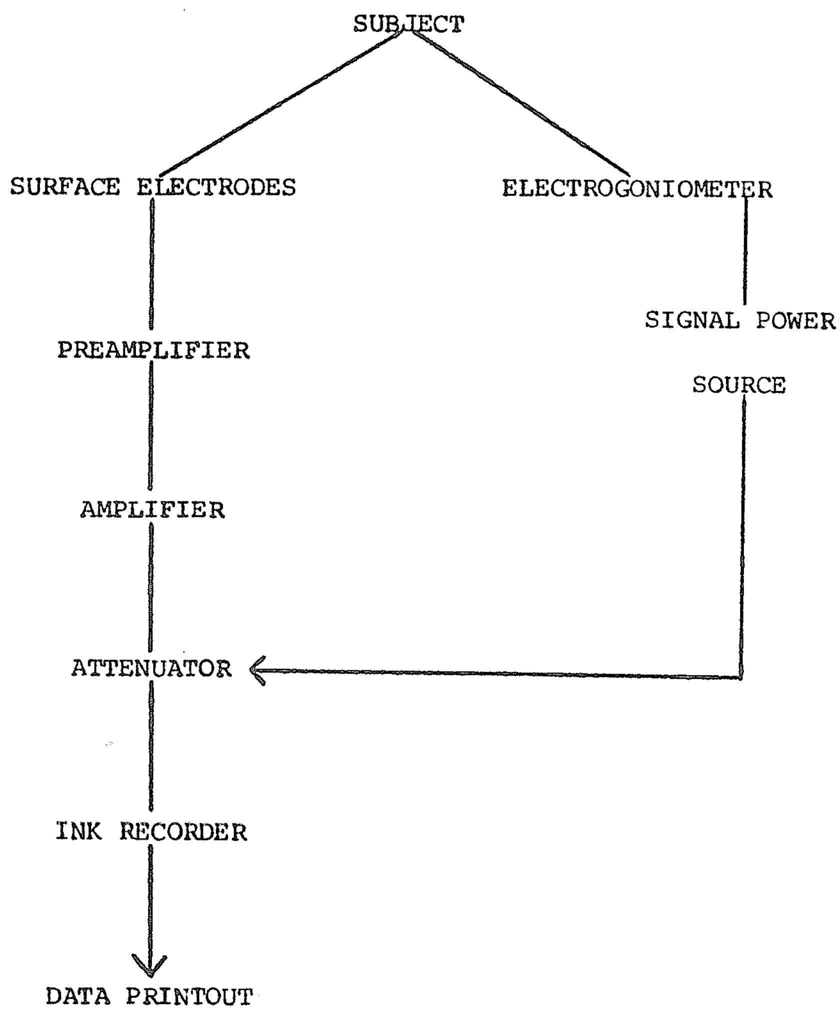


FIGURE 6. Flow diagram of data acquisition.

between actual movement and the amount of torque transmitted to the shaft of the potentiometer.

Thermoplastic girdles were used as external attachments for the goniometer (Figs. 7 and 8). Four different sizes of sacral girdles were constructed, each contoured to fit snugly over the iliac crests and around the pelvis. To enhance contact, the girdles were designed to cover a large surface area, the waist section was lined with foam and Velcro straps were used to adjust the fit. The rectangular plastic base of the hollow shaft of the goniometer was attached to the back of the pelvic girdle by means of an adjustable bracket, necessary because of the variation in trunk length between subjects.

The thoracic girdle consisted of a band and metal-reinforced vertical plate. The girdle conformed to the rib cage and was lined with foam to prevent slipping; the vertical plate fitted between the scapulae and served to increase the surface area of the girdle. A Velcro strap was used to secure the girdle to the rib cage. The potentiometers and square-section rod assembly were attached by a tripod mount to a knob on the vertical plate of the girdle.

EVALUATION OF ELECTROGONIOMETER

Delimitation of Spinal Segment

The spine consists of multiple joints and therefore thoracolumbar rotation is the result of both rotation in the horizontal plane and translation in three possible planes at each individual joint of a spinal segment. In order to compare the range of thoracolumbar rotation within a subject group, it was necessary to define the cranial

FIGURE 7. Attachment of goniometer--posterior view.

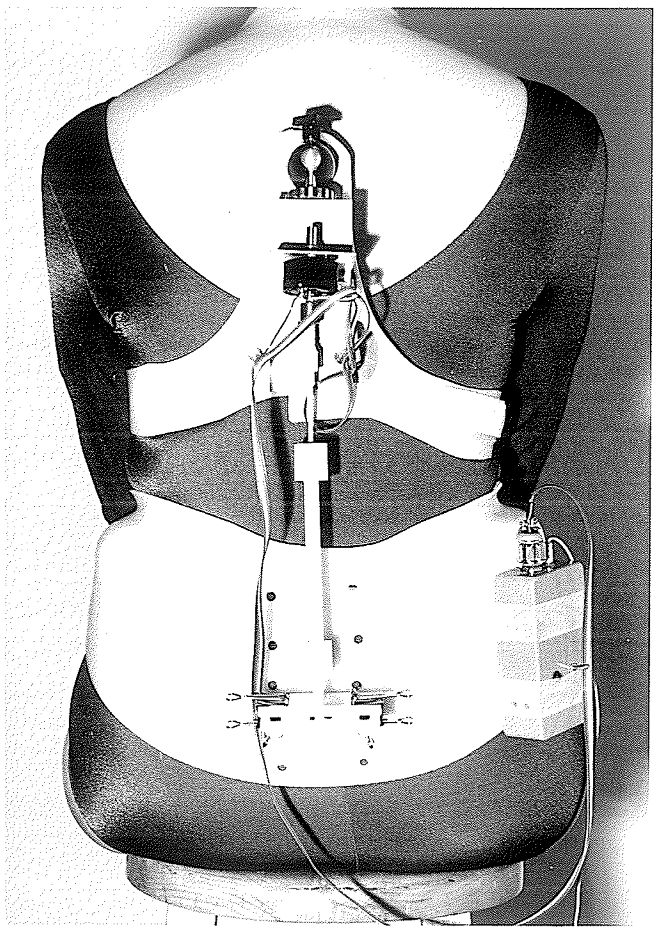
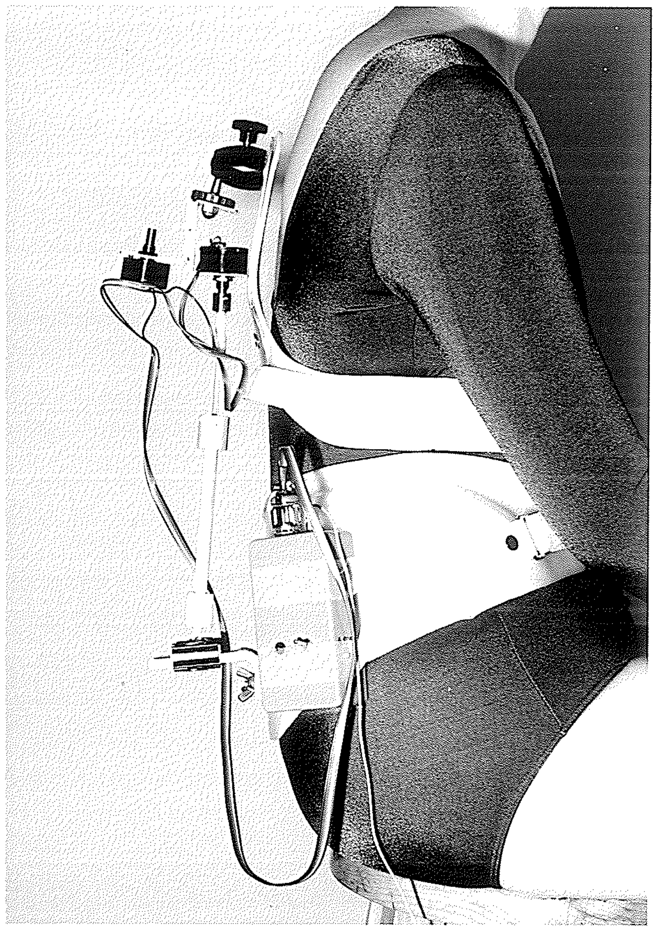


FIGURE 8. Attachment of goniometer--lateral view.



and caudal limits of the spinal segment to be measured and to ensure that all measurements taken were of this section only.

In this study the sacrum was defined as the caudal limit of the thoracolumbar spinal segment to be measured, however the cranial limit had to be determined.

Preliminary trials with the electrogoniometer led to modification of the thoracic harness to eliminate possible interference from scapular movement. The thoracic girdle was applied to the lower part of the thoracic cage and the values derived from the electrogoniometer during trunk rotation were compared to those given by Gregersen and Lucas (1967). From the initial data it was proposed that the goniometer was measuring rotation between the tenth thoracic vertebra (T_{10}) and the sacrum.

To verify this fact, the procedure would ordinarily be to apply simultaneously the goniometer and a system of external markers, have the subject move through a range and then compare the values from the goniometer to those from the external markers (Tata, 1980). This could not be done because of the position of the goniometer in the midline of the vertebral column. Therefore, the verification of level of placement was done in two steps.

First, plastic straws were mounted in foam blocks and attached with double-sided adhesive tape to designated thoracic and lumbar spinous processes and to the sacrum of four subjects. A Polaroid camera was mounted on a rigid beam above the subject and floor markings and a plumb line were used to ensure consistent alignment from subject to subject. The straws were aligned and photographs were taken first in the neutral sitting position and then at the end of the full range trunk rotation to the right and left sides. From the photographs, the angles formed by the thoracic and lumbar straws relative to the sacrum were measured with a protractor and the means of these values were compared to the values from the studies of Gregersen and Lucas (1967), Lumsden and Morris (1968) and White and Panjabi (1978)(Table 4). It can be seen that the lower thoracic and lumbar values derived from the external markers corresponded closely to the values reported by Gregersen and Lucas (1967) and Lumsden and Morris (1968).

Second, the electrogoniometer was applied with the thoracic girdle aligned with the tenth thoracic (T_{10}) spinous process. Full range rotation to both sides was carried out and the mean of these values was compared to the T_{10} level values from the marker study and from the Gregersen and Lucas (1967) study (Table 5). The difference between the goniometer value and the external marker value represents a 3% error which was considered acceptable. While there is a 5° (14%) difference between the goniometer value in this study and that of Gregersen and Lucas (1967), it must be pointed out that in the latter study the values reported for rotation in the lower thoracic spine (T_9, T_{11}, T_{12}) were derived from only one subject at each level and an intersubject difference would be expected due to biological variation.

On the basis of these findings, it was felt that, using the T_{10} spinous process as a bony landmark for the thoracic harness, the goniometer was measuring the relative rotation in the T_{10} to sacrum spinal segment.

TABLE 4. COMPARISON OF VALUES FOR THORACOLUMBAR ROTATION.

SPINAL SEGMENT	EXTERNAL MARKERS (n=3)	GREGERSEN & LUCAS (1967)	LUMSDEN & MORRIS (1968)	WHITE & PANJABI (1978)
T_1-Sacrum	97°	87°		87°
T_4-Sacrum	69°	83°		62°
T_7-Sacrum	49°	48°		38°
T_{10}-Sacrum	33°**	37°*		23°
L_4-Sacrum	13°		11°	7°

*Figure derived from average difference between T_9-sacrum and T_{11}-sacrum.

**Measurements from 4 subjects.

TABLE 5. COMPARISON OF VALUES FOR ROTATION OF THE T_{10}-SACRUM SPINAL SEGMENT.

	GONIOMETER VALUES n=4	EXTERNAL MARKERS n=4	GREGERSEN & LUCAS (1967)
T_{10}-Sacrum	32°	33°	37°

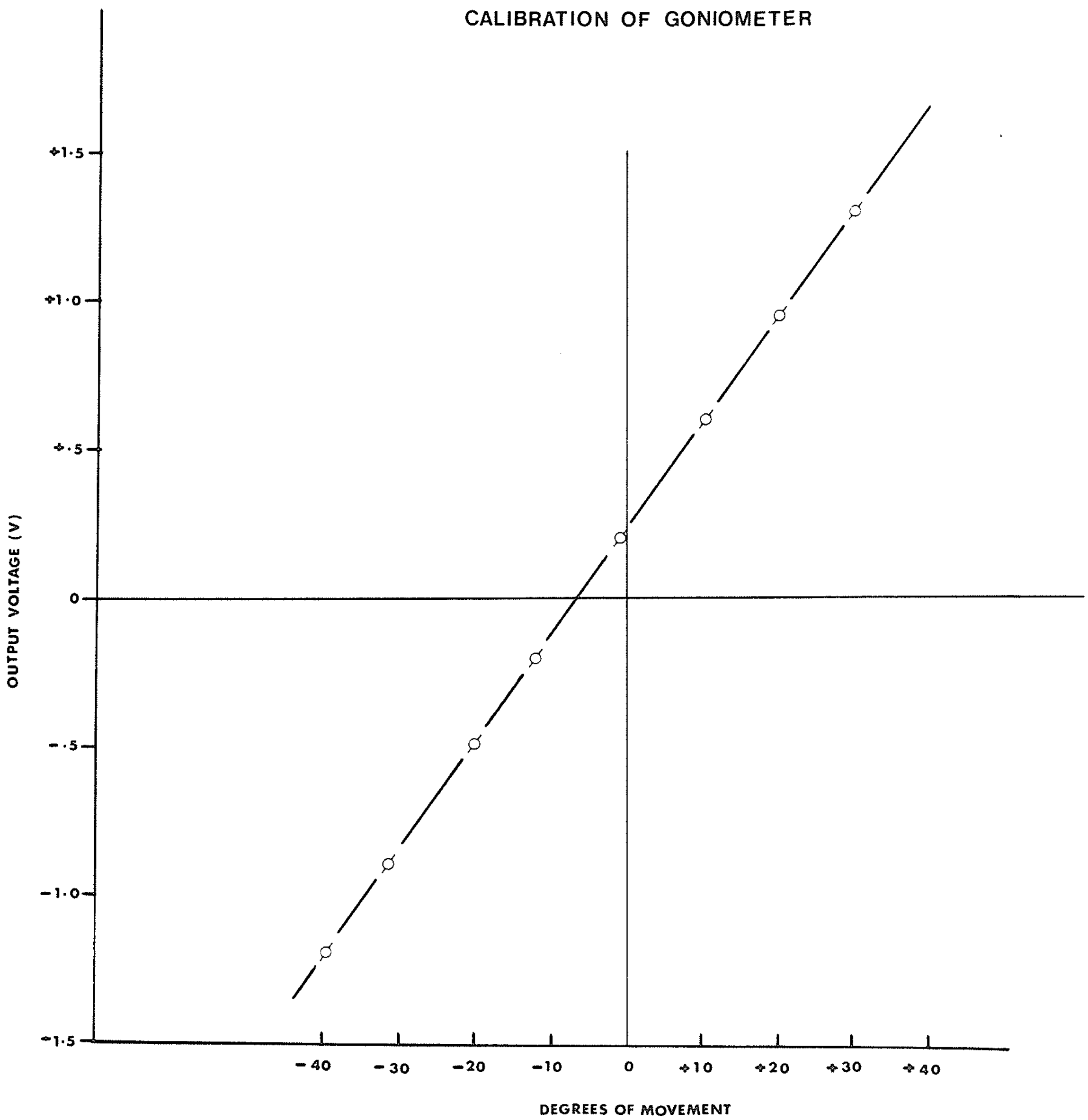
Calibration and Accuracy

In order to determine if the signal from the electrogoniometer reproduced faithfully the torque applied to the shaft of the potentiometer, the relationship between degrees of movement and voltage output was plotted. A protractor was modified to fit around the shaft of the potentiometer attached to the square-section rod and a knob with a pointer was fixed to the shaft. The shaft of the potentiometer was then rotated in 1^{o} increments through a total of 80^{o} (40^{o} to the right and 40^{o} to the left) and voltmeter readings were taken at each degree of change. Figure 9 shows that there was a linear relationship between degrees of rotation of the shaft of the potentiometer and the voltage output of the circuit.

This procedure also established that each degree of rotation resulted in a voltage change of 35 mV and therefore an output of 1 V from the circuit represented 28.6^{o} of rotation. The output from the electrogoniometer was fed to the chart recorder for analog representation and the attenuation of the goniometer channel was kept constant at 50 mV per division throughout the study. Thus one division of pen deflection on the chart represented 1.4^{o} of rotation.

As a test for accuracy, the analog signal of the chart recorder was compared to the voltmeter readings and was accurate to within 2%. With the goniometer fully assembled, there was a discrepancy of 1.8^{o} or 6% over a 30^{o} range and this is attributed to the slack in the rod and shaft coupling system. To avoid error as a result of decreased output from the batteries, these were recharged regularly and the output of the circuit was tested routinely to ensure that voltage output was constant at defined degrees of rotation.

FIGURE 9. Relationship between voltage output and degrees of movement of the electrogoniometer.


CALIBRATION OF GONIOMETER
+1·5
+1·0
+·5
0
-·5
-1·0
-1·5
OUTPUT VOLTAGE (V)
- 40
- 30
-20
-10
0
+10
+20
+30
+40
DEGREES OF MOVEMENT

Slipping and inaccurate attachment of the thoracic and pelvic girdles were other potential sources of error in the rotation measurements. Therefore, each subject performed the experimental exercise twice with a 10 minute rest between trials. The subjects were divided into two groups: for Group A the goniometer was removed from the girdles at the end of the first trial, the subjects rested with the girdles on and the goniometer was reapplied at the end of the rest period; for Group B the goniometer and the girdles were removed after the first trial and reapplied at the end of the rest period.

If slipping inside the girdles occurred, there should have been a difference in the amount of rotation registered between the first and second trials in Group A. If attachment was inaccurate, there should have been a significant difference in the amount of rotation registered between Group A and Group B in the second trial.

SUBJECT GROUP

One of the aims of this study was to acquire normal data for later comparison to data from subjects with adolescent idiopathic scoliosis. This condition is more common in females than in males. James (1973) states that the female to male ratio is 12:1, Cailliet (1975) and Riseborough and Herndon (1975) give the ratio of 9:1, while Keim (1978) states that 70% of subjects are female. Because of the higher prevalence of adolescent idiopathic scoliosis in females, only female subjects were selected for this study.

Subjects were chosen on the basis of their availability and were required to be in good health with no history of spinal pathology.

Other limitations were no abdominal surgery and no term pregnancies because of their possible effect on the function of the abdominal muscles.

The Faculty Committee on the Use of Human Subjects in Research approved this study, all subjects were volunteers and received no remuneration. Each subject was required to sign a consent form before participating in the study (Fig. 10).

The descriptive data on the subjects are presented in Table 6.

EXPERIMENTAL PROTOCOL

The subject routine used in this study is presented on page 87.

Bony landmarks were used in order to standardize electrode application and all electrodes were applied by the same person, using the same measuring tools. Skin resistance was reduced to practical levels (Quanbury, 1981) by rubbing it vigorously with an alcohol-soaked swab. Photographs were taken to record the electrode placement of each subject.

To avoid mistakes, the leads were attached to the electrodes in the same order each time. The chart speed was kept constant at 25 mm per second throughout the study and the sensitivity of each channel was held constant throughout each subject run.

A maximum isometric contraction was obtained for each muscle in order to establish a standard of muscle activity against which all subsequent contractions of that particular muscle could be measured. This was done using the positions recommended by Daniels and Worthingham (1980) for testing normal activity in order to ensure maximum recruitment of the muscle.

FIGURE 10

CONSENT FORM

I hereby consent to act as a subject in the research project on the electromyography of the trunk muscles during trunk rotation. The procedure, which involves photographic recordings, has been explained to me fully. Photographic records will be used for analytical purposes and may also serve as documentation in research papers and medical lectures.

My participation is voluntary and I reserve the right to withdraw immediately from the procedure whenever I wish.

Signature of Subject ______________________________

Signature of Parent or Guardian ______________________________
(in the case of subjects under the age of 18)

Dated: ____________________

TABLE 6. DESCRIPTIVE DATA OF SUBJECTS

NUMBER OF SUBJECTS:		20
AGE:	MEAN	23.5 ± 4.4 yrs
	RANGE	16.7 - 34.8 yrs
HEIGHT:	MEAN	160.3 ± 7.0 cm
	RANGE	145.0 - 173.8 cm
WEIGHT:	MEAN	54.0 ± 5.4 kg
	RANGE	45.5 - 68.2 kg
HANDEDNESS:	RIGHT	17
	LEFT	3

SUBJECT ROUTINE

The following routine was used with each subject:

1. Assign subject number, adjust number holder.
2. Meet subject, explain procedure, show equipment.
3. Sign consent form.
4. Record subject's number, age, height and weight.
5. Do coin toss to determine direction of first turn (heads = right; tails = left).
6. Have subject try on girdles, attach goniometer, adjust pelvic girdle bracket if necessary.
7. Seat subject and adjust seating if necessary.
8. Place subject in supine.
9. Rub skin of abdomen firmly with alcohol swabs.
10. Mark bony landmarks and draw guidelines.
11. Apply electrodes to abdominal area (4 pairs, 1 reference).
12. Practise maximum isometric positions and commands.
13. Attach leads in order--RULO, RLLO, LULO, LLLO.
14. Record subject number, date, side of first rotation on recorder chart.
15. Calibrate recorder.
16. Subject performs maximum isometric contraction--left shoulder to right hip, then right shoulder to left hip.
17. If satisfactory, record attenuator sensitivity for channels 1 to 4.
18. Detach leads.
19. Place subject in sitting.

20. Rub skin of back firmly with alcohol swab.

21. Mark bony landmarks, draw guidelines.

22. Apply electrodes to back area (2 pairs).

23. Place subject in prone.

24. Practise maximum isometric position and commands.

25. Attach leads in order--RES, LES.

26. Calibrate recorder.

27. Subject performs maximum isometric contraction.

27. If satisfactory, record attenuator sensitivity for channels 5 and 6.

28. Detach leads.

29. Photograph subject--anterior, posterior.

30. Attach leads.

31. Apply pelvic girdle, seat subject, adjust girdle.

32. Apply thoracic girdle.

33. Attach electrogoniometer.

34. Calibrate electrogoniometer, recalibrate electrode channels if necessary.

35. Start metronome, demonstrate exercise.

36. Subject practises exercise, chart recorder off.

37. Subject performs exercise, chart recorder on.

38. Subjects 1-10, remove electrogoniometer, rest in sitting for 10 minutes.

    For subjects 11-20, remove electrogoniometer and girdles, rest in sitting for 10 minutes.

39. For subjects 1-10 reattach electrogoniometer, check electrode connections, recalibrate all channels, restart metronome and subject

repeats exercise.

For subjects 11-20 reattach electrogoniometer, reapply pelvic and thoracic girdles, check electrode connections, recalibrate all channels, restart metronome and subject repeats exercise.

40. Run completed. Thank subject.

Each subject was fitted with one of four sizes of pelvic girdles to ensure maximum contact and to reduce slipping of the girdle to a minimum. The position of the thoracic girdle was kept constant across subjects by using the T_{10} spinous process as a bony landmark.

Subjects were seated on a stool such that hips and knees were in 90° flexion, pelvis and thighs were well supported and feet were flat on the floor. To ensure maximum excursion of the trunk, subjects were instructed to hold their arms at chin level in shoulder abduction and elbow flexion.

In the sitting position the subject was required to rotate as far as possible to one side, return to midline, rotate as far as possible to the opposite side and return to midline. This sequence of movements constituted one cycle and each cycle was repeated five times without interruption. A metronome was used to set a constant cadence for the exercise of approximately 16 seconds per cycle. To avoid bias, the side to which the subject would turn first was determined by coin toss: heads--subject turned to the left, tails--subject turned to the right. This was done for all right-handed subjects. Because only three subjects were left handed, a coin toss was used for the first subject and then all subsequent left-handed subjects were required to turn first to the side opposite to that of the previous left-handed subject.

After a period of practise, two experimental runs were done by each subject with a 10 minute interval between runs to minimize the effects of warmup and fatigue (Brandell, 1977). To check the reliability of the goniometer, the total subject group was divided into two groups of 10 subjects each. In Group A the goniometer was removed but the thoracic and pelvic girdles were left on during the rest period; in Group B both goniometer and girdles were removed before the rest period.

All subjects were sent a letter of thanks for their participation in the study.

DATA COLLECTION

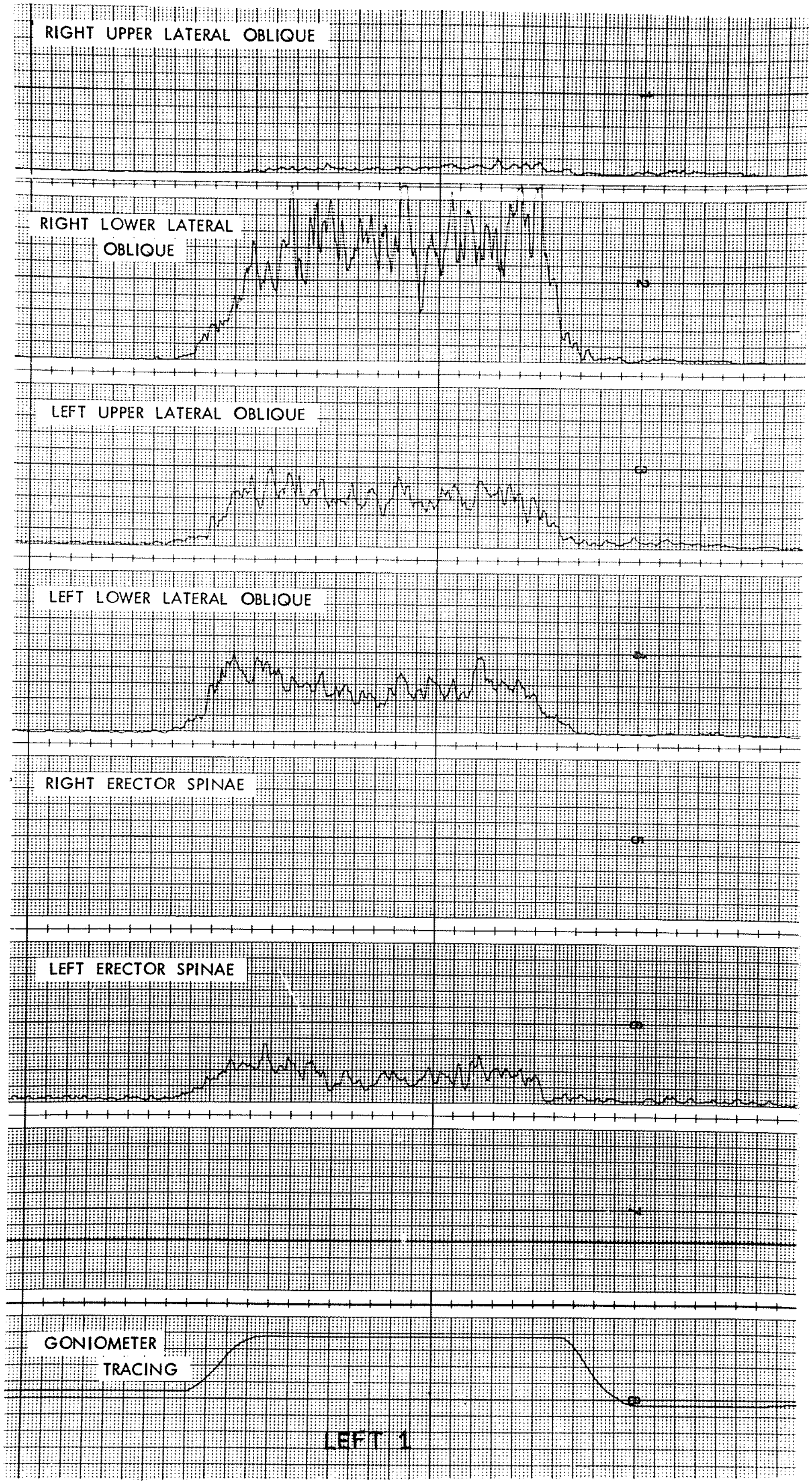
A sample of the data collection sheets used in this study can be found in Appendix A. Fifteen sheets were used to record 649 pieces of information for each subject.

The amount of rotation to left and right sides for both the first and second trials was calculated from the maximum deflection of the electrogoniometer tracing. The tracing was also used to determine the specific point in the rotation cycle of onset, peak and cessation of activity of a particular muscle (Fig. 11). This was then calculated as a percentage of the total rotation cycle.

To determine the amount of electrical activity generated during the maximum voluntary contraction (MVC) of a muscle, a one second sample of muscle activity during the MVC was selected by measuring 0.5 sec (12.5 mm) to either side of the point of maximum amplitude in the contraction and then measuring the area of the linear envelope in this section with a Talos digitizing tablet. The resulting value is the amount of integrated electrical activity of the MVC and is expressed in millivolt seconds (MV.sec).

The area of the linear envelopes recorded for each muscle was also measured with the digitizing tablet and each value was divided by

FIGURE 11. Example of chart recorder printout.


RIGHT UPPER LATERAL OBLIQUE
RIGHT LOWER LATERAL OBLIQUE
LEFT UPPER LATERAL OBLIQUE
LEFT LOWER LATERAL OBLIQUE
RIGHT ERECTOR SPINAE
LEFT ERECTOR SPINAE
GONIOMETER TRACING
LEFT 1

the time of the muscle contraction to give the integrated electrical activity of the muscle in millivolt seconds. This was then expressed as a percentage of the MVC for that muscle.

Statistical analysis of the data was done using the Statistical Analysis System (SAS) and the Statistics On Line (SOL) programs of the Computer Department for Health Sciences, University of Manitoba.

CHAPTER IV

RESULTS

ROTATION DATA

As described in a previous section, each subject performed two sequences of exercise with a 10 minute rest period between. The first sequence will be designated Trial 1; the second, Trial 2.

From calibration of the goniometer it was known that each division of deflection recorded on the chart was equal to 1.4^{o} of rotation. Therefore, the maximum amount of rotation registered by the goniometer and expressed in degrees was calculated by counting the number of divisions of excursion (each division equalled 0.8 mm) and multiplying this figure by 1.4.

For each trial there were five rotations per subject each to the left and to the right. The mean of the five values was calculated and represents the average amount of rotation to left or right per subject for that trial. Because the probable error in measurement over the five trials was ±1.4, representing 2% over 50 divisions, the mean value was expressed as the nearest whole number (Davis and Foote, 1956).

Table 7 presents the data on the mean amount of rotation to the left and right in all subjects for Trials 1 and 2. In both trials the amount of rotation to the left was greater than that to the right, however when these data were compared using a paired t Test (2-tailed) the differences were not significant (Table 8).

Overall, the amount of rotation to the left and to the right is less in Trial 2, however this difference is significant only in rotation to the right (Table 8). However, in six subjects rotation to the left was greater in Trial 2, in six subjects rotation to the right was

TABLE 7. MEAN ROTATION VALUES FOR TRIALS 1 AND 2, ALL SUBJECTS.

N = 20

	TRIAL 1		TRIAL 2	
SUBJECT	LEFT TURN	RIGHT TURN	LEFT TURN	RIGHT TURN
1	24	21	25	17
2	22	23	24	22
3	30	37	23	31
4	29	29	26	25
5	32	25	29	21
6	19	18	17	19
7	23	22	22	19
8	14	13	15	15
9	22	23	17	22
10	24	23	20	20
11	26	23	24	24
12	26	25	26	22
13	30	29	33	31
14	22	20	20	18
15	27	27	26	24
16	24	22	20	18
17	29	24	27	24
18	28	24	24	22
19	23	22	24	24
20	23	26	24	24
$\overline{X}$	25	24	23	22
VAR	18	23	18	17
SD	4	5	4	4
SEM	1	1	1	1

TABLE 8. COMPARISON OF MEAN AMOUNT OF ROTATION IN DEGREES

n = 20

α = .01

	LEFT TURN	RIGHT TURN	LEFT vs RIGHT
TRIAL 1	25 ± 4	24 ± 5	NS
TRIAL 2	23 ± 4	22 ± 4	NS
TRIAL 1 vs TRIAL 2	NS	p<.01	

greater in Trial 2 and in three subjects rotation to both left and right was greater in Trial 2.

Some subjects began both trials of the exercise sequence by turning first to the right (right first), some to the left (left first). The direction of the first turn was determined by coin toss. This was done to decrease the possibility of bias that might occur due to the uptake of the slack in the goniometer rod/shaft system during the first turn.

Table 9 shows the comparison of the amount of rotation to the left and to the right in each of Trials 1 and 2 between left first and right first subjects. A 2-tailed t Test for independent samples was used to compare the data and, in all cases, the differences were not significant.

To test for accuracy of attachment of the goniometer, the total subject group was divided into two groups of 10: Group A and Group B. As described previously, at the end of Trial 1 the goniometer was removed from the girdles worn by subjects in Group A and they rested for 10 minutes with the girdles in place. At the end of the rest period the goniometer was reattached and Trial 2 was carried out. For subjects in Group B, the goniometer and the girdles were removed at the end of Trial 1, they rested for 10 minutes, the girdles were then reapplied, the goniometer reattached and Trial 2 was carried out.

To test for homogeneity of the groups before the manipulation of goniometer and girdles occurred, rotation to the left and then to the right in Trial 1 was compared between Group A and Group B (Table 10), using a 2-tailed t Test for independent samples. There was no

TABLE 9. COMPARISON OF MEAN AMOUNT OF ROTATION BETWEEN LEFT FIRST AND RIGHT FIRST SUBJECTS.

	LEFT TURN				RIGHT TURN			
	LEFT FIRST (n=11)	vs	RIGHT FIRST (n=9)	P VALUE	LEFT FIRST (n=11)	vs	RIGHT FIRST (n=9)	P VALUE
TRIAL 1	24 ± 5		26 ± 3	NS	22 ± 4		26 ± 5	NS
TRIAL 2	23 ± 4		24 ± 4	NS	21 ± 3		24 ± 5	NS

$\alpha = .01$

TABLE 10. COMPARISON OF MEAN AMOUNT OF ROTATION BETWEEN GROUP A AND GROUP B.

	LEFT TURN				RIGHT TURN			
	GROUP A (n=10)	vs	GROUP B (n=10)	P VALUE	GROUP A (n=10)	vs	GROUP B (n=10)	P VALUE
TRIAL 1	24 ± 5		26 ± 3	NS	24 ± 6		24 ± 3	NS
TRIAL 2	22 ± 5		25 ± 4	NS	21 ± 5		23 ± 4	NS

$\alpha = .01$

significant difference between the two groups. The same test was then used to compare values of Group A to those of Group B during Trial 2, that is, after the goniometer and girdles had been reapplied. No significant difference was found.

MUSCLE ACTIVITY DATA

Details of the method used to analyze the amount of integrated electrical activity generated by muscle contraction were presented in the section on Data Collection. In summary, the mean of the integrated electrical activity divided by the time of muscle contraction produced by a specific muscle during five rotations each to the left and right sides over a defined period of time was measured and the resulting value was expressed as a percentage of the integrated electrical activity generated by that muscle over the same period of time during a maximum voluntary contraction (MVC). It is, however, impossible to determine if all possible motor units of the muscle are being recruited during the MVC and therefore, the value obtained from this contraction is only an approximation of the maximum performance of the muscle. Consequently, the values calculated for the percentage of MVC are a rough estimate of the activity of a muscle relative to its maximum possible performance and are therefore taken to the nearest whole number. However, the values are useful in that some quantitative comparison can be made between muscles and a determination can be made of the general patterns of muscle activity during a particular movement or sequence of movements (Basmajian, 1978; Letts and Quanbury, 1978; Perry et al., 1981).

To determine if a significant difference existed between levels of activity of the anterolateral abdominal and erector spinae muscles during the rotation cycle, the raw data were subjected to a three factor repeated measures analysis of variance in which the three factors were: subject (20 levels), muscle (six levels), and side (two levels). The result indicated that, overall, there was a significant difference ($p<.0001$) in the level of activity of the six muscles during rotation to the left and to the right. A *post hoc* analysis of means was then carried out to determine more precisely the difference in levels of activity within each of the muscles and also between the muscles during rotation to the left and right.

LEFT UPPER LATERAL OBLIQUE

Raw data for the amount of integrated electrical activity compared to the MVC of this muscle are presented in Table 11. It can be seen that the muscle was active in all subjects during both phases of the rotation. During rotation to the left the average amount of integrated electrical activity was 21% of MVC while during rotation to the right the average amount of integrated electrical activity was 29% of MVC. Overall, 16 subjects (80%) showed greater activity of the left upper lateral oblique muscle during rotation to the right than to the left. However, statistical analysis using a paired t Test (2-tailed) revealed that these differences in levels of activity were not significant.

In summary, the left upper lateral oblique muscle was active during rotation to the left and to the right and the level of activity

TABLE 11. MEAN INTEGRATED MUSCLE ACTIVITY OF LEFT UPPER LATERAL OBLIQUE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	44	17
2	27	34
3	41	23
4	10	14
5	11	7
6	16	32
7	18	54
8	7	12
9	16	44
10	19	37
11	19	46
12	10	17
13	25	27
14	7	8
15	11	19
16	31	74
17	15	20
18	13	21
19	40	47
20	45	29
$\bar{X}$	21	29
VAR	159	295
SD	13	17

expressed as a percentage of MVC was approximately equal in both directions.

LEFT LOWER LATERAL OBLIQUE

Table 12 presents the raw data for the integrated electrical activity compared to the MVC for this muscle. During rotation to the left the mean integrated electrical activity was 31% of MVC while during rotation to the right it was 11%. The muscle showed negligible activity during rotation to the left in one subject (5%), and was inactive during rotation to the right in one subject (5%). Overall, the muscle was more active during rotation to the left than it was during rotation to the right in 19 subjects (95%) and a statistical analysis of the data using a paired t Test (2-tailed) showed that this difference in activity levels was significant ($p<.01$).

LEFT ERECTOR SPINAE

The levels of integrated electrical activity of this muscle are presented in Table 13. During rotation to the left the muscle was active in all subjects and showed an average level of integrated activity of 16% of MVC. During rotation to the right the muscle was active in 19 subjects (95%) and had an average level of integrated activity of 10% of MVC. Overall, the muscle was more active during rotation to the left than to the right in 17 subjects (85%) and a statistical analysis of the data for all subjects using a paired t Test (2-tailed) showed that the difference in the level of activity was significant ($p<.01$).

TABLE 12. MEAN INTEGRATED MUSCLE ACTIVITY OF LEFT LOWER LATERAL OBLIQUE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	19	8
2	93	10
3	37	32
4	33	0
5	18	13
6	28	11
7	22	2
8	23	1
9	19	2
10	19	3
11	14	2
12	66	28
13	25	1
14	10	8
15	0	23
16	24	7
17	27	12
18	94	21
19	30	9
20	24	21
$\bar{X}$	31	11
VAR	614	92
SD	25	10

TABLE 13. MEAN INTEGRATED MUSCLE ACTIVITY OF LEFT ERECTOR SPINAE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	19	14
2	1	12
3	20	8
4	17	8
5	4	3
6	6	1
7	18	6
8	11	15
9	15	7
10	6	4
11	11	0
12	17	4
13	9	2
14	4	3
15	18	17
16	25	19
17	12	19
18	11	7
19	32	8
20	56	42
$\overline{X}$	16	10
VAR	149	92
SD	12	10

RIGHT UPPER LATERAL OBLIQUE

The data for integrated electrical activity of this muscle can be seen in Table 14. It can be seen that the muscle was active during both left and right turn phases of rotation in all subjects. During rotation to the left the mean level of integrated activity was 34% of the MVC while during rotation to the right the mean integrated activity level was 18% of MVC. Overall, the muscle was more active during rotation to the left in 15 subjects (75%) and a statistical analysis of the data for all subjects, using a paired t Test (2-tailed), showed that the difference in the level of activity was significant ($p<.01$).

RIGHT LOWER LATERAL OBLIQUE

Table 15 presents the data for the levels of integrated electrical activity of this muscle during the two phases of rotation. During rotation to the left the mean integrated electrical activity was 16% of MVC while during rotation to the right it was 28%. The muscle was inactive during rotation to the left in five subjects (25%), showed negligible activity in one subject (5%), but was active in all subjects during rotation to the right. Overall, the muscle was more active during rotation to the right in 18 subjects (90%) and a statistical analysis of the data for all subjects, using a paired t Test (2-tailed), showed that the difference in the level of electrical activity was significant ($p<.05$).

TABLE 14. MEAN INTEGRATED MUSCLE ACTIVITY OF RIGHT UPPER LATERAL OBLIQUE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	29	19
2	57	12
3	21	39
4	30	13
5	13	18
6	30	13
7	31	10
8	61	24
9	44	27
10	32	16
11	21	23
12	20	7
13	18	20
14	47	12
15	23	10
16	91	26
17	37	16
18	48	19
19	10	21
20	24	19
$\overline{X}$	34	18
VAR	373	55
SD	19	7

TABLE 15. MEAN INTEGRATED MUSCLE ACTIVITY OF RIGHT LOWER LATERAL OBLIQUE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	4	35
2	5	23
3	19	24
4	0	17
5	23	19
6	6	27
7	0	5
8	0	13
9	0	16
10	7	8
11	1	11
12	13	36
13	25	91
14	14	28
15	0	7
16	0	11
17	8	33
18	49	55
19	125	71
20	24	33
$\bar{X}$	16	28
VAR	814	488
SD	29	22

RIGHT ERECTOR SPINAE

The data for levels of integrated electrical activity can be seen in Table 16. Rotation to the left produced a mean level of integrated activity of 9% of MVC while rotation to the right resulted in a mean integrated activity level of 15% of MVC. In one subject (5%) the muscle was inactive during rotation to the left. Overall, the right erector spinae was more active during rotation to the right in 14 subjects (70%) and a statistical analysis of the data for all subjects, using a paired t Test (2-tailed), showed that the difference in electrical activity was significant ($p<.05$).

* * *

In summary, when the activity levels of each muscle are compared during rotation, the right and left upper lateral obliques, the left lower lateral oblique and left erector spinae are most active during rotation to the left while the left and right upper lateral obliques, the right lower lateral oblique and the right erector spinae are most active during rotation to the right.

The levels of activity between muscles were then compared to determine which muscles showed the greatest activity during rotation to a particular side. Table 17 presents the mean levels of integrated electrical activity of all muscles during rotation and their rank order of activity. It can be seen that, in rank order, the right upper lateral oblique, left lower lateral oblique, left upper lateral oblique, right lower lateral oblique, left erector spinae and right erector spinae were active during rotation to the left while, during rotation to the right, the left upper lateral oblique, right lower

TABLE 16. MEAN INTEGRATED MUSCLE ACTIVITY OF RIGHT ERECTOR SPINAE EXPRESSED AS A PERCENTAGE OF MVC

SUBJECT	LEFT TURN AND RETURN	RIGHT TURN AND RETURN
1	14	10
2	12	7
3	10	16
4	9	18
5	4	6
6	4	9
7	8	24
8	16	14
9	8	7
10	3	7
11	11	11
12	3	9
13	0	13
14	11	12
15	14	12
16	9	35
17	4	4
18	11	24
19	1	30
20	33	36
$\overline{X}$	9	15
VAR	52	93
SD	7	10

TABLE 17. MEAN LEVELS OF INTEGRATED ELECTRICAL ACTIVITY EXPRESSED AS A PERCENTAGE OF MVC OF ALL MUSCLES DURING ROTATION TO THE LEFT AND TO THE RIGHT

	LEFT UPPER LATERAL OBLIQUE	LEFT LOWER LATERAL OBLIQUE	LEFT ERECTOR SPINAE	RIGHT UPPER LATERAL OBLIQUE	RIGHT LOWER LATERAL OBLIQUE	RIGHT ERECTOR SPINAE
ROTATION TO THE LEFT	21 (3)*	32 (2)	16 (5)	34 (1)	16 (4)	9 (6)
ROTATION TO THE RIGHT	29 (1)	11 (5)	10 (6)	18 (3)	28 (2)	15 (4)

* ( ) = Rank Order.

lateral oblique, right upper lateral oblique, right erector spinae, left lower lateral oblique and left erector spinae were active.

Using a paired t Test for data with similar variances and the Wilcoxon Signed-Ranks Test for Two Groups (Sokal and Rohlf, 1981) for data with unequal variances, multiple comparisons were made between the activity levels of various muscles to determine if there were significant differences in the activity levels. An example of how the Wilcoxon Signed-Rank Test for Two Groups was performed on the data is given in Appendix B.

Table 18 presents a summary of the results of statistical tests done to compare the mean activity levels of all muscles during rotation to the left. It can be seen that there was no significant difference in the level of activity between the right upper lateral oblique and the left lower lateral oblique, nor between the left lower lateral oblique and the left upper lateral oblique. There was, however, a significant difference between the activity levels of the right upper lateral oblique and the left upper lateral oblique, and also between the left lower lateral oblique and left erector spinae and finally between the left upper lateral oblique and the left erector spinae. Therefore, two muscles appear to be more active than the rest and so might be considered to be primarily responsible for rotation to the left: right upper lateral oblique and left lower lateral oblique. The other muscles, although active, appear to have less important roles and may act as synergists.

Table 19 presents a summary of the results of the statistical tests done to compare the mean activity levels of all muscles during

TABLE 18. SUMMARY OF THE STATISTICAL ANALYSES OF THE COMPARISON OF THE MEAN LEVELS OF INTEGRATED ELECTRICAL ACTIVITY OF ALL MUSCLES DURING ROTATION TO THE LEFT

MUSCLE	vs MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	-10	6	NS
LULO	LES	+6	2	.05
LULO	RULO	-13	5	.05
LULO	RLLO	+5	6	.05
LULO	RES	+12	3	.01
LLLO	LES	+16	7	.05
LLLO	RULO	-3	6	NS
LLLO	RLLO	+15	8	NS
LLLO	RES	+22	6	.01
LES	RULO	-19	5	.01
LES	RLLO	-1	6	NS
LES	RES	+6	2	.01
RULO	RLLO	+18	9	.01
RULO	RES	+25	4	.01
RLLO	RES	+7	7	NS

$\alpha = .05$

KEY: LULO = Left Upper Lateral Oblique
LLLO = Left Lower Lateral Oblique
LES = Left Erector Spinae
RULO = Right Upper Lateral Oblique
RLLO = Right Lower Lateral Oblique
RES = Right Erector Spinae

TABLE 19. SUMMARY OF THE STATISTICAL ANALYSES OF THE COMPARISON OF THE MEAN LEVELS OF INTEGRATED ELECTRICAL ACTIVITY OF ALL MUSCLES DURING ROTATION TO THE RIGHT

MUSCLE vs	MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	+18	5	.01
LULO	LES	+19	4	.01
LULO	RULO	+11	4	.05
LULO	RLLO	+1	7	NS
LULO	RES	+14	3	.01
LLLO	LES	+1	3	NS
LLLO	RULO	-8	3	.01
LLLO	RLLO	-17	5	.01
LLLO	RES	-5	3	NS
LES	RULO	-8	3	.01
LES	RLLO	-18	6	.01
LES	RES	-5	2	.05
RULO	RLLO	-10	5	NS
RULO	RES	+3	2	NS
RLLO	RES	+14	5	.01

$\alpha = .05$

KEY: LULO = Left Upper Lateral Oblique
LLLO = Left Lower Lateral Oblique
LES = Left Erector Spinae
RULO = Right Upper Lateral Oblique
RLLO = Right Lower Lateral Oblique
RES = Right Erector Spinae

rotation to the right. It can be seen that there was no significant difference in muscle activity between the left upper lateral oblique and the right lower lateral oblique, nor between the right lower lateral oblique and right upper lateral oblique or between the right upper lateral oblique and the right erector spinae. However, there was a significant difference between the left upper lateral oblique and the right upper lateral oblique, between the right lower lateral oblique and the right erector spinae and between the right and left erector spinae. Therefore, two muscles appear to be more active than the rest and so might be considered to be primarily responsible for rotation to the right: left upper lateral oblique and right lower lateral oblique. The other muscles are active, however they appear to have less important roles and possibly act as synergists.

POSITIONAL DATA

In addition to determining the relative levels of muscle activity during rotation, the sequence of participation of each muscle during movement was also investigated.

As described previously, the amount of rotation to the left and right sides was measured from the goniometer tracing and the final value for each side was the mean of five turns to that side. For each subject, the total excursion to left and right, measured in degrees, was designated 100% of the rotation cycle. Within the rotation cycle there were the following components: initial position in midline (0% of cycle), rotation to the extreme left (25% of cycle), return to midline

(50% of cycle), rotation to the extreme right (75% of cycle) and return to midline (100% of cycle).

Three positional parameters of the EMG tracing were selected for evaluation: onset, peak and cessation of muscle activity. These three points were located and marked on the chart recording of the activity of each muscle during the left turn and return phase and also during the right turn and return phase of the entire sequence of movement in Trial 1. Each point was compared to the simultaneous deflection of the goniometer and, in this way, the onset, peak and cessation of muscle activity in each of the two major phases of rotation could be correlated with a specific degree of trunk rotation in that phase. Thus each point was given a value in degrees and could then be expressed as a percentage of the trunk excursion in the left turn and return phase or in the right turn and return phase. This, in turn, could be expressed as a percentage of the total trunk excursion during one complete rotation (left turn and return phase plus right turn and return phase). Once the data were normalized in this fashion comparisons could be made between muscles and between subjects.

Data on the pattern of activity of each muscle will be presented, followed by comparison of the activity patterns between muscles during the rotation cycle.

LEFT UPPER LATERAL OBLIQUE

The onset, peak and cessation data for this muscle during rotation to the left and right are presented in Table 20. It can be seen that the pattern of events was consistent across 20 subjects.

TABLE 20. LEFT UPPER LATERAL OBLIQUE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

SUBJECT	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	3	24	32	50	73	86
2	0	23	50	51	73	97
3	0	24	49	50	75	100
4	1	23	26	50	75	88
5	0	24	46	53	75	95
6	0	24	45	50	75	94
7	0	24	43	50	74	100
8	2	23	29	52	75	80
9	0	22	25	53	75	85
10	0	20	46	50	75	98
11	0	23	28	48	73	87
12	0	24	27	50	74	92
13	0	25	48	51	74	96
14	0	24	42	51	71	100
15	1	24	42	52	73	85
16	1	24	37	51	75	100
17	0	24	50	50	71	100
18	0	23	45	50	75	97
19	0	24	50	50	74	100
20	0	24	45	51	75	100
$\overline{X}$	0	24	40	51	74	94
VAR	1	1	82	2	2	42
SD	1	1	9	1	1	7

During rotation to the left, the muscle became active, on average, at the 0% position of the cycle. In 15 subjects (75%) the muscle became active at the very beginning of rotation, at 0% of the cycle. Onset for the remaining five subjects (25%) was before the 4% position of the cycle. Peak activity occurred, on average, at the 24% position of the cycle, that is, before the extreme left position (25% of cycle) was reached. This was the pattern found in 95% of the subjects. The muscle became inactive, on average at the 40% position of the cycle and, in 85% of the subjects, muscle activity stopped before the trunk returned to midline (50% of cycle).

During rotation to the right, the muscle became active, on average, at the 51% position of the cycle; that is, as the trunk began to move from the midline position (50% of cycle) to the right. This pattern of onset at or shortly past the midline position was seen in 95% of subjects. The peak of muscle activity occurred, on average, at the 74% position of the rotation cycle or just before the trunk reached the extreme right position (75% of cycle). The muscle ceased activity, on average, at the 94% position of the cycle, or just before the trunk reached the midline (100% of cycle) from the extreme right position.

In summary, the left upper lateral oblique became active immediately as the trunk began to rotate to left and to right, peak activity occurred just before the trunk reached the extremes of rotation and activity stopped just before the trunk returned to the midline from the extreme position.

LEFT LOWER LATERAL OBLIQUE

Raw data for onset, peak and cessation of activity for this muscle are presented in Table 21. During rotation to the left, the muscle became active at the 0% position of the cycle. Peak muscle activity occurred, on average, at the 23% position of the cycle; that is, before the trunk reached the extreme left position (25% of cycle). This was the pattern observed in 90% of the subjects. Muscle activity stopped, on average, at 42% of the cycle, before the trunk returned to the midline position (50% of cycle) and this was seen in 75% of subjects.

During rotation to the right, the muscle was inactive in one subject. In the remaining 19 subjects, the average onset of activity occurred at 68% of the cycle, before the trunk reached the extreme right position (75% of cycle). This was the pattern observed in 11 of the 19 subjects (58%). In the remaining eight subjects (42%) peak activity occurred at or immediately after the 75% position of the cycle; that is, after the trunk began to move from the extreme right position (75% of cycle) back to the midline (100% of cycle). Muscle activity stopped, on average, at the 94% position of the cycle; that is, as the trunk approached the midline position (100% of cycle).

In summary, activity in the left lower lateral oblique muscle during rotation to the left was consistent, with onset of activity at the beginning of the cycle, peak activity occurring before the extreme left position was reached and cessation of activity before the trunk returned to midline. Muscle activity was less consistent during rotation to the right. In general, the muscle became active as the trunk

TABLE 21. LEFT LOWER LATERAL OBLIQUE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

SUBJECT	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	0	24	44	64	87	100
2	0	21	49	68	73	100
3	0	15	49	61	77	96
4	3	18	25	--	--	--
5	0	24	50	76	97	100
6	0	23	49	59	76	93
7	0	23	40	75	88	100
8	2	24	25	73	75	75
9	0	24	25	68	75	88
10	1	19	38	75	99	100
11	0	24	44	82	99	100
12	0	21	28	72	94	100
13	0	24	49	83	100	100
14	0	27	38	52	81	100
15	0	22	50	75	89	100
16	0	23	39	79	95	100
17	0	24	50	50	84	100
18	0	23	50	78	95	100
19	0	25	50	50	74	98
20	0	21	45	51	79	100
$\overline{X}$	0	23	42	68	86	94
VAR	1	7	86	124	95	39
SD	1	3	9	11	10	6

moved from midline to the right, peak activity occurred as the trunk began to move back to the midline from the extreme right position and activity stopped as the trunk regained the midline position.

LEFT ERECTOR SPINAE

The onset, peak and cessation positions for this muscle are presented in Table 22. It can be seen that there was a high degree of variation in the pattern of muscle activity across the 20 subjects with the greatest variation occurring during rotation to the right.

During rotation to the left, the muscle became active before the trunk reached the extreme left position (25% of cycle) in 16 subjects (80%), having a mean onset position of 13% of the cycle for the entire group. Peak muscle activity occurred, on average, at the 30% position of the cycle, just after the trunk reached the extreme left position and began to return to midline. Muscle activity ceased, on average, at 38% of the cycle, before the trunk reached the midline position (50% of cycle), and this was the pattern observed in 80% of subjects.

During rotation to the right the muscle was inactive in one subject. For the entire group, the mean onset time occurred at the 64% position of the rotation cycle; that is, before the trunk reached the extreme right position (75% of cycle). This was the pattern observed in 14 of the 19 subjects (74%) in which the muscle was active. Peak muscle activity occurred, on average, at 80% of the cycle; that is, immediately past the extreme right (75%) position. This was the pattern observed in 12 of the 19 subjects (63%) in which the muscle was active. The muscle ceased activity, on average, at 93% of the cycle,

TABLE 22. LEFT ERECTOR SPINAE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

SUBJECT	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	19	25	34	62	71	87
2	2	25	44	50	68	80
3	0	21	36	60	75	94
4	24	35	38	58	79	99
5	5	22	25	58	74	75
6	18	31	36	63	67	81
7	0	23	25	59	79	100
8	2	33	33	59	75	96
9	0	23	25	61	85	100
10	45	50	61	85	97	100
11	0	20	26	--	--	--
12	0	22	26	59	72	75
13	14	28	42	82	91	100
14	47	50	68	75	96	100
15	38	45	54	71	86	100
16	0	29	36	77	93	100
17	8	24	40	44	70	94
18	37	50	60	80	95	100
19	0	24	27	65	75	100
20	3	22	25	51	69	82
$\overline{X}$	13	30	38	64	80	93
VAR	273	108	177	128	108	89
SD	17	10	13	11	10	9

before the trunk regained the midline position (100% of cycle), and this was observed in 17 of the 19 subjects (89%) in which the muscle was active.

In summary, the pattern of activity in the left erector spinae muscle during trunk rotation was variable with more consistency displayed during rotation to the left. During rotation to the left, the muscle became active as the trunk moved from midline toward the left, peak activity occurred past the extreme left position and activity stopped as the trunk moved from the extreme left position back toward midline. During rotation to the right, the muscle became active as the trunk moved from midline toward the right, peak activity occurred past the extreme right position and activity stopped before the trunk regained the midline position.

RIGHT UPPER LATERAL OBLIQUE

The positional data for this muscle are presented in Table 23. It can be seen that the sequence of muscle activity was consistent across the 20 subjects for rotation in both directions.

During rotation to the left the mean position of onset occurred at 1% of the cycle, as the trunk moved away from the midline position (0% of cycle) toward the left. The mean position of peak activity was 24% of the cycle, just before the trunk reached the extreme left position (25% of cycle) and the mean cessation position was 46% of the cycle, immediately before the trunk reached the midline position (50% of cycle) from the extreme left position.

TABLE 23. RIGHT UPPER LATERAL OBLIQUE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

SUBJECT	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	0	24	45	53	72	91
2	0	24	50	50	72	100
3	0	24	47	50	75	92
4	0	23	40	50	75	88
5	2	25	40	50	73	100
6	0	25	50	53	75	100
7	0	24	50	52	74	91
8	0	24	41	51	75	75
9	0	25	50	50	74	85
10	0	24	50	50	71	92
11	0	21	40	50	73	78
12	0	25	46	50	66	95
13	3	25	43	50	73	96
14	0	25	50	50	70	100
15	1	25	34	51	70	76
16	3	25	44	55	74	98
17	0	25	50	50	69	100
18	0	25	46	50	73	86
19	17	25	50	51	73	82
20	0	25	48	57	74	96
$\overline{X}$	1	24	46	51	73	91
VAR	15	1	23	2	6	70
SD	4	1	5	1	2	8

During rotation to the right, the mean onset position occurred at 51% of the cycle, as the trunk moved toward the right. The mean peak position was at 73% of the cycle, before the trunk reached the extreme right position (75% of cycle), and the mean cessation position was at 91% of the cycle, before the trunk returned to the midline position (100% of cycle).

In summary, when rotation to the left occurred, the right upper lateral oblique muscle became active at the beginning of the cycle, peak activity occurred just before the extreme left position was reached, and the muscle stopped being active before the trunk returned to midline. During rotation to the right, the onset of activity also occurred at the beginning of the cycle with peak activity occurring before the extreme right position was reached and cessation of activity occurring before the trunk returned to midline. The pattern of muscle activity was consistent across all 20 subjects.

RIGHT LOWER LATERAL OBLIQUE

The raw data for onset, peak and cessation of muscle activity are presented in Table 24. It can be seen that the activity pattern was variable during rotation to the left, but was more consistent during rotation to the right.

During rotation to the left, the muscle was inactive in five subjects (25%). In nine of the 15 subjects (60%) in which the muscle was active, onset occurred before the trunk reached the extreme left position (25% of cycle), while in the remaining six subjects (40%) onset occurred after the trunk reached the extreme left position (25% of cycle).

TABLE 24. RIGHT LOWER LATERAL OBLIQUE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
SUBJECT	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	45	50	50	50	72	75
2	12	24	48	50	70	87
3	1	24	49	50	75	93
4	--	--	--	50	69	75
5	26	38	50	50	74	75
6	12	27	38	51	75	97
7	--	--	--	57	74	75
8	--	--	--	51	75	81
9	--	--	--	51	72	75
10	26	49	50	97	100	100
11	7	25	25	50	74	96
12	26	33	50	50	72	80
13	9	25	48	51	73	99
14	20	31	32	53	71	95
15	28	47	50	90	100	100
16	--	--	--	47	74	100
17	3	50	50	50	73	97
18	26	48	50	50	59	100
19	0	25	50	50	74	98
20	5	25	40	47	69	100
$\bar{X}$	16	35	45	55	75	90
VAR	167	121	63	181	87	112
SD	13	11	8	14	9	11

Peak position was also variable. In nine of the 15 subjects (60%) in which the muscle was active, peak activity occurred close to the extreme left position, while in the remaining 40% of subjects, peak activity occurred closer to the midline position (50% of cycle). The average position at which the muscle ceased activity was 45%, with 80% of subjects showing this pattern.

In rotation to the right, the average onset position was 55% of the cycle as the trunk moved away from the midline (50% of cycle) toward the right and this was the pattern of activity seen in 90% of subjects. Peak muscle activity occurred, on average, at the 75% or extreme right position of the cycle. In 75% of subjects, peak activity occurred close to the extreme right position. On average, muscle activity ceased at the 90% position of the cycle, as the trunk approached the midline.

In summary, activity in the right lower lateral oblique muscle was consistent during rotation to the right with onset of activity at the beginning of the cycle, peak activity occurring as the trunk reached the extreme right position and cessation of activity as the trunk returned to midline. The pattern of muscle activity was less consistent during rotation to the left. Five subjects showed no activity but, in general, the muscle became active as the trunk moved from midline to the extreme left, peak activity occurred as the trunk began to move back to midline from the extreme left, and activity stopped as the trunk neared the midline position.

RIGHT ERECTOR SPINAE

Table 25 displays the onset, peak and cessation positions for this muscle. It can be seen that there was great variation in the pattern of the muscle activity across the 20 subjects.

During rotation to the left, the muscle was inactive in one subject (5%). For the entire group the mean onset time occurred at the 12% position of the rotation cycle, that is, before the trunk reached the extreme left position (25% of cycle). This was the pattern observed in 15 of the 19 subjects (79%) in which the muscle was active. Peak activity occurred, on average, at the 27% position of the cycle as the trunk began to move from the extreme left position (25% of cycle) back toward midline. In 14 of the 19 subjects (74%) in which the muscle was active, peak activity occurred close to the extreme left position. The muscle ceased activity, on average, at the 44% position of the cycle before the trunk regained the midline position (50% of cycle).

During rotation to the right, the muscle became active, on average, at the 59% position of the cycle, before the trunk reached the extreme right position (75% of cycle). This was the pattern observed in 85% of subjects. Mean peak muscle activity occurred at the 76% position of the cycle. In 15 subjects (75%), peak activity occurred close to the point where the trunk reached the extreme right position. Muscle activity ceased, on average, at the 83% position of the cycle as the trunk moved from the extreme right position back to midline (100% of cycle) and this was the pattern observed in 75% of subjects.

TABLE 25. RIGHT ERECTOR SPINAE

ONSET-PEAK-CESSATION POSITIONS AS PERCENTAGE OF TOTAL CYCLE

	LEFT TURN AND RETURN			RIGHT TURN AND RETURN		
SUBJECT	ONSET	PEAK	CESSATION	ONSET	PEAK	CESSATION
1	0	9	24	72	75	75
2	0	21	32	66	89	100
3	3	24	46	51	75	80
4	16	25	40	53	73	75
5	6	23	31	55	76	85
6	25	33	46	50	75	81
7	6	34	49	50	75	85
8	20	35	55	75	92	100
9	11	40	55	59	79	80
10	25	34	50	52	74	75
11	25	33	50	58	59	79
12	6	23	47	50	71	75
13	--	--	--	60	75	96
14	20	26	49	56	71	82
15	15	39	55	80	84	86
16	25	27	40	54	74	79
17	10	18	35	81	90	95
18	0	27	49	57	63	71
19	22	25	39	53	73	77
20	0	24	44	51	75	75
$\overline{X}$	12	27	44	59	76	83
VAR	94	58	77	103	65	78
SD	10	8	9	10	8	9

In summary, the sequence of activity of the right erector spinae during rotation was variable, although there was more consistency during rotation to the right. During rotation to the left, the muscle became active as the trunk moved from midline toward the left, peak activity occurred close to the extreme left position and muscle activity stopped before the trunk regained the midline position. During rotation to the right, the muscle became active as the trunk moved from the midline toward the right, peak activity occurred close to the extreme right position and activity ceased as the trunk moved from the extreme right back to midline.

COMPARISON OF POSITIONAL EVENTS

The mean values for the onset and peak positions for the 20 subjects were used to compare the sequence of activity in the six muscles during rotation to the left and right. Cessation times were considered to be too variable and were not used. A summary of these values and the rank order of recruitment of the muscles is presented in Table 26.

In order to determine that the difference in the sequence of events was significant, the mean onset and peak data for each muscle were compared to those of all the other muscles and were analyzed using a paired t Test for data with similar variances and the Wilcoxon Signed-Ranks Test for Two Groups (Sokal and Rohlf, 1981) for data with unequal variances. There were 15 possible muscle combinations for each parameter and the summaries of the results of the statistical analyses are presented in Tables 27 to 30.

TABLE 26. SUMMARY OF ONSET AND PEAK MUSCLE ACTIVITY DATA EXPRESSED AS THE MEAN PERCENTAGE OF ROTATION CYCLE

ROTATION TO THE LEFT ( ) = Rank Order of Event

MUSCLE	ONSET	PEAK
Left Upper Lateral Oblique	0 (1)	24 (2)
Left Lower Lateral Oblique	0 (1)	23 (1)
Left Erector Spinae	13 (4)	30 (4)
Right Upper Lateral Oblique	1 (2)	24 (2)
Right Lower Lateral Oblique	16 (5)	35 (5)
Right Erector Spinae	12 (3)	27 (3)

ROTATION TO THE RIGHT ( ) = Rank Order of Event

MUSCLE	ONSET	PEAK
Left Upper Lateral Oblique	51 (1)	74 (2)
Left Lower Lateral Oblique	68 (5)	86 (6)
Left Erector Spinae	64 (4)	80 (5)
Right Upper Lateral Oblique	51 (1)	73 (1)
Right Lower Lateral Oblique	55 (2)	75 (3)
Right Erector Spinae	59 (3)	76 (4)

In Table 26 it can be seen that the left upper lateral oblique, left lower lateral oblique and right upper lateral oblique became active at the beginning of the rotation cycle as the trunk moved from the midline toward the left. When the trunk was approximately halfway between the midline and the extreme left position, the right erector spinae, left erector spinae and right lower lateral oblique became active and their onset positions were not significantly different (Table 27).

In Table 26 it is shown that peak activity occurred first in the left lower lateral oblique followed by the left upper lateral oblique and the right upper lateral oblique, all occurring before the trunk reached the extreme left position. Peak activity in the right and left erector spinae muscles occurred when the trunk moved past the extreme left position and began to return to midline. While the right lower lateral oblique showed peak activity last compared to the other muscles, its peak position was not significantly different from that of the left erector spinae (Table 28). Both muscles showed peak activity when the trunk was approximately halfway between the extreme left position and midline.

Table 26 shows that, during rotation to the right, the left upper lateral oblique and right upper lateral oblique were recruited immediately as the trunk began to rotate from the midline position toward the right. There was no significant difference between the onset positions of these two muscles (Table 29). The next muscles to be recruited were the right lower lateral oblique and right erector spinae; there was no significant difference between their onset positions, nor was there a significant difference between the onset positions of the right erector

TABLE 27. SUMMARY OF THE STATISTICAL ANAYLSES OF THE COMPARISON OF ONSET POSITIONS--ROTATION TO THE LEFT

MUSCLE vs	MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	0	0	NS
LULO	LES	-13	4	.01
LULO	RULO	-1	1	NS
LULO	RLLO	-16	3	.01
LULO	RES	-12	2	.01
LLLO	LES	-13	4	.01
LLLO	RULO	-1	1	NS
LLLO	RLLO	-16	3	.01
LLLO	RES	-12	2	.01
LES	RULO	+12	4	.01
LES	RLLO	-1	0	NS
LES	RES	+1	0	NS
RULO	RLLO	-15	4	.01
RULO	RES	-11	2	.01
RLLO	RES	+6	5	NS

α = .05

KEY: LULO = Left Upper Lateral Oblique

LLLO = Left Lower Lateral Oblique

LES = Left Erector Spinae

RULO = Right Upper Lateral Oblique

RLLO = Right Lower Lateral Oblique

RES = Right Erector Spinae

TABLE 28. SUMMARY OF THE STATISTICAL ANALYSES OF THE COMPARISON OF PEAK POSITIONS--ROTATION TO THE LEFT

MUSCLE vs	MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	+1	1	NS
LULO	LES	-7	2	.05
LULO	RULO	-1	0	.01
LULO	RLLO	-11	3	.01
LULO	RES	-4	2	.05
LLLO	LES	-8	3	.01
LLLO	RULO	-2	1	.01
LLLO	RLLO	-12	3	.01
LLLO	RES	-5	2	.01
LES	RULO	+6	3	.05
LES	RLLO	-4	3	NS
LES	RES	+3	3	NS
RULO	RLLO	-10	3	.01
RULO	RES	-3	2	.05
RLLO	RES	+10	4	.05

$\alpha = .05$

KEY: LULO = Left Upper Lateral Oblique
LLLO = Left Lower Lateral Oblique
LES = Left Erector Spinae
RULO = Right Upper Lateral Oblique
RLLO = Right Lower Lateral Oblique
RES = Right Erector Spinae

TABLE 29. SUMMARY OF THE STATISTICAL ANALYSES OF THE COMPARISON OF ONSET POSITIONS--ROTATION TO THE RIGHT

MUSCLE vs	MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	-17	3	.01
LULO	LES	-13	3	.01
LULO	RULO	0	0	NS
LULO	RLLO	-4	3	.05
LULO	RES	-9	2	.01
LLLO	LES	+3	3	NS
LLLO	RULO	+17	3	.01
LLLO	RLLO	+13	6	.01
LLLO	RES	+9	4	.05
LES	RULO	+13	3	.01
LES	RLLO	+9	3	.01
LES	RES	+5	4	NS
RULO	RLLO	-4	3	.01
RULO	RES	-8	2	.01
RLLO	RES	-4	3	NS

$\alpha = .05$

KEY: LULO = Left Upper Lateral Oblique
LLLO = Left Lower Lateral Oblique
LES = Left Erector Spinae
RULO = Right Upper Lateral Oblique
RLLO = Right Lower Lateral Oblique
RES = Right Erector Spinae

spinae and the left erector spinae. The last muscle to become active was the left lower lateral oblique, when the trunk was approximately halfway between midline and the extreme right position.

Peak activity, as shown in Table 26, occurred first in the right upper lateral oblique, followed by the left upper lateral oblique, both occurring before the trunk reached the extreme right position. There was no significant difference between the peak activity positions of the right lower lateral oblique, the right erector spinae and the left erector spinae, all of which occurred as the trunk reached the extreme right position (Table 30). Peak activity occurred last in the left lower lateral oblique, when the trunk was approximately halfway between the extreme right position and midline.

In summary, during rotation to the left, the left upper lateral oblique, left lower lateral oblique and right upper lateral oblique became active first and showed peak activity before the trunk reached the extreme left position. The right erector spinae, left erector spinae and right lower lateral oblique became active when the trunk was approximately halfway between midline and the extreme left and showed peak activity when the trunk moved past the extreme left position back toward midline.

During rotation to the right the left upper lateral oblique and right upper lateral oblique became active first and showed peak activity before the trunk reached the extreme right position. The right lower lateral oblique, right erector spinae and left erector spinae were recruited next and showed peak activity when the trunk reached the extreme right position. The left lower lateral oblique muscle was

TABLE 30. SUMMARY OF THE STATISTICAL ANALYSES OF THE COMPARISON OF PEAK POSITIONS--ROTATION TO THE RIGHT

MUSCLE vs	MUSCLE	MEAN DIFFERENCE	STANDARD ERROR OF THE MEAN	P VALUE
LULO	LLLO	-12	2	.01
LULO	LES	-6	3	.05
LULO	RULO	+2	0	.01
LULO	RLLO	-1	2	.05
LULO	RES	-2	2	.05
LLLO	LES	+6	2	.05
LLLO	RULO	+14	2	.01
LLLO	RLLO	+11	3	.01
LLLO	RES	+10	4	.05
LES	RULO	+7	3	.01
LES	RLLO	+5	3	NS
LES	RES	+3	3	NS
RULO	RLLO	-2	2	.05
RULO	RES	-3	2	.01
RLLO	RES	-1	2	NS

α = .05

KEY: LULO = Left Upper Lateral Oblique
LLLO = Left Lower Lateral Oblique
LES = Left Erector Spinae
RULO = Right Upper Lateral Oblique
RLLO = Right Lower Lateral Oblique
RES = Right Erector Spinae

recruited last when the trunk was approximately halfway between midline and the extreme right position and it showed peak activity when the trunk was approximately halfway between the extreme right position and midline.

CHAPTER V

DISCUSSION

MEASUREMENT OF ROTATION

(Please note Tables 7 to 10 in the Results).

A non-invasive technique for measuring thoracolumbar rotation was developed and used to measure the amount of axial rotation in 20 female subjects. Using plastic thoracic and pelvic girdles and an attached electrogoniometer, it was found that, when the thoracic girdle was aligned with the T_{10} spinous process, the average amount of rotation to each of the right and left sides was approximately 24^{o}, for a total side-to-side rotation of 48^{o}.

The average total amount of rotation found in this study differs substantially from the amount of 36.5^{o} measured by Gregersen and Lucas (1967) and the 19^{o} derived from the literature by White and Panjabi (1978) for the T_{10} to sacrum spinal segment. However, as mentioned previously, the data in the Gregersen and Lucas study were collected from a very small number of subjects and therefore were possibly not representative of the general population. Also, because an invasive technique was used, pain may have limited the amount of trunk rotation that the subjects could perform. The values cited by White and Panjabi (1978) were derived from a review of the literature that did not include the work of Gregersen and Lucas (1967) on the thoracolumbar spine or of Lumsden and Morris (1968) on the L_4-S_1 spinal segment, and therefore most likely represent data from experiments on cadaver specimens which should not be compared to *in vivo* data.

It is also possible that the goniometer used in the present study measured the amount of rotation in a spinal segment longer than T_{10} to the sacrum. On the basis of the preliminary study it was felt that the spinal segment being measured was T_{10} to the sacrum; however because the technique used to measure rotation was non-invasive, a precise delimitation of the spinal segment was not possible. In order to compare the amount of rotation across subjects it is essential that the same spinal segment be measured in each case. The variation in the amount of rotation between the 20 subjects in this study was low as indicated by the standard deviations of 4.3 and 4.8 during left and right turns respectively in Trial 1, and of 4.3 and 4.1 for left and right turns during Trial 2. Therefore, it would appear that, by aligning the thoracic girdle with the T_{10} spinous process, the same spinal segment is being measured in each subject.

When the results of this investigation are studied, it can be seen that the amount of rotation to the left was less in Trial 2 for 13 (65%) subjects and during rotation to the right was less in Trial 2 for 14 (70%) subjects. This could be the result of a variety of factors such as fatigue, discomfort, slipping of the girdles, lack of effort on the part of the subjects or unreliability of the electro-goniometer. To decrease the possible effect of fatigue, subjects were allowed to rest for 10 minutes between trials. Discomfort from the restriction of the girdles might also account for the discrepancy. In this case, however, a greater difference would be expected in the data for Trial 2 between subjects in Group A who rested with the girdles in place and subjects in Group B who rested with the girdles off. No significant difference was found between the two groups during Trial 2, although it could be argued that removal of the girdles for 10 minutes had no effect on the discomfort experienced by the subject when the girdles were reapplied and the subject was required to perform the rotation exercise for the second time. Movement of the body inside the girdles, or slipping, could also lead to a decrease in rotation from Trial 1 to Trial 2. If this were the case, the amount of rotation recorded from subjects in Group B during Trial 2 should have been greater than that from Group A during Trial 2 as the girdles were reapplied securely to the subjects in Group B at the beginning of Trial 2. However, no significant difference was found and it was concluded that slipping did not contribute to the decrease in rotation in the second trial. To ensure that the effort put forth by the subjects was similar, all subjects were instructed to rotate as far as possible to each side during both trials of the exercise and the cadence of the metronome was constant throughout the experiment. However, because the second trial was familiar, subjects may not have tried as hard on the second trial with a consequent loss of several degrees of movement.

To test the reliability of the goniometer, it was first established that the subjects in Groups A and B were statistically similar with respect to rotation when the same procedure, that is, the protocol of Trial 1, was applied to them. If, prior to Trial 2, the goniometer was applied differently to Group A from Group B, a significant difference in the amount of rotation would be expected if the goniometer were unreliable. The null hypothesis for this reasoning was that there was no difference in the amount of rotation between Group A and Group B during Trial 2. The difference between the two groups proved to be not significant and therefore the null hypothesis was accepted. While it would appear that the goniometer used in this study was reliable, a further investigation could be carried out in which more repetitions are required.

The mean difference in the amount of rotation between Trial 1 and Trial 2, while statistically significant to the right, is small-- 1.6° to the left and 1.7° to the right. The discrepancy is attributed to decreased effort on the part of the subject during the second trial.

MUSCLE ACTIVITY DURING ROTATION

COMPARISON OF THE DATA TO THOSE OF PREVIOUS STUDIES

Few investigators have studied the role of the abdominal muscles during trunk rotation in the sitting position. Walters and Partridge (1957) and Partridge and Walters (1959) found that rotation of the trunk in the sitting position was executed almost entirely by the internal oblique muscle with little participation from the external oblique muscle. If the muscles that they designated as internal oblique and external oblique were considered to be the lower lateral oblique and upper lateral oblique respectively, the data from the present study do not support the findings of these two researchers. It was found in the present investigation that both the upper and lower lateral oblique muscles were active throughout the cycle of rotation with both contralateral and ipsilateral upper lateral obliques recruited first in the cycle, followed soon after by the ipsilateral lower lateral oblique. During rotation the contralateral upper lateral oblique and the ipsilateral lower lateral oblique showed the greatest amount of electrical activity of the six muscles studied and there was no significant difference in their level of activity.

Carman et al. (1971) observed that the contralateral external oblique was the most active muscle during trunk rotation. The results of the present study agree with those of Carman et al. (1971) in that the contralateral upper lateral oblique showed the greatest amount of electrical activity, however, there was no significant difference between the amount of electrical activity of the contralateral upper lateral oblique, and the ipsilateral lower lateral oblique.

The statement of Farfan (1975) that the oblique abdominal muscles are chiefly responsible for producing a torque on the lumbar spine is supported by the data from this study. The upper lateral oblique muscles become active early in the rotation cycle and the muscles that show the greatest amount of electrical activity during rotation are the contralateral upper lateral oblique and the ipsilateral lower lateral oblique.

In studies of the erector spinae muscle, Portnoy and Morin (1956) found that this muscle was active bilaterally during trunk rotation and that the muscle of either side could predominate regardless of the direction of rotation. In the present study it was also observed that both left and right erector spinae muscles were active during trunk rotation, however the ipsilateral muscle was significantly more active than the contralateral in the majority of subjects (85% during rotation to the left, 70% during rotation to the right).

Morris et al. (1962) and Waters and Morris (1970) observed that the ipsilateral erector spinae is active during trunk rotation and they stated that this activity served to stabilize the trunk rather than to initiate movement. The opinion that erector spinae does not initiate rotation is supported by the present study. Onset positions of both contralateral and ipsilateral erector spinae were significantly different from those of the upper lateral obliques which became active at the beginning of the rotation cycle. While it may be possible that the erector spinae acts as a stabilizer, the greater amount of electrical activity in the ipsilateral muscle suggests that the muscle may, in fact, have a role in rotation *per se*.

Jonsson (1970) found that the ipsilateral iliocostalis and the contralateral longissimus in the lower lumbar area were active during trunk rotation. No attempt was made in the present study to distinguish between the individual segments of erector spinae in the lower lumbar area as, according to major anatomy texts, the muscle does not divide into three columns until the upper lumbar area (Gray's Anatomy, 1973; Hollinshead, 1976; Grant's Method, 1980). However, the finding that erector spinae was active bilaterally during both left and right phases of the rotation cycle is not inconsistent with the observations of Jonsson (1970).

Donisch and Basmajian (1972) observed that the long back muscles in the lumbar area were active during trunk rotation although they were less active than the same muscles in the thoracic region. They also found that the lumbar muscles were active contralaterally in 56% of subjects, ipsilaterally in 12% of subjects and showed activity unrelated to the side of rotation in 28% of subjects with the activity being even more inconsistent when the subject returned to the starting position from the rotated position. The levels of electrical activity found in the present study do not support the findings of Donisch and Basmajian (1972). During rotation to the left, 85% of the subjects showed greater activity in the ipsilateral erector spinae, 15% in the contralateral muscle; during rotation to the right, 70% of subjects showed greater activity in the ipsilateral erector spinae, 30% in the contralateral muscle. The onset and peak positions of the erector spinae muscles were, however, very variable. During rotation to the left, peak activity of the right erector spinae occurred in 63% of subjects when the trunk reached the extreme left position and began to return to the midline, in effect, when the trunk was rotating to the right. During rotation to the right, peak activity of the left erector spinae occurred in 63% of subjects when the trunk reached the extreme right position and began to return to the midline, in effect, when the trunk was rotating to the left.

Afanasiev (1980) observed that there was a difference in activity levels between right and left long back muscles only in the thoracic region with the ipsilateral muscles predominating in trunk rotation. Again, the data from the present study do not support the inference that no difference exists in activity levels of long back muscles in the lumbar area. There was a statistically significant difference in the electrical activity of each erector spinae between rotation to the left and rotation to the right.

Two previous studies have investigated the simultaneous role of abdominal and back muscles during trunk rotation. Carlsöö (1961) proposed that the deep back muscles initiate rotation with the lateral abdominal muscles being mobilized secondarily. The findings of the present study do not support this sequence of recruitment as it was observed that the two upper lateral obliques and the ipsilateral lower lateral oblique became active at a point in the rotation cycle before the two erector spinae muscles became active. Rab et al. (1977), in their study of cadaver specimens, determined that the contralateral external oblique and quadratus lumborum plus the ipsilateral internal oblique and erector spinae are active in trunk rotation. Because the study was conducted with *post mortem* material, investigation of the recruitment of muscles was impossible. Data from the present study support the assertion that the contralateral upper lateral oblique and ipsilateral lower lateral oblique and erector spinae, among other muscles, are active during trunk rotation.

POSSIBLE ROLES OF MUSCLES DURING ROTATION

In order to discuss the function of the anterolateral abdominal and erector spinae muscles during rotation, it is necessary to have a classification of muscle function. That of Gowitzke and Milner (1980) will be used and is presented in Table 31.

As can be seen from Tables 11-16, the amount of electrical activity observed in each of the six muscles under investigation was very variable from person to person. The variation may be due to the fact

TABLE 31. CLASSIFICATION OF MUSCLE FUNCTION

1. PRIME MOVER - A muscle that makes the major contribution to movement.

2. ANTAGONIST - A muscle whose action is opposite to that of the prime mover and which is silent when the prime mover contracts strongly.

3. SYNERGIST - A muscle which cooperates with the prime mover so as to enhance movement.

   (a) Conjoint Synergist - Two muscles that act together to produce a movement which neither could produce alone.

   (b) Neutralizing or Counteracting Synergist - Muscles that contract to prevent undesirable movement that would result from the unopposed action of another muscle or muscles that cross two or more joints.

   (c) Stabilizing Synergists - Muscles that contract to stabilize more proximal joints so that the distal segments can move effectively.

(Gowitzke and Milner, 1980, pp. 107-109) that the electrical output of the muscle during rotation was expressed as a percentage of a maximum voluntary contraction of that muscle and it was not possible to determine if the MVC, in fact, represented the maximum possible output for that muscle. It may be also that differences in body length between subjects result in muscles moving lever arms of varying lengths with more effort required to move a longer lever arm. No attempt was made in this study to correlate muscle activity with body length and possibly this relationship should be investigated. The variation in muscle activity might also be attributed to biological differences although this appears unlikely when the data are compared to those for rotation which have a much smaller variance.

Despite the variation, a pattern of activity is evident. With the exception of the left upper lateral oblique, the muscles are significantly more active during rotation to one side than to the other with the right upper lateral oblique, left lower lateral oblique and left erector spinae muscle more active during rotation to the left, and the left upper lateral oblique, right lower lateral oblique and right erector spinae more active during rotation to the right. On the basis of this greater electrical activity during rotation to a particular side, these muscles can be termed prime movers. In addition, recruitment of these muscles also followed a pattern with the upper lateral obliques and ipsilateral lower lateral oblique becoming active at the beginning of the cycle before activity began in the ipsilateral erector spinae (see Table 26). Across the 20 subjects there is no consistent pattern of activity in either peak positions or in cessation positions.

However, in 72% of the subjects, peak activity occurs in the upper lateral obliques before the trunk reaches the position of extreme rotation while the peak activity of both erector spinae muscles and the contralateral lower lateral oblique occurs after the trunk begins to move from the position of extreme rotation back to the midline. No consistent pattern of activity is evident in the cessation positions.

In the majority of subjects, all six muscles were active throughout the cycle of rotation. However, during rotation to the left, the right lower lateral oblique was totally inactive in five subjects (25%) and the right erector spinae was inactive in one subject (5%). During rotation to the right, the left lower lateral oblique was inactive in one subject (5%) and the left erector spinae was inactive in one subject (5%). This inactivity would be predicted on the basis of reciprocal inhibition of antagonists when prime movers are strongly active (Guyton, 1976; Gowitzke and Milner, 1980). The fact that inactivity is seen in so few subjects is surprising and suggests that these muscles have an important function, perhaps synergistic, during rotation.

One of the functions of the contralateral lower lateral obliques during rotation could be that of pulling the trunk back to midline from the position of extreme rotation to the opposite side. For instance, the right lower lateral oblique acts to pull the trunk back toward midline from the extreme left position. This concept is supported by the fact that in 79% of the 19 subjects in which it was active, the peak activity of the left lower lateral oblique during rotation to the right occurred after the extreme right position was reached and the trunk began to turn back toward midline. Correspondingly, in 60% of the 15 subjects in which it was active, the peak activity of the right lower lateral oblique during rotation to the left occurred after the extreme left position was reached and the trunk began to turn back toward midline. Therefore, the contralateral lower lateral oblique could be considered as a prime mover for trunk rotation from the extreme opposite position.

In addition, there is some similarity in the pattern of activity of the contralateral lower lateral oblique and erector spinae muscles. During rotation to the left the average amount of electrical activity put forth by the right lower lateral oblique was 16% of MVC and that of the right erector spinae was 9% of MVC; during rotation to the right the average amount of electrical activity put forth by the left lower lateral oblique was 11% of MVC and that of the left erector spinae was 10% of MVC. There was no significant difference in the amount of electrical activity between these two contralateral muscles during rotation. Also, during rotation to the left, there was no significant difference in the onset positions of the right lower lateral oblique and the right erector spinae; while during rotation to the right there was no significant difference between the onset positions of the left lower lateral oblique and the left erector spinae. This similarity in activity between the anteriorly placed contralateral lower lateral oblique and the posteriorly placed contralateral erector spinae suggests that these two muscles may act together as stabilizing synergists to study the upper trunk as it rotates on the fixed pelvis.

The erector spinae muscle may have another function besides acting as a prime mover during rotation to the ipsilateral side and as a stabilizing synergist with the lower lateral oblique during rotation to the contralateral side. The two erector spinae muscles may act as neutralizing or counteracting synergists to prevent trunk flexion during the contraction of the anteriorly placed contralateral lower lateral oblique which works to pull the trunk back to midline from the extreme opposite position. The tendency for trunk flexion to occur is increased when the upper limbs are raised in front of the body, as they were in this experiment, in effect, creating a lever arm with a force that lies anterior to the centre of mass of the body and which would pull the trunk into flexion. When the peak activity positions of the erector spinae muscles are compared to that of the contralateral lower lateral oblique during rotation, it can be seen that, although significantly different, peak activity in all muscles occurred when the trunk was moving from the extreme opposite position back toward midline. In addition, the levels of electrical activity of the contralateral lower lateral oblique compared to those of the erector spinae muscles show no significant difference during trunk rotation (see Tables 12 and 13).

In summary, it would appear that the erector spinae muscles have three possible functions during thoracolumbar rotation: as prime movers, as stabilizing syngerists and as neutralizing synergists.

The ipsilateral upper lateral oblique muscle is strongly active during rotation, ranking third in amount of activity after the contralateral upper lateral oblique and the ipsilateral lower lateral oblique, two of the prime movers. This large amount of electrical activity suggests that the muscle must play a specific role during trunk rotation. If the amount of electrical activity put forth by the ipsilateral and contralateral upper lateral oblique muscles were equal, rotation would likely be prevented and the tendency instead would be toward trunk flexion. However, this was not the case, the contralateral upper lateral oblique was significantly more active than its ipsilateral counterpart. When the pattern of muscle activity is examined, it can be seen that there was no significant difference in the position of onset of muscle activity in the two upper lateral oblique muscles during rotation to the left or right. It is proposed that the ipsilateral upper lateral oblique contracts simultaneously with the contralateral upper lateral oblique in order to stabilize the aponeurotic sheath of the rectus abdominis muscle and the linea alba. This will create a firm base from which the contralateral upper lateral oblique muscle, working with reversed origin and insertion, can contract to pull the upper trunk into rotation.

APPLICATION

One of the purposes of this study was to establish normal baseline data which could later be compared to data obtained from female subjects with adolescent idiopathic scoliosis in order to determine if differences exist between the two groups. A non-invasive technique was developed to measure the range of spinal rotation and was used, in conjunction with electromyography, to pinpoint specific positional events in the activity of anterolateral abdominal and erector spinae muscles during thoracolumbar rotation. An average range of movement was established for rotation in a spinal segment from the T_{10} spinous process to the sacrum and can be compared to the range in the same segment in subjects with scoliosis. Patterns of muscle activity were found in the majority of subjects and specific functions for the muscles have been proposed. These patterns can be compared to those of scoliotic subjects to determine if there is a difference in muscle function.

The combination of electromyography of abdominal and back muscles and electrogoniometry of the thoracolumbar spine could also be used to investigate the patterns of muscle activity that occur in normal persons during various types of locomotion. This, in turn, might be applied to investigation of range of movement and muscle activity in subjects with different types of spinal pathology. Also, the same technique could be used in ergonomic studies to investigate trunk movement and the role of trunk muscles during the performance of upper or lower limb activities.

Knowledge of the patterns of vertebral movement and of the function of abdominal and back muscles is essential for those health care personnel who are involved in the prevention of spinal pathology as well as in the early treatment and rehabilitation of persons with spinal dysfunction. Inquiry into the mechanisms of movement is essential as it is only through an understanding of the normal organism that insight into the nature of dysfunction can be gained.

CHAPTER VI

SUMMARY

The purpose of this study was to establish a non-invasive technique for measuring thoracolumbar rotation of the spine and to investigate the activity of the anterolateral and erector spinae muscles during spinal rotation in normal female subjects. This was done in order to establish normal baseline data for a subsequent study of adolescent idiopathic scoliosis.

An electrogoniometer was developed which could measure horizontal rotation in a defined spinal segment. It was attached to the body of the subject by thermoplastic thoracic and pelvic girdles. The accuracy and reliability of the goniometer were checked and found to be within acceptable limits.

The results of a cadaver survey and a pilot study indicated that specific areas in which external oblique and internal oblique could be isolated could not be found consistently from subject to subject. Therefore, the anterolateral muscles were considered as a group and surface electrodes were placed as follows: on the left upper lateral oblique, left lower lateral oblique, left erector spinae, right upper lateral oblique, right lower lateral oblique and right erector spinae.

To facilitate evaluation, the raw EMG signal was converted into a linear envelope by full wave rectification and low pass filtering processing. The goniometer tracing and EMG signal were recorded simultaneously on a moving chart.

Twenty healthy female volunteers were required to perform a defined rotation exercise while in the sitting position. The exercise consisted of five cycles of rotation done to a cadence set by a metronone.

Each cycle involved turning from the midline to one side, back to midline, to the opposite side and back to midline. The complete exercise was performed twice with a ten minute rest between trials.

The amount of rotation to each side was measured from the goniometer tracing. The amount of electrical activity generated by each muscle was determined by measuring the area of the linear envelope over a specific period of time, giving an integrated electromyogram. The resultant value was expressed as a percentage of the integrated EMG of the maximum voluntary contraction for that muscle. The positions of the onset, peak and cessation of muscle activity were marked on the chart, compared to the goniometer tracing, and were ultimately expressed as points occurring at a specific percentage of the total rotation cycle.

The total average amount of thoracolumbar rotation in the spinal segment measured from the T_{10} spinous process to the sacrum was 48°. All six muscles were active during both left and right phases of the rotation cycle except in a few subjects. Muscle function was classified according to the system proposed by Gowitzke and Milner (1980). The muscles showing the greatest amount of electrical activity were considered to be prime movers and these were the contralateral upper lateral oblique, the ipsilateral lower lateral oblique and the ipsilateral erector spinae. The contralateral lower lateral oblique appears to function as a prime mover to pull the trunk back toward the midline from the extreme ipsilateral position. The muscles displaying less electrical activity were considered to be synergists. It is proposed that the contralateral lower lateral oblique, in addition to its function as a prime mover, acts as a stabilizing synergist with the erector spinae of the same side. These two muscles steady the upper trunk as it rotates over the fixed pelvis. The erector spinae muscle, besides acting as a prime mover ipsilaterally and a stabilizing synergist contralaterally, may act bilaterally as a neutralizing synergist to prevent trunk flexion that might result during contraction of the contralateral lower lateral oblique as the trunk rotates from the extreme ipsilateral position back to midline. The role of the ipsilateral upper lateral oblique may be that of stabilizer for the aponeurotic sheath of rectus abdominis and the linea alba. This stabilization would allow the contralateral upper lateral oblique to contract with reverse origin and insertion in order to effect rotation of the upper trunk.

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APPENDIX A

ROTATION STUDY
DATA CAPTURE SHEETS

SUBJECT

HEIGHT .

WEIGHT .

AGE .

HANDEDNESS
LEFT = 1
RIGHT = 2

FIRST TURN
LEFT = 1
RIGHT = 2

MAXIMUM ELECTRICAL ACTIVITY IN 1 SECOND [M.V.C.]

RULO

LULO

RLLO

LLLO

RES

LES

ATTENUATION

RULO

LULO

RLLO

LLLO

RES

LES

RANGE OF ROTATION

FER_1 .

FER_2 .

FER_3 .

FER_4 .

FER_5 .

FEL_1 .

FEL_2 .

FEL_3 .

FEL_4 .

FEL_5 .

SUBJECT ____________

RANGE OF ROTATION

SER1										SER4
SER2										SER5
SER3										SEL1

SEL2										SEL5
SEL3										
SEL4										

MEASURED IN MILLIVOLT-SECONDS AMOUNT OF ELECTRICAL ACTIVITY/CONTRACTION

L1

RULO									LULO
RLLO									LLLO
RES									LES

L2

RULO									LULO
RLLO									LLLO
RES									LES

L3

RULO									LULO
RLLO									LLLO
RES									LES

L4

RULO									LULO
RLLO									LLLO
RES									LES

L5

RULO									LULO
RLLO									LLLO
RES									LES

R1

RULO									LULO
RLLO									LLLO
RES									LES

R2

RULO									LULO
RLLO									LLLO
RES									LES

R3

RULO									LULO
RLLO									LLLO
RES									LES

R4

RULO									LULO
RLLO									LLLO
RES									LES

R5

RULO									LULO
RLLO									LLLO
RES									LES

AS % OF M.V.C.

AMOUNT OF ELECTRICAL ACTIVITY/CONTRACTION

L1

RULO										LULO
RLLO										LLLO
RES										LES

L2

RULO										LULO
RLLO										LLLO
RES										LES

L3

RULO										LULO
RLLO										LLLO
RES										LES

L4

RULO										LULO
RLLO										LLLO
RES										LES

L5

RULO										LULO
RLLO										LLLO
RES										LES

R1

RULO										LULO
RLLO										LLLO
RES										LES

R2

RULO										LULO
RLLO										LLLO
RES										LES

R3

RULO										LULO
RLLO										LLLO
RES										LES

R4

RULO										LULO
RLLO										LLLO
RES										LES

R5

RULO										LULO
RLLO										LLLO
RES										LES

DEGREES   MUSCLE: ______   SUBJECT ______

Left		Right	
LEFT TOTAL$_1$	__ __ . __	RIGHT TOTAL$_1$	__ __ . __
L ON$_1$	__ __ . __	R ON$_1$	__ __ . __
LPK$_1$	__ __ . __	RPK$_1$	__ __ . __
L OFF$_1$	__ __ . __	L OFF$_1$	__ __ . __
LEFT TOTAL$_2$	__ __ . __	RIGHT TOTAL$_2$	__ __ . __
LON$_2$	__ __ . __	RON$_2$	__ __ . __
LPK$_2$	__ __ . __	R PK$_2$	__ __ . __
LOFF$_2$	__ __ . __	R OFF$_2$	__ __ . __
LEFT TOTAL$_3$	__ __ . __	RIGHT TOTAL$_3$	__ __ . __
LON$_3$	__ __ . __	RON$_3$	__ __ . __
LPK$_3$	__ __ . __	RPK$_3$	__ __ . __
LOFF$_3$	__ __ . __	ROFF$_3$	__ __ . __
LEFT TOTAL$_4$	__ __ . __	RIGHT TOTAL$_4$	__ __ . __
LON$_4$	__ __ . __	RON$_4$	__ __ . __
LPK$_4$	__ __ . __	RPK$_4$	__ __ . __
LOFF$_4$	__ __ . __	ROFF$_4$	__ __ . __
LEFT TOTAL$_5$	__ __ . __	RIGHT TOTAL$_5$	__ __ . __
LON$_5$	__ __ . __	RON$_5$	__ __ . __
LPK$_5$	__ __ . __	RRK$_5$	__ __ . __
LOFF$_5$	__ __ . __	ROFF$_5$	__ __ . __

% OF CYCLE

MUSCLE: ____________________ SUBJECT ____________

LEFT TOTAL$_1$	__ __ . __	RIGHT TOTAL$_1$	__ __ . __
L ON$_1$	__ __ . __	R ON$_1$	__ __ . __
LPK$_1$	__ __ . __	RPK$_1$	__ __ . __
L OFF$_1$	__ __ . __	L OFF$_1$	__ __ . __
LEFT TOTAL$_2$	__ __ . __	RIGHT TOTAL$_2$	__ __ . __
LON$_2$	__ __ . __	RON$_2$	__ __ . __
LPK$_2$	__ __ . __	R PK$_2$	__ __ . __
LOFF$_2$	__ __ . __	R OFF$_2$	__ __ . __
LEFT TOTAL$_3$	__ __ . __	RIGHT TOTAL$_3$	__ __ . __
LON$_3$	__ __ . __	RON$_3$	__ __ . __
LPK$_3$	__ __ . __	RPK$_3$	__ __ . __
LOFF$_3$	__ __ . __	ROFF$_3$	__ __ . __
LEFT TOTAL$_4$	__ __ . __	RIGHT TOTAL$_4$	__ __ . __
LON$_4$	__ __ . __	RON$_4$	__ __ . __
LPK$_4$	__ __ . __	RPK$_4$	__ __ . __
LOFF$_4$	__ __ . __	ROFF$_4$	__ __ . __
LEFT TOTAL$_5$	__ __ . __	RIGHT TOTAL$_5$	__ __ . __
LON$_5$	__ __ . __	RON$_5$	__ __ . __
LPK$_5$	__ __ . __	RRK$_5$	__ __ . __
LOFF$_5$	__ __ . __	ROFF$_5$	__ __ . __

APPENDIX B

EXAMPLE OF WILCOXON SIGNED-RANKS TEST FOR TWO GROUPS, ARRANGED AS PAIRED OBSERVATIONS (Sokal and Rohlf, 1981).

Mean Integrated Electrical Activity Levels of the Left Lower Lateral Oblique Muscle Compared to Those of the Left Erector Spinae Muscle During Rotation to the Left.

n = 20

(1) LLLO	(2) LES	(3) D	(4) RANK (R)
19	19	+0	+1
93	1	+92	+18
37	20	+17	+12
33	17	+16	+11
18	4	+14	+9
28	6	+22	+14
22	18	+4	+5
23	11	+12	+7
19	15	+4	+5
19	6	+13	+8
14	11	+3	+4
66	17	+49	+16
25	9	+16	+11
10	4	+6	+6
0	18	-18	-13
24	25	-1	-2
27	12	+15	+10
94	11	+83	+17
30	32	-2	-3
24	56	-32	-15

1. The differences are computed between the 20 pairs of observations. These are entered in Column (3) labelled D.

2. The differences are ranked from the smallest to the largest without regard to sign.

3. The original signs of the differences are assigned to the ranks.

4. The positive and negative ranks are summed separately. In this case, the sum of positive ranks = 154.0 and the sum of negative ranks = 33.0. The sum that is smaller in absolute value, T_s is compared with the values in Table 30 (Sokal and Rohlf, 1981) for n = 20.

   Since T_s = 33.0, which is equal to or less than the entry for two-tailed α = .01 in the table, the observed difference is significant at the 1% level. Mean integrated electrical activity in the left lower lateral oblique muscle is significantly different from that of the left erector spinae muscle during rotation to the left.