The Interrelation of Spinal Curves, Pelvic Tilt and Muscle Lengths in the Adolescent Female

Thoracic kyphosis, lumbar lordosis and pelvic tilt were measured in standing in one hundred and three adolescent females, using a specially designed inclinometer. Indices of the muscle lengths (abdominals, erector spinae, iliopsoas, gluteals, rectus femoris and hamstrings) were measured using inclinometry and goniometry and expressed as angles of joint position.

Multiple regression analysis revealed that the index of erector spinae length was negatively correlated with lumbar lordosis ($r = -0.24$, $p < 0.05$). The abdominal length index was positively correlated with lumbar lordosis ($r = 0.209$, $p < 0.05$), and the hamstring length index was negatively correlated with lordosis ($r = -0.213$, $p < 0.05$).

No muscle length index was significantly related to pelvic tilt. A negative association between the degree of thoracic kyphosis and the abdominal length index was found ($r = -0.245$, $p < 0.05$).

ROWENA M. TOPPENBERG

Rowena Toppenberg, B.Phty(Hons), is a specialist tutor in the Department of Physiotherapy, University of Queensland. Her interests lie in the assessment of musculoskeletal disorders and she has been involved in a number of research studies in this field.

MARGARET I. BULLOCK

Margaret Bullock, Ph.D., B.Sc.App., is Professor of Physiotherapy and Head of the Department of Physiotherapy at the University of Queensland. She has had a long term interest in the collection of anthropometric data in normals and in their use for maintenance of postural well being.

Alterations in the normal relationships between the alignment of the spine, the position of the pelvis and the length of the muscles attaching to the spine and pelvis have been implicated as contributory factors to the development of low back pain (Janda 1978, 1980; Cailliet 1981, McKenzie 1981). In particular, imbalances between the predominantly postural and phasic muscle groups are thought to cause overstress of already vulnerable spinal levels and to perpetuate uncoordinated and abnormal movement patterns in the lumbo-sacral region (Janda 1978).

No data appears to exist which presents a quantitative profile of normal postures of the thoracic, lumbar and pelvic regions, normal muscle lengths in the lumbo-pelvic region and the relationships between these major features in the pain-free population. Accordingly, a study was mounted in the Department of Physiotherapy, University of Queensland to address these issues.

Because of the rapid growth changes occurring during adolescence, and the number of postural problems which become apparent during this period, the need for an understanding of the relationships between postural features in this age group is particularly important. For this reason, the study concentrated on adolescent females as a subject group.

The Study

To determine the interrelationships of muscle lengths and spinal curves in the sagittal plane, two series of measurements were undertaken. The first involved the recording of the angle of pelvic inclination and the inclinations of the spine at L5-S1, and T12-L1, and T1 – T2 with the vertical. From the latter three measurements, the magnitude of lumbar lordosis and of thoracic kyphosis could be calculated. The second entailed the measurement of the lengths of lumbar erector spinae, abdominal, gluteal, iliopsoas, rectus femoris and hamstring muscles. Using these sets of data, relevant analyses could provide pertinent information to enhance basic understanding of posture and muscle balance in the normal.

Subjects

A total of 103 adolescent females participated in this study. Subjects were selected at random from students attending one Secondary Girls' School and were included if they were healthy and aged between 12½ and 16 years. Students were excluded if they had suffered from any musculo-skeletal disorder of the spine or lower limbs, any neuromuscular disorder, any general systemic disease, or any chronic respiratory disease which had caused structural changes to the chest and thorax. Those who had participated regularly in activities involving rigorous training or stretching programmes which would influence muscle length were also excluded.

No limitations were placed on subject height or weight. The stature of the group ranged between 142 and 175cm (mean = 161cm) and weight between 32 and 75 kg (mean = 52 kg).

Equipment

In this study, an inclinometer was used for measuring angles of inclination of the thoracic, lumbar and pelvic regions, anthropometric calipers being used to identify pelvic reference points. A Myrin goniometer was used to measure muscle length indices.

A light, perspex inclinometer was constructed for the study. Modelled on the design described by Loebl (1967), it consisted of a protractor mounted on a base, to which were attached two supports, two centimetres apart, enabling them to span comfortably one intervertebral space (see Figure 1).

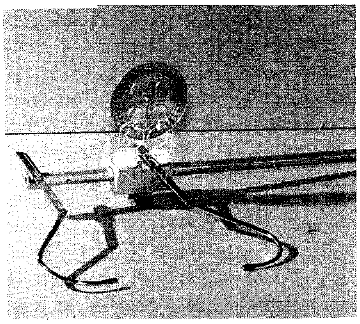

Figure 1: The inclinometer used for measurement of spinal inclinations and mounted on calipers for the measurement of pelvic inclination.

When the inclinometer was positioned along the contour of the spine, a vertically hanging needle attached to its mid point subtended an angle with the slope of the inclinometer, so indicating the angle of spinal inclination.

The adjustable calipers of a portable anthropometer were used in conjunction with the inclinometer to measure pelvic inclination. The inclinometer was mounted on the calipers so as to read 0° when they were horizontal and to provide the angle of pelvic inclination in the sagittal plane when the caliper arms were positioned at the level of the posterior superior iliac spine (PSIS) and the pubic symphysis respectively, using anatomical reference points described by Fick (1911) in Brunnstrom (1981).

A 'Myrin' goniometer, in which a gravity reference marker hanging from its central point indicates angles with the vertical, was used in the measurement of indices of muscle length.

The reliability of the inclinometer and the Myrin goniometer was tested against an M.C. clinometer (used in Metrology, and of known accuracy to 1 minute) in the measurement of 14 and 10 different inclined surfaces respectively. In each case, dependant t tests revealed that there was no significant difference between angles recorded by the two experimental instruments and the M.C. clinometer. Calculation of the 95% confidence intervals indicated that the inclinometer and Myrin goniometer were accurate to within ± ¼° and ½° respectively.

Measurement Procedure

For all measurements, subjects were suitably undressed and, prior to the recording of either series, appropriate body points were identified and marked.

Spinal curves

Measurement of spinal inclinations followed a standardized procedure. Initially, with the subject in prone lying, reference points were marked at the left and right posterior superior iliac spines (PSIS) and at the intersection of the line joining them over the sacral surface and the vertical line of the spine. Also marked were the interspaces of L5-S1, T12-L1 and T1-T2. All measurements of spinal inclinations were taken with the subject in erect standing, with feet together, hands by the sides, head erect and eyes focussed directly ahead.

For the sagittal curves of the spine, the inclinometer was placed along the slope of the vertebrae at each of the levels of the three marked interspaces, so that the zero reading of the inclinometer matched the marked point. The vertically hanging needle of the inclinometer indicated the angles of inclination of these three levels. From these values, the angles of lordosis and kyphosis were determined, adapting a method proposed by Cobb (1960) for the calcualtion of the magnitude of a scoliotic curve. Figure 2 illustrates the geometry appropriate to this calculation.

A more straightforward reading was possible for the angle of pelvic inclination. Using the calipers to mark the PSIS and the most prominent point of the symphysis pubis, the angle of antero-posterior pelvic inclination could be read directly from the inclinometer mounted on the calipers.

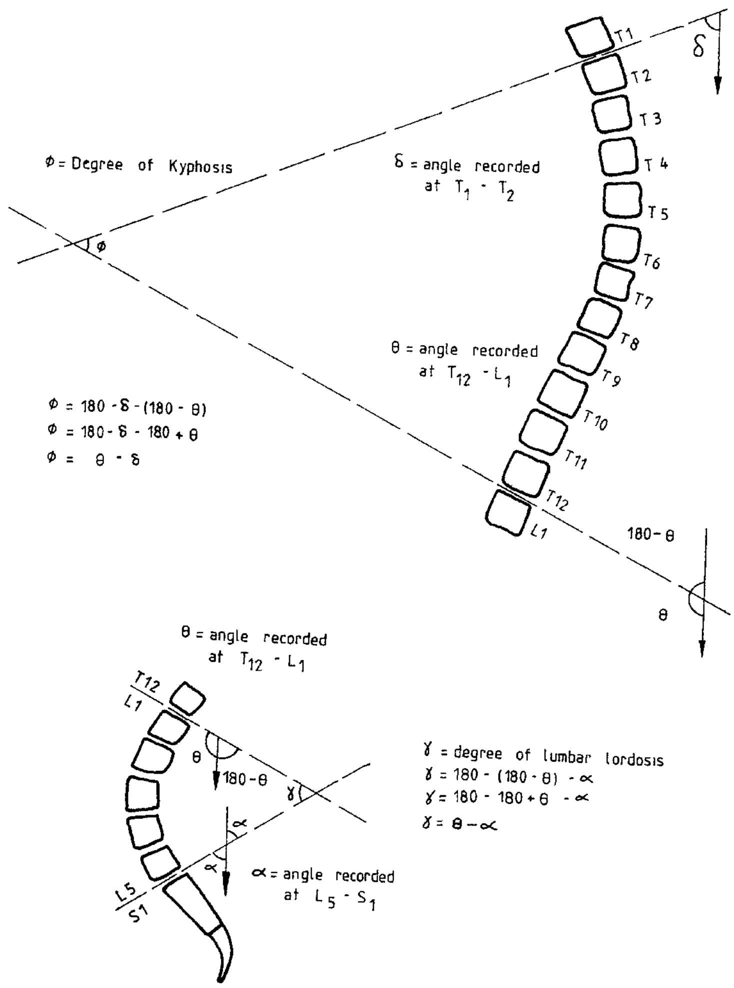

Figure 2: Calculation of thoracic kyphosis and lumbar lordosis using the measured angles of inclination at T12, T12-L1 and L5-S1.

Muscle lengths

Muscle length as an absolute value is not a dimension of relevance to studies such as this. Of more importance is the measure of 'functional' muscle length, that is, the degree to which muscle length allows a certain movement (on which it has influence) to be carried out. Accordingly, appropriate methods of assessing muscle lengths were developed for each of the six muscles examined, so that in each case the figure recorded provided an 'index' of muscle length, in terms of angles of movement. Such a method was independent of body segment lengths and therefore allowed for the variability in size in the normal population.

Lumbar erector spinae length

Lengthening of the lumbar erector spinae occurs when the lumbar spine is maximally flexed and, in the absence of any other limiting factor (such as joint stiffness or abdominal bulk) these muscles limit the extent of lumbar spinal flexion on forward bending (Taylor and Twomey, 1980). Modifying a clincial test described by Janda (1980), the degree of lumbar spinal curvature in forward bending (*ie* lumbar kyphosis) was used as an index of lumbar erector spinae length.

From the erect standing position, the subject bent forward as though to touch the toes, curling the spine fully. If tight hamstrings limited the movement, the subject was allowed to flex the knees to ensure full spinal flexion. In this position, the inclinometer was placed on the interspaces of L5-S1 and T12-L1 and angles of inclination recorded. These two values allowed calculation of lumbar kyphosis angle by subtracting the measured angle at T12-L1 from that at L5-S1. This was then recorded as the index of lumbar erector spinae length.

Abdominal length

The abdominal muscles, particularly rectus abdominus, are lengthened when the spine is fully extended and the distance between the pubic symphysis and the sternum and ribs anteriorly is greatest. Accordingly, the maximum lumbar lordosis was taken as an index of abdominal muscle length. It was measured in the following way:

With the subject in prone lying, the T8-9 interspace was marked. Then one researcher stabilized the pubic insertion of the abdominals by holding the pelvis firmly onto the plinth. The subject then pushed up on her hands, arching her back into full extension until a stretching sensation in the abdominal muscles was perceived. The inclinometer was placed at the L5-S1 and T8-9 levels and readings taken. The T8-9 interspace was chosen as it was considered representative of the corresponding anterior level of the insertion of rectus abdominus (Pick and Howden 1977). Maximum lumbar lordosis was calculated using the geometrical approach outlined earlier.

Gluteal length

The gluteus maximus, located posteriorly to the hip, functions as the most powerful hip extensor (Karlsson and Jonsson 1965, Wheatly and Jahnke 1951). Alternatively, working with reversed origin and insertion, the gluteal group of muscles can effect backward rotation of the pelvis. As an index of the length of these posterior hip muscles, the range of hip flexion from the horizontal, with the pelvis in a fixed and standardized position was measured. Both left and right legs were tested as follows:

With the subject supine, the bony landmarks of greater trochanter and lateral epicondyle of the femur and the head and lateral malleolus of the fibula were identified. Ribbon was taped between each pair of points on the femur and fibula to indicate the lines of the underlying bones and to facilitate measurement over the curved contours of subcutaneous fat and muscle bulk. The subject was then positioned with the legs over the edge of the plinth, as described by Janda (1980). While the tested leg was flexed at hip and knee, the lumbar spine was palpated to ensure its flattening onto the plinth (that is, elimination of the lumbar lordosis). Hip flexion beyond this point was avoided as it resulted in the buttock lifting from the plinth and subsequent lumbar flexion.

In the testing position, the marker ribbons were adjusted to account for skin movement over bony landmarks. Then the Myrin goniometer was placed at the distal end of the femur so that its 0-180 degree axis coincided with the ribbon marking the line of femur. This provided a measure of the thigh angle with the horizontal—the index of gluteal length.

Iliopsoas length

Iliopsoas length was estimated by measuring the angle of the extended thigh with the horizontal, while the opposite hip was flexed and pelvis stabilized as emphasized by Janda (1980) and described for the gluteals. To minimize position changes during the study, measurement of iliopsoas length followed the measure of gluteal length of the opposite side. With the thigh extended, the Myrin goniometer was placed at the distal end of the femur, ensuring that its 0-180° axis lay along the line of the marker ribbon. The hip was then passively extended further until resistance was encountered, at which point a reading was taken. With the thigh in a horizontal position, the goniometer read 90°. The difference between the measured thigh angle and 90° therefore indicated the angle of the subject's thigh with the horizontal. This calculation gave the index of iliopsoas length.

Rectus femoris length

As rectus femoris is a two-joint muscle, an index of its length must take into account the position of both the hip and the knee. For the purpose of this study, rectus femoris length was expressed as the maximum degree of knee flexion possible when the thigh was stabilized in the horizontal position and the hip extended in the standardized lying position (see Figure 3).

The subject lay with the leg over the edge of the plinth and the opposite hip and knee flexed (as for the iliopsoas length test). The thigh on the measured side was stabilized manually in a horizontal position by one examiner and the opposite hip was stabilized in flexion by a second examiner. The subjects's knee was then flexed until resistance was encountered and a stretch in the muscle belly was perceived. The Myrin goniometer was positioned on the distal end of the fibula so that its 0-180° axis lay along the marker ribbon delineating the line of the fibula. The angle with the vertical recorded in this position was added to 90° to give the magnitude of knee flexion from the horizontal—that is, the index of rectus femoris length.

Hamstring length

The method of measuring hamstring length was that described by Janda (1980) and commonly used clinically, involving a measure of hip flexion with the knee in extension and pelvis stabilized. With the subject in lying, the Myrin goniometer was strapped onto the fibula proximal to the lateral malleolus with its 0-180° axis along the marker ribbon. A reading was taken in the starting position before the leg was raised passively to the point where the knee began to flex or the examiner palpating the ipsilateral anterior superior iliac spine perceived backward movement of the pelvis. A second goniometer reading was then noted. The difference between the two readings gave the angle of hip flexion under the specified circumstances and provided the index of hamstring length.

Reliability and Repeatability Tests

The accuracy of measurements and the validity of their analysis depended upon the reliability of the examiner as a measurer and upon whether the position assumed by the subject for measurement was consistent with her normal movement and was truly representative of her usual range of motion under these circumstances. To test these factors, a series of trials was carried out prior to the full scale measurement of subjects.

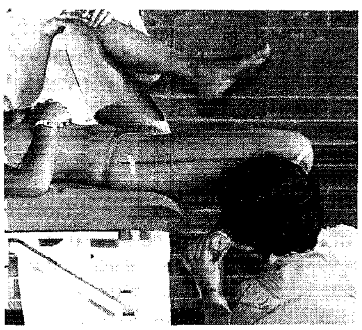

Figure 3: Measurement of the index of rectus femoris length.

To determine operator reliability in accurately palpating spinal levels, 15 trials were conducted in which the markings made by the operator at PSIS, L5-S1, T12-L1, T8-T9 and T1-T2 levels were checked by an experienced manipulative therapist. The percentage agreement by the two operators was calculated for each level. It was found that there was 100% agreement for PSIS, L5-S1 and T1-T2 levels and 93% for T12-L1 and T8-T9 levels. In the two cases of disparity, the operator palpated one level too low. On the basis of these results, the operator was considered to be adequate for the study.

The repeatability of the measurement of spinal curves pelvic inclination and muscle lengths was also tested to determine the consistency of the subject's position and the operator's measuring method. The thoracic and lumbar spinal curves and pelvic inclination of 30 subjects were each measured three times and an analysis of variance performed on each set of three readings. The results indicated that there was no significant difference among the three trials for any measurement. The average correlation coefficients for each measure were all very high, being 0.96. 0.97 and 0.94 respectively.

Trials were also conducted to establish the repeatability of muscle length measurements. Three repetition measurements for the lumbar erector spinae and abdominals were taken on 26 subjects and for the remaining muscles on 13 subjects, using both left and right legs. Following the analysis of variance for each muscle length index, no significant difference among the three trials was found for any index. The average correlation coefficients for the measures of the muscle lengths were all high and ranged between 0.96 and 0.99. Because of this repeatability, it was considered valid to measure thoracic kyphosis, lumbar lordosis, pelvic inclination and each muscle length once only for the major study.

Results

The data collected from measurement of 103 subjects were collated so that relevant analyses could be undertaken. Normal values for spinal curves, pelvic inclination and muscle lengths were calculated and these are reported elsewhere (Toppenberg 1984). To determine the relationships between spinal curves, pelvic inclination and muscle lengths, multiple regression analysis was employed. This method of analysis was chosen as it allows the examination of the relationships between one variable and a combination of other variables simultaneously. In addition to its descriptive use (that is, describing the magnitude of the relationships between variables) multiple regression can be used for prediction (Thorndike 1978).

The results of the analyses for kyphosis, lordosis and pelvic tilt with the measured muscle lengths are presented in Table 1. As this Table reveals, a number of significant correlations emerged. For example, abdominal length was negatively correlated with thoracic kyphosis ($r = -0.245$, $p < 0.05$) and positively correlated with lumbar lordosis ($r = 0.209$, $p < 0.05$), while hamstring muscle length was significantly negatively correlated with lumbar lordosis ($r = -0.213$, $p < 0.05$). In addition, erector spinae length was negatively correlated with lordosis ($r = -0.24$, $p < 0.05$) suggesting that shorter erector spinae muscles are associated with greater degrees of lumbar lordosis.

Overall, considered together, the muscle lengths were found not to be good predictors of thoracic kyphosis. They contributed only nine percent of the variance of kyphosis. In contrast, multiple regression analysis showed that muscle length was highly related to lumbar lordosis, explaining 21.5 percent of the variance of lordosis. The muscle lengths found to be the best predictors of lordosis were the erector spinae, the abdominals and the hamstrings. No muscle length was revealed as being significantly related to the degree of pelvic inclination and indeed the muscle lengths proved to be very poor predictors of pelvic tilt.

It is important to realize that when so many correlations as have been reported in this study are calculated, there is a very high possibility that one will be significant by chance. However, of the four significant correlations found, it is not possible to assess which one, if any, is not a true reflection of a relationship between the variables. In addition it must be recognized that correlation does not imply causation. There can be correlation without causation and vice versa (Hopkins and Glass

Table 1:
Multiple regression analyses: kyphosis, lordosis and pelvic tilt with muscle lengths

Muscle Lengths (Predictors)	*Spinal Curves and Pelvic Tilt (Criterion)*		
	Thoracic Kyphosis	*Lumbar Lordosis*	*Pelvic Tilt*
Erector spinae	0.016	−0.240*	−0.027
Abdominals	−0.245*	0.209*	0.109
Iliopsoas	−0.051	−0.196	−0.014
Gluteal	−0.106	−0.110	−0.041
Rectus Femoris	0.027	−0.078	0.131
Hamstrings	−0.193	−0.213*	−0.026
R SQUARE	0.091	0.215	0.052

*significant, $p < 0.05$

1978). Of basic importance is the fact that the correlation does summarize the direction and magnitude of the relationships between variables and that it may also give clues to causation which can be pursued in future studies.

Discussion

This study of interrelationships between spinal curves, pelvic inclination and muscle lengths has revealed some interesting points of relevance to clinicians.

Consideration of anatomy and muscle actions suggests that in terms of kyphosis, the muscles of the upper trunk and upper limbs would have more influence on the thoracic curve than those of the lower trunk and lower limbs. Nevertheless, in this study which dealt principally with the lumbar region and the pelvis, it seemed wise also to include measurement of the thoracic spinal curve. This was particularly so as the literature concerning Scheuermann's disease has suggested an association between tight hamstrings and the increased kyphosis which occurs in this disease (Lambrinudi 1934, Salter 1970, Apley 1977, Fisk 1981). Fisk (1981) reported hamstring extensibility of only 30 degrees in all subjects examined who were suffering from Scheuermann's disease. However, while this association may exist in certain pathological conditions, this study showed that in the normal adolescent female population, there is no significant relationship between hamstring length and the magnitude of the curve in the thoracic region. In normals, hamstring length was not found to be an important predictor of thoracic kyphosis.

The most significant finding in relation to the thoracic curve was that abdominal length was significantly negatively correlated with it. That is, the greater degrees of thoracic curvature appeared to be associated with the shorter abdominal lengths. Of the muscle lengths measured, the abdominals were the only group which could be regarded as a significant predictor of thoracic kyphosis. It is possible that shortened abdominal length may be indicative of conditions involving abnormal degrees of kyphosis, bearing in mind that such a situation could be negated by the influence of other spinal abnormalities, such as lordosis.

With reference to the lumbar spinal curve, this study revealed that together, the muscle lengths measured were significant predictors of lumbar lordosis and explained 21.5% of its variance. Those muscles which separately were particularly good predictors of the magnitude of the lumbar curve were the erector spinae, the abdominals and the hamstrings. Each of these was significantly correlated with lumbar lordosis. For example, lumbar erector spinae length was negatively correlated with lordosis indicating that the greater the curvature of the lumbar spine, the shorter the erector spinae in that region. This finding tends to support the relationships between hyperlordosis and tight lumbo-dorsal fascia suggested by Janda (1980) and Cailliet (1981). As hyperlordosis has been noted to be commonly associated with back pain and is thought to be capable of causing back pain (Adams and Hutton 1983, Cailliet 1981, Janda 1980, Micheli 1979, Stanitski 1982), it is probable that tight erector spinae also occur in back pain. Indeed, tight erector spinae alone are reported to be a cause of back pain due to their influence on the lumbopelvic rhythm during flexion (Cailliet 1981).

The demonstrated association between tight erector spinae and lumbar lordosis and the possible relationship with back pain suggests that examination of both erector spinae length and the degree of lordosis may be valuable in screening patients for potential back problems. Early identification of a possible predisposition to back pain could allow the introduction of an early preventive programme of muscle stretching. However, the correlation between erector spinae length and lumbar curvature found in this study in no way confirms the existence of a causative relationship between muscle length, lordosis and back pain. Further research would be necessary to establish this.

The study demonstrated that increasing abdominal length was associated with an increase in the lumbar curve. Such a finding corresponds to the relationship between hyperlordosis and the protruding abdomen due to weak abdominal muscles as proposed by Kendall and Kendall (1949), Janda (1980) and Cailliet (1981). These authors claimed that this posture is associated with back pain.

The findings of this study imply that shortening of the abdominal muscles could lead to a decrease in the lumbar lordosis and could thereby eliminate excessive pain-provoking stress on the posterior elements of the spine (Cailliet 1981, Adams and Hutton 1980, 1983; Miller, Haderspeck and Schultz 1983). However, this hypothesis is based on the existence of a causal relationship between abdominal length and lumbar lordosis which has not been confirmed simply by the relationship found in this study. More extensive investigations would be necessry to explore these points and their possible association with back pain.

A surprising feature of the analysis was the significant negative correlation between hamstring length and lumbar lordosis, in which the shorter hamstrings were associated with a greater degree of spinal curvature. However the hamstrings are reported to cause backward pelvic tilting and therefore a flattening of the lumbar lordosis when they shorten in contraction (Crouch 1972). The findings of this study raise questions as to whether this is so, or alternatively whether the traditionally held view of the relationship between pelvic tilt and lumbar lordosis is correct.

The relationship between hamstring length and the lumbar curve established by this study implies a probable indirect involvement of tight hamstrings in the pathogenesis of back pain.

Although a clinical trial would resolve the question, it is possible that timely stretching of hamstrings could help to prevent hyperlordosis and its subsequent back pain.

Paradoxically, muscle length was found to have no significant association with pelvic inclination. This was despite the fact that all of the muscles measured attach to the pelvis and, by their contraction, are capable of changing the position of the pelvis in the sagittal plane. The muscle lengths measured accounted for only 5.2 percent of the variance of pelvic inclination. These results suggest that other factors (such as the structure of the sacrum or the lumbo-sacral angle) may account for the position of the pelvis in the sagittal plane. This study did not include measurement of the lumbo-sacral angle but investigation of its magnitude and its relationship to pelvic inclination appears warranted.

Conclusions

This study has revealed some interesting interrelationships between muscle lengths, spinal curves and pelvic inclination. The negative relationship between abdominal length and thoracic curvature should alert the physiotherapist to assess the abdominals in cases of kyphosis. The significant relationships found to exist between lumbar curvature and lengths of abdominals and lumbar erector spinae confirm observations reported by clinicians and suggest the likelihood of possible associations with back pain. This highlights the need for physiotherapists to routinely evaluate both the degree of lumbar spinal curvature and the relevant muscle lengths when assessing patients with back pain. Further such observations could be of value as part of the postural screening of normals, in the development of appropriate prevention programmes.

The results of this study revealed no significant relationship between muscle lengths and pelvic inclination. Additional study of the lumbosacral angle and its relationship with pelvic inclination could throw further light on the mechanics of this region, particularly with regard to posturally induced back pain.

The adolescent female is particularly susceptible to the development of postural defects, since this not only is a period of rapid growth, but also ushers in the time of sexual maturity and its associated physical changes. It is especially important in this group therefore, that physiotherapists be alert to the need for thorough and regular scrutiny of any factors which could point to the development of later postural problems.

This study has provided information basic to the understanding of normal interrelationships in posture, which can act as a guide to clinicians when assessing postural abnormalities. It has also highlighted the importance of undertaking further studies in the field and in particular of mounting clinical trials aimed at identifying suitable predictors of low back pain.

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