AN *IN VIVO* STUDY OF THE AXIAL ROTATION OF THE HUMAN THORACOLUMBAR SPINE [a b c]

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In order to make quantitative measurements of axial rotation (rotation in the transverse plane) of the thoracolumbar spine in this study of living subjects, Steinmann pins were inserted in thoracolumbar spinous processes of seven young male subjects, and direct measurements of the angular displacement of the pins were made. A review of the literature has failed to disclose a similar study. Axial rotation has been measured in the isolated spine (8), but in living subjects it has only been studied by direct observation or by roentgenographic methods which are of limited value for obtaining accurate measurement of this rotation. For example, these studies have resulted in disagreement about the occurrence of axial rotation in the lumbar part of the spine.

In the past, measurement of motion between adjacent vertebrae in the sagittal plane (flexion and extension) (1, 2, 4, 17, 18, 20, 21) and in the coronal plane (lateral bending) (3, 4, 6, 9, 10, 12, 19), has been carried out both in the spines of living subjects and in isolated spines. Although these studies present a comprehensive description of motion in the sagittal plane, a controversy exists concerning one of the mechanisms by which motion in the coronal plane occurs. Certain investigators (3, 6, 9, 19) studying cadaver spines, models of the spine, and roentgenograms concluded that axial rotation of the vertebral bodies must occur if motion in the coronal plane is to take place. Others (12, 18), on the basis of roentgenograms of the spines of living subjects and studies of the spines of stillborn infants, stated that motion in the coronal plane can and does occur without

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axial vertebral rotation. This study is, in part, an attempt to clarify these areas of disagreement.

While the present study made possible detailed measurements of axial rotation in living subjects, one major limitation of it is apparent, in that motion at only a few vertebral levels was measured in any one subject. It would be desirable to use several subjects with placement of a pin at each vertebral level. This was not feasible because of the discomfort and inconvenience experienced by the subjects. However, it is believed that the pooled data from the subjects should yield a representative pattern of axial rotation, although the data would, of course, not be valid for the total pattern of rotation of any one subject. The study should provide a basis for a first approximation of the pattern of axial rotation of the human thoracolumbar spine.

METHOD

The amount of axial rotation in the erect spine was measured in subjects while the trunk was rotated from side to side as far as possible during standing and sitting. It was also measured during normal level walking. In addition to the studies of these basic activities, preliminary investigations were made of the axial rotation that occurs during lateral bending. Thirty-four pin studies were made on the seventeen vertebral levels of the thoracolumbar spine in seven subjects. Additional information on shoulder and pelvic-girdle rotation was also obtained.

Subjects

Seven male subjects between twenty and twenty-six years old were studied in eighteen sessions (see Table 1 for a description of the subjects). These subjects were normal, average young men; no athletes, acrobats, or other persons who might be expected to have an unusual range of spine motion were included. No structurally fixed scoliotic curves were found in the subjects. Curves of 5 degrees and less were measured in four subjects; these were regarded as physiological (7) and it was felt that their extent would not affect axial rotation. Two subjects had roentgenographic evidence of spina bifida occulta of the first sacral vertebral segment. The subjects underwent no training or exercise which might have changed the character of their usual performance.

Pin Insertion

Anteroposterior and lateral roentgenograms were evaluated initially for each subject. After a ten-minute providone-iodine (Betadine) surgical scrub of the skin over the posterior thoracolumbar region and 1 percent lidocaine local anesthesia over the selected spinous processes, small vertical incisions of one-eighth to three-sixteenths of an inch were made so that the skin would not adhere to the pins. Specially tip-threaded Steinmann pins, three thirty-

TABLE 1.—*Data on Subjects*

Subject	Age (years)	Height (inches)	Weight (pounds)	Spine length (inches)	Left limb length (inches)	Right limb length (inches)	No. of sessions	Total no. of pins	Roentgenographic evaluation of spine
J. D.	22	73	160	36½	39	39	4	8	No abnormality of thoracolumbar spine
S. G.	23	69½	178	36¾	36	36	2	4	Physiological scoliosis at thoracolumbar junction
D. P.	22	73	180	37	39	38	1	2	Physiological scoliosis in middle of thoracic spine; spina bifida occulta of S–1
P. Q.	24	67¼	120	35	36	36	1	2	Physiological scoliosis at thoracolumbar and lumbosacral junctions
D. T.	26	69¼	157	36	37	37	4	8	Physiological scoliosis in middle of thoracic spine; spina bifida occulta of S–1
J. W	23	68½	146	35¼	35⅜	35⅜	4	8	Bifid spinous process of T–11
N. W.	20	72	160	37	38	38⅛	2	4	No abnormality of thoracolumbar spine

seconds of an inch in diameter and ranging in length from three to four and one-quarter inches, were inserted into the spinous processes by means of a hand drill. Lateral roentgenograms were then made, with the x-ray film perpendicular to the floor and the subject in the erect position, in order to confirm the level of the pin. The angle between the pin and the floor was measured directly from the horizontal margin of the film.

Method of Recording

Displacement of the pin (axial rotation) was transmitted through a flexible extension arm to a relative-rotation transducer (Fig. 1) (a variable differential transformer calibrated with use of a horizontally oriented Palmgren rotatory table, eight inches in diameter, which was accurate to ±0.1 degree [e]). This arm was attached to one of the pins and suspended in such a way that only horizontal rotation about the longitudinal axis of the erect spine was transmitted. The angular motion of the rotation was changed into linear motion by the transducer and was transmitted to a Honeywell 1508 Visicorder. The tracing on Kodak Linagraph paper from the Visicorder represented the total amount of axial rotation which had occurred below the level of the pin (Fig. 2).

Sacral Belt

In each of these studies, a sacral belt made of elastic webbing with a posterior metal and leather base was applied to the subject's pelvis. Into this base, an aluminum rod, one-half inch in diameter, was inserted so that when the belt was tight the rod was held perpendicular to the coronal plane at approximately the level of the second sacral vertebra. The sacral belt was applied to the skin in such a way that no motion occurred between it and the underlying skin. However, it was observed that some slight motion of the belt, skin, and subcutaneous tissues occurred in relation to the deeper musculoskeletal tissues, particularly during walking—such motion was reduced when the pelvic fixation device, to be described, was used. (To determine the reliability of the belt as an indicator of pelvic rotation, Steinmann pins of the design described above were inserted into the posterior superior iliac spines of subjects D. T. and D. P. The amount of pelvic rotation recorded from these pins during standing and walking was compared with that recorded from the sacral belt in the same subjects during the same maneuvers.)

For calculation of thoracolumbar rotation during standing and sitting, the amount of pelvic rotation recorded from the sacral-belt rod was subtracted from the amount recorded from the thoracolumbar pins. Thus, rotation reported for these maneuvers represented thoracolumbar rotation only.

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[e] Results for the rotations during standing, sitting, and lateral bending are rounded to the nearest degree because, although the method was accurate to one tenth of a degree, the fact that individual effort was involved in these maneuvers makes it more realistic to assume accuracy to the nearest whole number.

Rotation During Standing

For measurement of rotation during standing, subjects were placed in a pelvic fixation device (Fig. 1) in an erect position. In this apparatus, the feet were secured with steel heel cups and leather straps, and the upper extremities were held down by means of spring-supported cloth loops held in the subject's hands and fixed to the platform of the device. Contoured an-

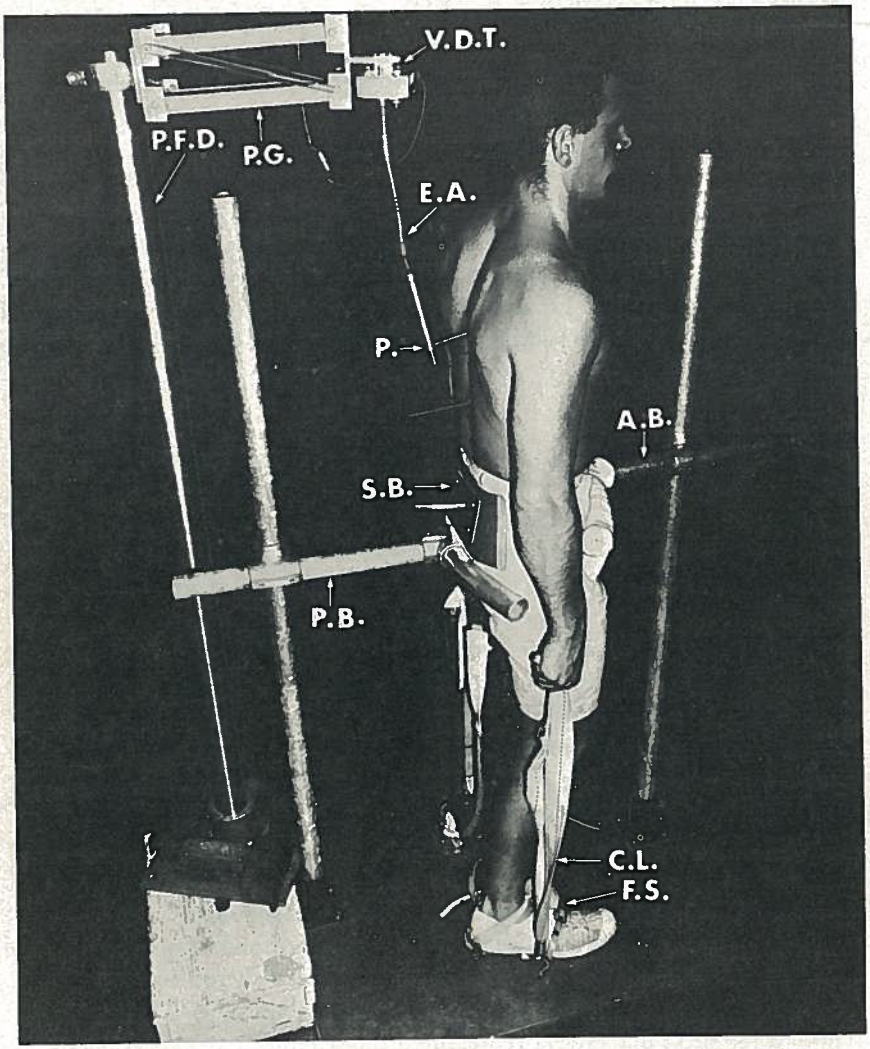


FIGURE 1.—Instrumentation for recording axial rotation of the thoracolumbar spine. Standing position: *A.B.*, anterior bar; *C.L.*, spring-supported cloth loops; *E.A.*, bellows-coiled spring extension arm; *F.S.*, foot strap; *P.*, Steinmann pin; *P.B.*, posterior bar; *P.F.D.*, parallelogram fixation device; *P.G.*, parallelogram; *S.B.*, sacral belt; *V.D.T.*, variable differential transformer.

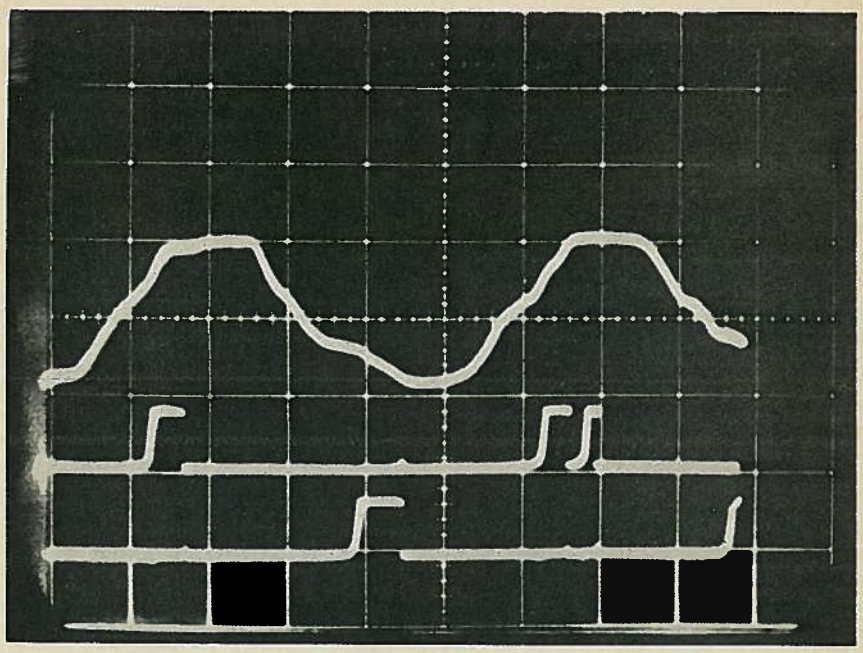


FIGURE 2.—Recording (upper tracing) of axial rotation at level of second thoracic vertebra during walking (subject J. D.). Space between horizontal bars represents 5 degrees. Middle tracing shows times of left heel-strike; lower tracing shows time of right heel-strike.

terior and posterior bars were fixed firmly against the pelvis, while a bicycle seat was raised tightly against the perineum. Rotation was recorded as the subjects rotated several (three to ten) times to the right and left (about the longitudinal axis of the erect spine) with maximum effort.

Rotation During Sitting

For measurement of axial rotation during sitting, the subjects were placed in a seated position(thigh-trunk angle, 90 degrees) and secured by the pelvic fixation device (Fig. 3). Rotation was performed as in the standing position.

Rotation During Walking

Axial rotation of the thoracolumbar spine during locomotion was studied as the subjects walked on a level treadmill at 4.38 kilometers per hour (previously determined to be an average comfortable or natural walking speed [11]). Shoulder-girdle rotation was measured in three subjects by means of a shoulder bar. Subjects were centered on the treadmill and instructed to walk as naturally as possible, allowing the arms to swing freely (Fig. 4). The effect of carrying ten-pound weights in each hand during walking was evaluated in two subjects.

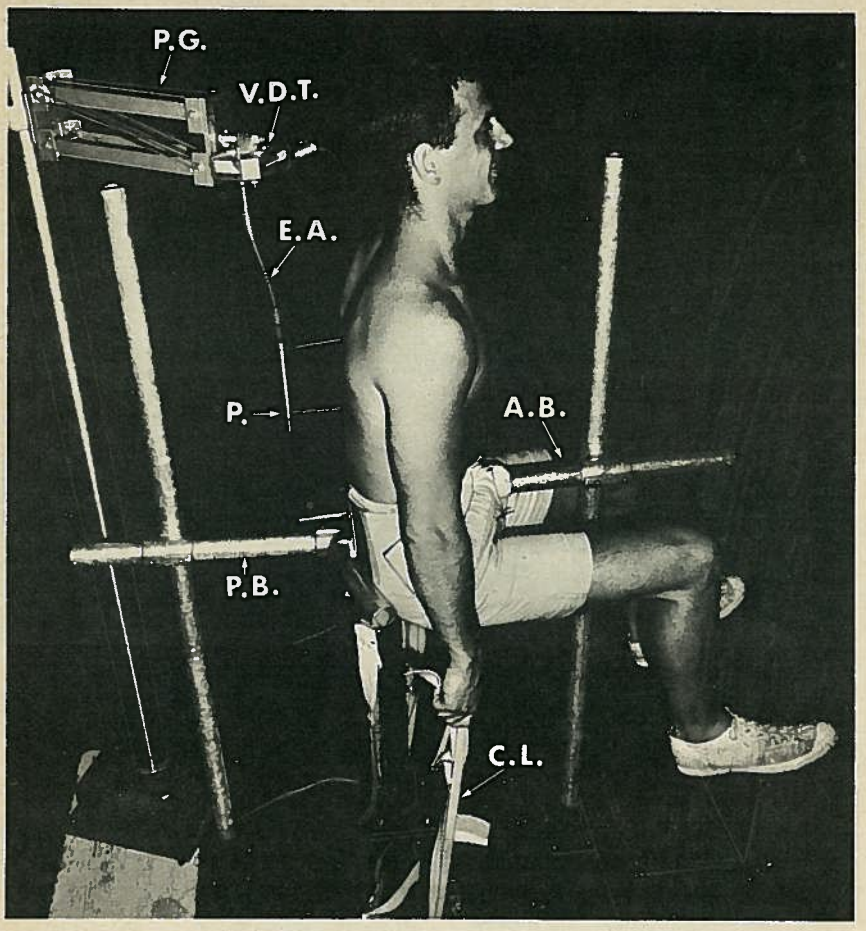


FIGURE 3.—Sitting position: *A.B.*, anterior bar; *C.L.*, spring-supported cloth loop; *E.A.*, extension arm; *P.*, Steinmann pin; *P.B.*, posterior bar; *P.G.*, parallelogram; *V.D.T.*, variable differential transformer.

For the study during walking, the feet were equipped with devices which produced electrical signals at heel-strike. The recording of axial rotation was correlated with the electrical signals produced by each heel-strike as monitored on a Type 564 storage oscilloscope with a memory recorder. The records thus produced were photographed with a Polaroid Land camera on Type 47 and Type 3000 Polaroid film. In order to compensate for the vertical displacement of the trunk during walking, the relative-rotation transducer was mounted on a hinged parallelogram fixation device suspended first by a counter-weight and later by elastic bands (Fig. 4).

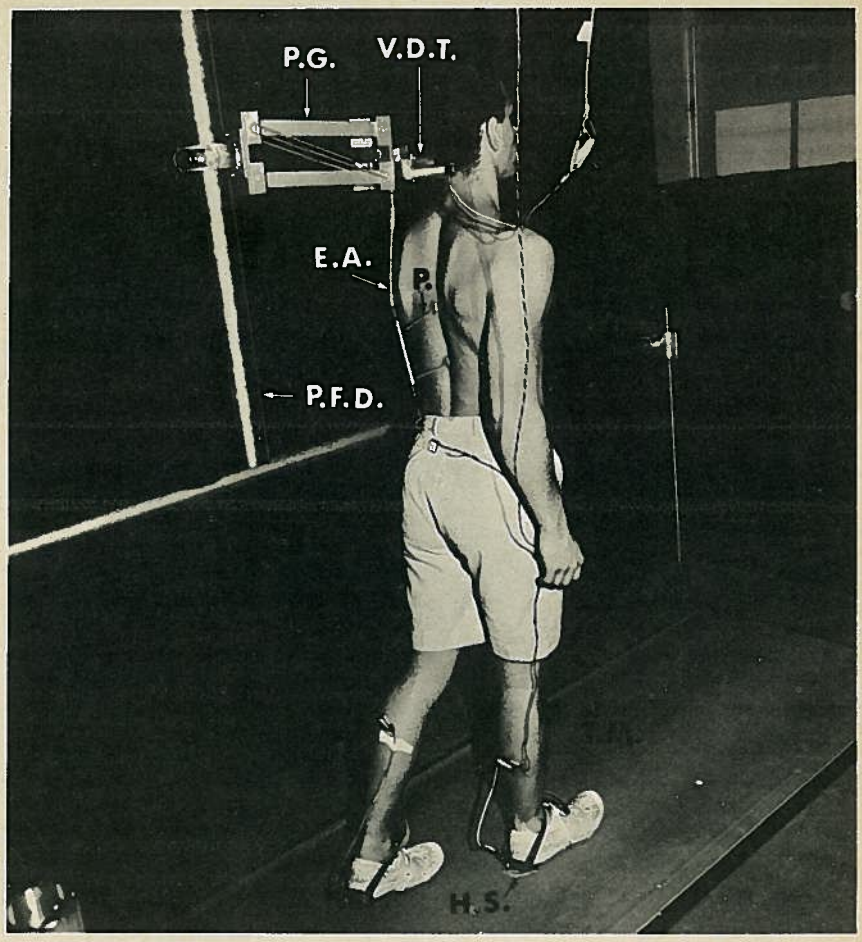


FIGURE 4.—Instrumentation for recording axial rotation of the thoracolumbar spine during walking on treadmill: *E.A.*, extension arm; *H.S.*, heel-strike device; *P.*, Steinmann pin; *P.F.D.*, parallelogram fixation device; *P.G.*, parallelogram; *T.M.*, treadmill; *V.D.T.*, variable differential transformer.

Rotation During Lateral Bending

Studies of axial rotation as it occurs during motion of the spine in the coronal plane were carried out in three subjects by means of a miniaturized axial-rotation recorder which was suspended between a Steinmann pin inserted into a thoracolumbar spinous process and a pin mounted in the sacral belt. This recorder provided measurement of relative axial rotation between these pins when the spine was bent laterally in the coronal plane (and also when it was flexed forward). A sliding (compensating) mechanism placed between the Steinmann pins allowed for small movements of the pins that

might occur in the sagittal and coronal planes; this arrangement assured measurement of only axial rotatory motion (Fig. 5).[f]

The subject was placed standing in the pelvic fixation device. A bar in the coronal plane was placed in front of him which he slid along as he bent to the side; this bar limited motion to the coronal plane. Axial rotation was recorded in the manner described previously, as the subject bent 45 to 50 degrees to one side and then the other. Because of the greater torques imposed by the apparatus in this study, the pins occasionally loosened after repeated lateral bending. In these cases the experiment was terminated.

Method of Calculation

For the standing and sitting maneuvers, each numerical value for the amount of rotation at a given vertebral level in a given subject represents the maximum rotation achieved in the several attempts. For walking, each numerical value is an average of ten measurements. Correction was necessary for the angulation of the Steinmann pins from the horizontal plane and for their lengths; all numerical values are corrected for these two factors. Curves shown in Figures 6 through 8 are intended to give a profile of the amount and pattern of axial rotation, which can be expected to vary in different subjects.

RESULTS AND DISCUSSION

Axial Rotation of the Thoracolumbar Spine: Standing Position

Results of maximum axial rotation of all seven subjects studied during standing are given in Table 2 and graphically depicted in Figure 6. The values represent total axial rotation from one side to the other in relation to the fixed pelvis and are cumulative. The following observations were made: An average of 74 degrees of rotation occurred between the first and twelfth thoracic vertebrae. In one subject, 11 degrees of rotation occurred at the thoracolumbar joint and 9 degrees between the first and fifth lumbar vertebrae. The average cumulative amount of rotation measured at the first thoracic vertebra was 102 degrees.

With regard to adequacy of fixation of the pelvis, it should be pointed out that both pelvic pin and sacral belt were studied in only two subjects, D. P. and D. T., during standing and level walking. There is close agreement between the values obtained for rotation in D. T. during standing and D. P. during level walking; there is significant disagreement between the values obtained for D. P. during standing and for D. T. during level walking (see Tables 2 and 4). It is believed that the displacement of 20 degrees, as recorded with use of the pelvic pin in D. P. during standing, reflects an inadequacy of fixation of the pelvis in the pelvic fixation device when pelvic rotation was being measured with use of the pin. On the other

[f] The recorder gave information accurate to within ±5 percent for lateral bending within a range of 45 to 50 degrees from the standing position. Figures for this part of the study have been rounded off to the nearest degree.

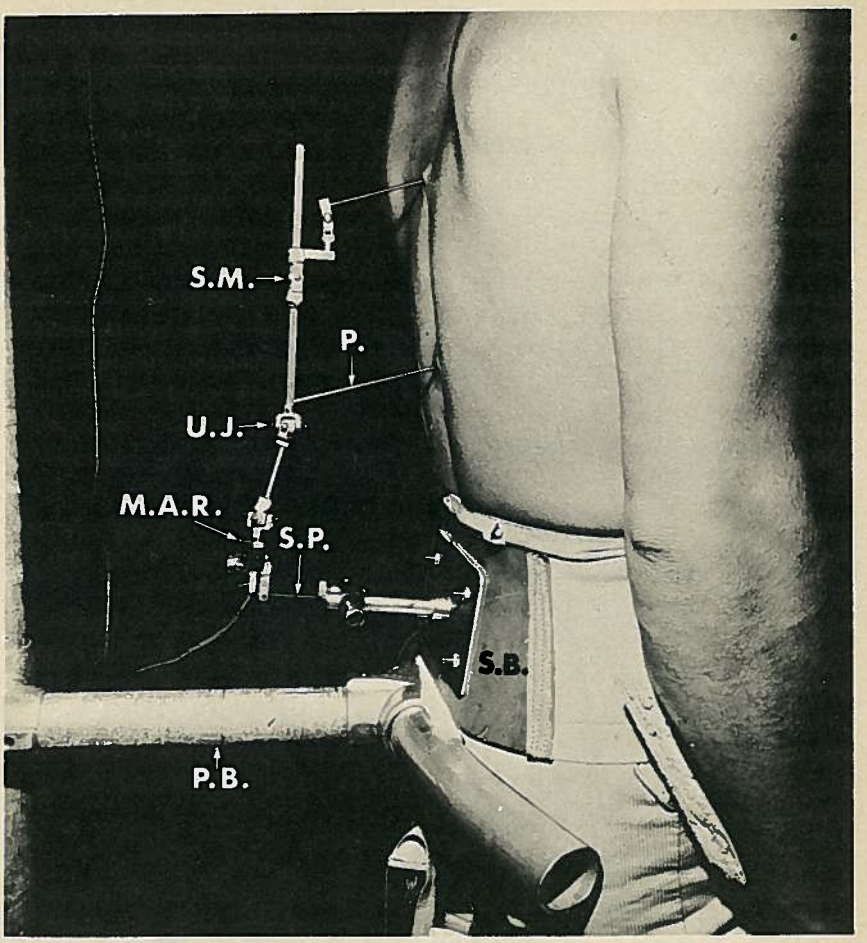
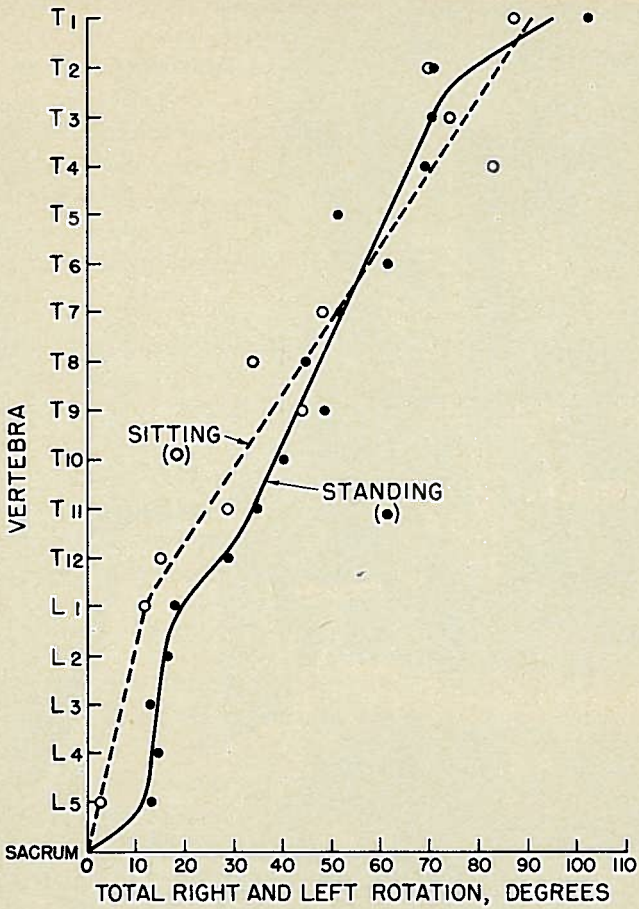


FIGURE 5.—Instrumentation for recording axial rotation of the thoracolumbar spine during lateral bending: *M.A.R.*, miniaturized axial rotation recorder; *P.*, Steinmann pin; *P.B.*, posterior bar; *S.B.*, sacral belt; *S.M.*, sliding mechanism; *S.P.*, sacral pin; U.J., universal joint.

hand, the recorded discrepancy in rotation at this level in D. T. during walking may be due to some shifting of the sacral belt (with the skin). We were not entirely satisfied with the accuracy of the measurements of motion at the lumbosacral level, and a further study in this laboratory is planned; the method will be elaborated, and intraosseous pins alone will be used.

If it is assumed that there may have been inadequate fixation of the pelvis or minor slippage of the sacral belt, any resulting error would be reflected in the magnitudes of the values obtained for total rotations in the spine. The differences between any two levels, however, would not be affected (except for the lumbosacral joint), nor would there be any alteration in the observed



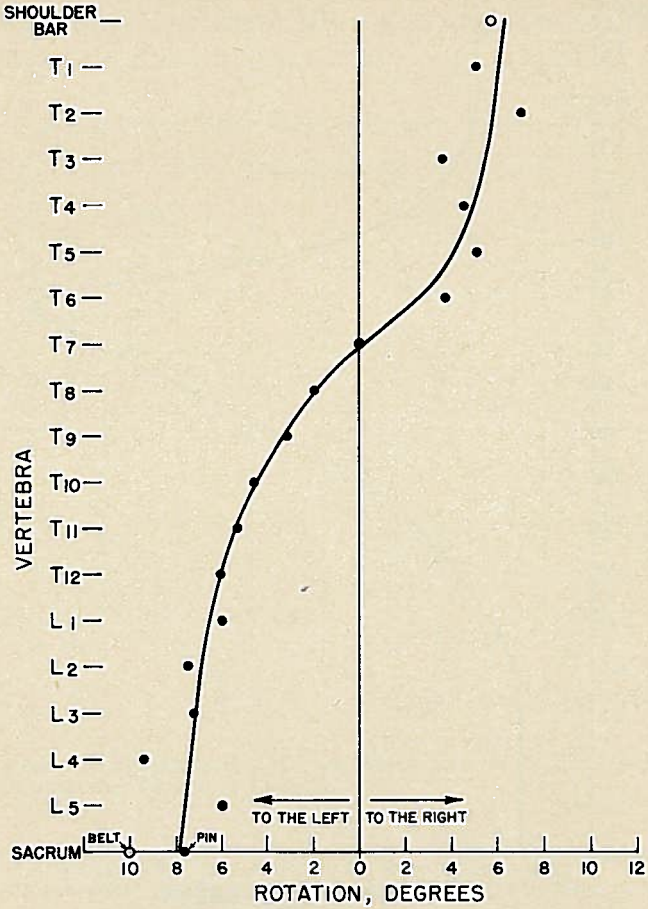
Maximum Total Axial Rotation of the Thoracolumbar Spine in the Standing and Sitting Positions (Pelvis Immobilized)

FIGURE 6

level of the displacement node (described below) during walking. It therefore seems likely that the factor of possible inadequate fixation of the pelvis does not detract from the validity of the observed overall pattern of motion and the observed occurrence of axial rotation during lateral bending.

Anatomical Analysis

The pattern of rotation observed in this part of the study may be analyzed through an examination of the anatomical basis of thoracolumbar axial rotation. The center of axial rotation of any thoracic or lumbar vertebra can be determined theoretically as the intersection of two lines passing through the centers of the surfaces of the articular facets and drawn perpendicular to

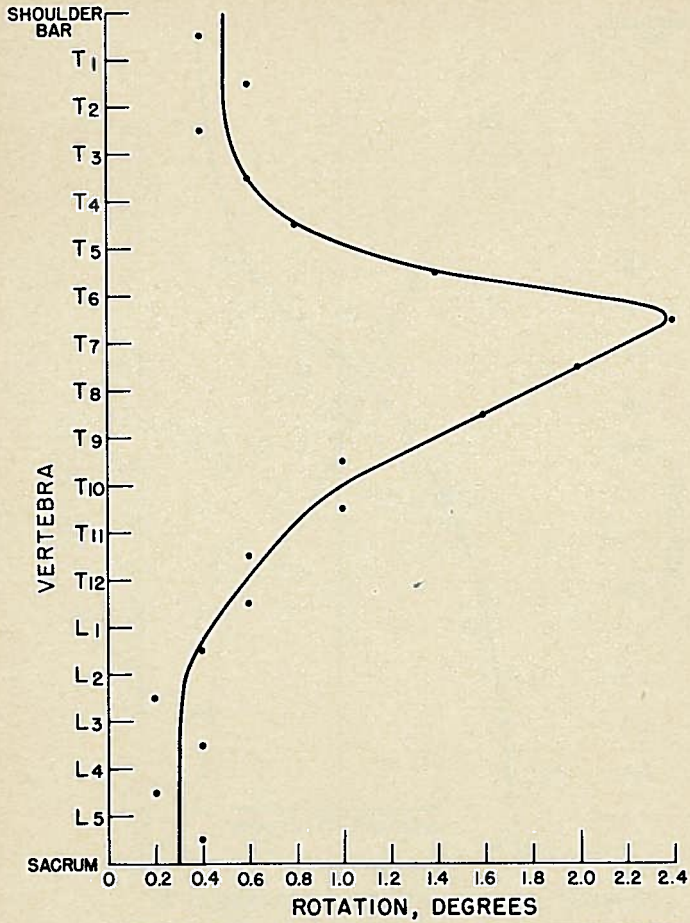


Axial Rotation of the Thoracolumbar Spine during Locomotion
(Left Heel Strike to Right Heel Strike, 4.38 km/hr)

FIGURE 7

the plane of these articular surfaces (13) (Fig. 9–A and 9–B). Depending on the orientation of the planes of these articular surfaces in the thoracic vertebrae, the center of rotation may fall within or be anterior to the intervertebral disk—in which case considerable axial rotation could occur (Fig. 9–C). In the lumbar spine, the center is posterior to the disk; in this case, axial rotation should be restricted (Fig. 9–D).

By this method, it can be shown that the center of axial rotation of a typical thoracic vertebra with inferior articular processes oriented midway between a sagittal and a coronal plane lies within or anterior to the intervertebral disk, whereas the center of rotation of a typical lumbar vertebra, with articular processes aligned in a more sagittal plane, lies posterior to the disk.



Axial Rotation Between Adjacent Vertebrae during Locomotion (4.38 km/hr) (Derived from Curve of Fig. 7)

FIGURE 8

This anatomical arrangement probably explains the observed minimum axial rotation in the lumbar vertebrae and the greater rotation in the thoracic vertebrae. This arrangement suggests that the lumbar intervertebral disks are subject to a significantly greater shearing force (Fig. 10) than the thoracic disks and that the thoracic disks are subject to a greater twisting force. This, in turn, may have a bearing on the rate of degeneration at various disk levels.

The pattern of rotation observed at the thoracolumbar joint is also interesting in this respect. Struthers, in an early anatomical investigation, noted that in man the transition between the lumbar and thoracic types of articulating facets usually occurs at the twelfth thoracic level (16). This means

TABLE 2.—*Maximum Axial Rotation of the Thoracolumbar Spine: Standing Position*

Level	J.D.	S.G.	D.P.	P.Q.	D.T.	J.W.	N.W.	Rotation for each level	No. of subjects
T–1		105				99		102	2
T–2	70							70	1
T–3		70						70	1
T–4			63				75	69	2
T–5	51							51	1
T–6		50				69		62	2
T–7	47	45				50	59	50	4
T–8	42					43	55	45	3
T–9					49			49	1
T–10					41			41	1
T–11	35							35	1
T–12				18	[a]34	29	30	28	4
L–1						18		18	1
L–2					18	15		16	2
L–3					13			13	1
L–4				15				15	1
L–5	17				13	9		13	3
Pelvic pin			(20)		(1)				
No. of pins	6	4	2	2	[a]8	8	4	Total: 34	

[a] Subject had two separate studies of T–12. The amount of rotation reported here is the maximum recorded for him at this level.

that the inferior articular processes of the twelfth thoracic vetebra are oriented in a sagittal plane, whereas the superior articulating processes are oriented midway between the sagittal and the coronal planes. Theoretically, therefore, it would be expected that the twelfth thoracic vertebra would rotate in the same manner as the lumbar vertebrae, and minimum rotation was, in fact, observed at this level in one subject (P.Q.). However, the large amount of rotation measured in another subject (J. W.) at the twelfth thoracic vertebra underlines the observation that variation from this anatomical pattern exists.

Axial Rotation of the Thoracolumbar Spine: Sitting Position

Eighteen studies were made of twelve vertebral levels of the thoracolumbar spine in five seated subjects. Results are given in Table 3. An interesting comparison may be made between the patterns of rotation observed for this position and those observed for the standing position.

Lumbar Spine

Axial rotation at the lumbosacral joint was measured in two subjects and found to be significantly less than that observed at this level in the same sub-

TABLE 3.—*Maximum Axial Rotation of the Thoracolumbar Spine: Sitting Position*

Level	J. D.	S. G.	D. T.	J. W.	N. W.	Rotation for each level	No. of subjects
T-1				87		87	1
T-2	70					70	1
T-3		74				74	1
T-4					83	83	1
T-5							
T-6		45		68		57	2
T-7	48	49		50	45	48	4
T-8	33			35		34	2
T-9			44			44	1
T-10							
T-11	29					29	1
T-12				15		15	1
L-1				11		11	1
L-2							
L-3							
L-4							
L-5	3			3		3	2
Pelvic pin			(3)				
No. of pins	5	3	2	7	2	Total: 19	

jects during standing. (The measurements during both standing and sitting were made with use of the sacral belt.) The average amount of rotation for the two subjects was 3 degrees for the seated maneuver as compared with 13 degrees during standing.

A similar decrease in rotation during sitting as compared with standing may occur at the other lumbar levels; at the first lumbar vertebra studied in one subject (J. W.), 11 degrees of rotation occurred during sitting as compared with 18 degrees at the same level during standing. In the same subject, 4 degrees of rotation occurred at the thoracolumbar joint during sitting as compared with 11 degrees during standing.

Thoracic Spine

Rotation of the thoracic spine was studied in all five subjects. Observations made on the lower part of the thoracic spine suggest that in this region rotation is somewhat less during sitting than during standing. In one subject (J. W.), upper thoracic rotation (at the first thoracic vertebra) was also less during sitting than standing. For the other subjects, however, the amount of upper thoracic rotation observed during sitting was quite similar to that observed during standing and in some case was greater. There was no signifi-

TABLE 4.—*Axial Rotation of the Thoracolumbar Spine: Level Walking*

	J.D.	S.G.	D.P	P.Q.	D.T.	J.W.	N.W.	Rotation for each level
Shoulder bar	5. 4	6. 1				6. 1		5. 8
T–1		5. 0				5. 1		5. 1
T–2	7. 0							7. 0
T–3		3. 7						3. 7
T–4							4. 3	4. 3
T–5	5. 0							5. 0
T–6	6. 4	[a]0						3. 2
T–7		[a]0				[a]0	[a]0	[a]0
T–8						2. 0		2. 0
T–9					3. 2			3. 2
T–10					4. 5			4. 5
T–11	5. 4							5. 4
T–12				9. 2	3. 4	[b]5. 6		6. 1
L–1	5. 9					6. 0		6. 0
L–2					6. 8	8. 1		7. 5
L–3					7. 1			7. 1
L–4				9. 4				9. 4
L–5	5. 1				5. 7	7. 0		5. 9
Pelvic pin			7. 4		7. 5			7. 5
No. of pins	6	4	1	2	7	8	2	Total: 30

[a] A minimum amount of rotation occurred at this level; the direction was sometimes that of pelvic rotation and sometimes that of shoulder-girdle rotation.

[b] Subject J. W. had two separate studies of T–12 during walking. The amount of rotation reported is an average for him at this level for the two studies.

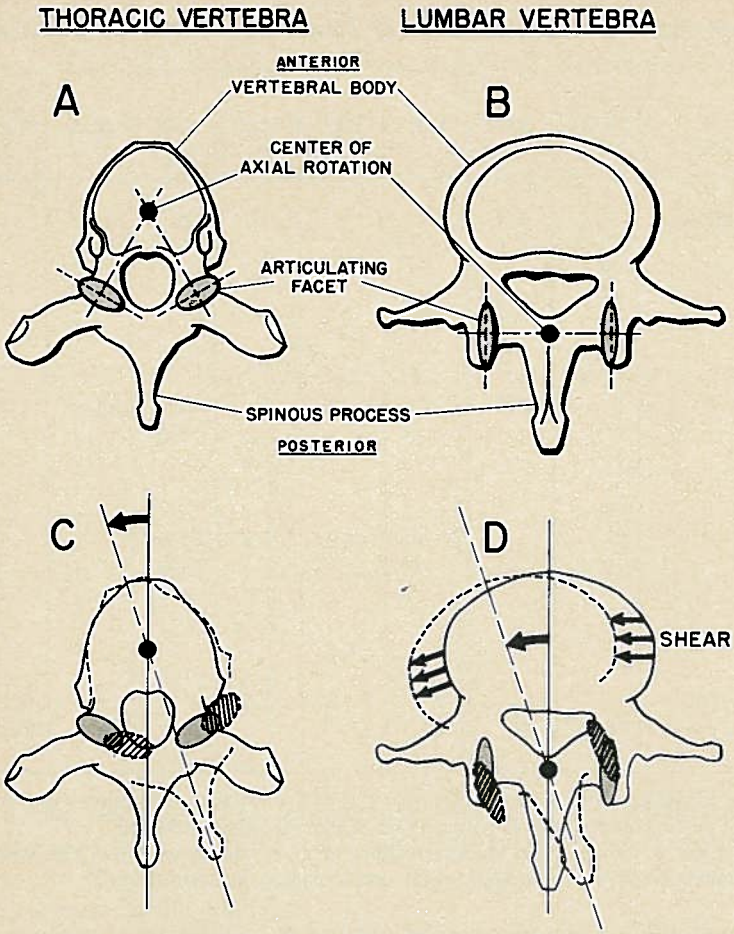
cant variation in the pattern and amount of axial rotation in the thoracic spine during sitting and standing.

Figure 6 shows the cumulative, side-to-side maximum axial rotation of the thoracolumbar spine of the subjects studied in the seated and standing positions. When the curve for the seated position is compared with that for standing, it may be observed that during sitting there is a marked difference in the amount of rotation at the lumbosacral joint, less difference in the lumbar spine, and essentially none in the thoracic spine.

Axial Rotation of the Thoracolumbar Spine: Level Walking

Individual and group average figures for axial rotation of the thoracolumbar spine during walking are given in Table 4 and Figures 7 and 8. The results are those obtained during one half (heel-strike to toe-off) of a complete walking cycle.

Figure 7 is a diagram of the pattern of axial rotation of the thoracolumbar spine during level walking; the curve is based on average measurements

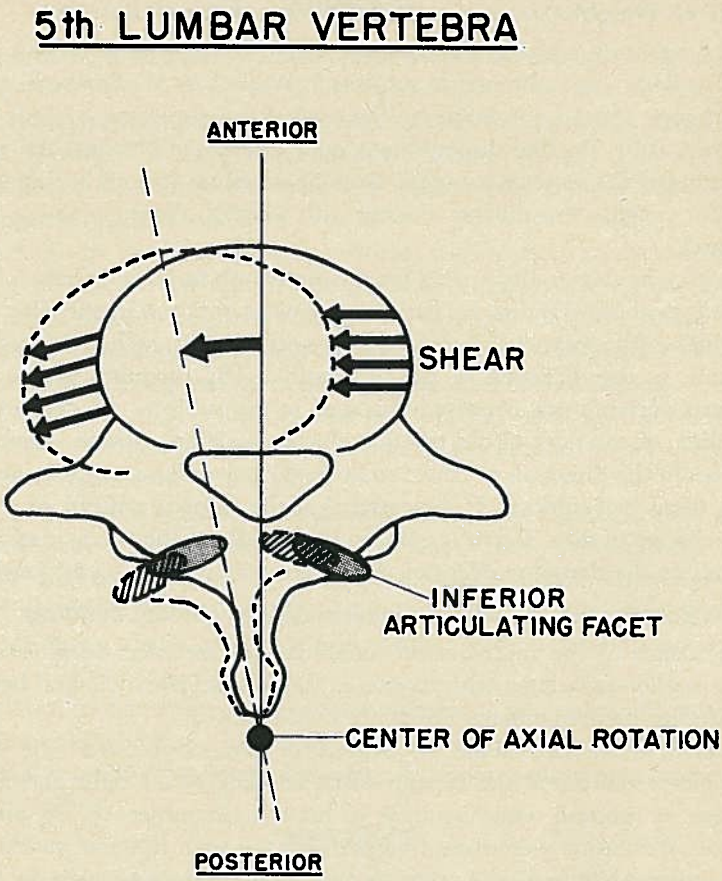


Mechanism of Axial Rotation in a Thoracic and a Lumbar Vertebra

FIGURE 9

for all subjects. Certain observations can be made from analysis of this figure. First, it appears that the pelvis and lumbar spine rotate as a functional unit. Second, in the lower thoracic spine, rotation diminishes gradually up to the seventh thoracic vertebra. Third, it appears that the seventh thoracic vertebra represents the area of transition (displacement node) from vertebral rotation in the direction of the pelvis to rotation in the opposite direction—that of the shoulder girdle. Fourth, the amount of rotation in the upper thoracic spine increases gradually from the seventh to the first thoracic vertebra.

Figure 8 is a graph of the amounts of axial rotation measured between adjacent vertebrae during normal level walking (derived from Fig. 7).



Mechanism of Axial Rotation at Lumbosacral Joint

FIGURE 10

Minimum (0.2 to 0.6 degree) rotation occurs at the lumbosacral joint, between adjacent lumbar vertebrae, and between adjacent lower thoracic vertebrae. Relative rotation is also minimum (0.3 to 0.8 degree) in the upper part of the thoracic spine (the first to the fifth thoracic vertebrae) and between the first thoracic vertebra and the shoulder girdle. In contrast, 1.4 to 2.4 degrees of rotation occur between adjacent midthoracic vertebrae (the sixth to the eighth). On the basis of this analysis, it appears that the greatest axial rotation and, hence, the greatest stress, occur in the midthoracic vertebrae during walking.

Effect of Weight-Carrying on the Pattern of Axial Rotation

The effect of carrying a ten-pound weight in each hand during normal level walking was evaluated in subjects J. W. and N. W. For both subjects, this change appeared to influence the level of the displacement node during walking. In J. W., the displacement node alternated between the sixth to seventh and the seventh to eighth thoracic vertebral regions during walking without weights, but during walking with weights, the node always shifted upward.

N. W. was also studied with a pin at the seventh thoracic vertebra. During walking without weights, he had 0.4 degree of rotation in the direction of shoulder-girdle rotation. During walking with weights, he had 3.3 degrees of rotation in the direction of pelvic rotation. The direction at the fourth thoracic vertebra was likewise influenced in this subject: 4.3 degrees in the direction of shoulder-girdle rotation during walking without weights; 5.0 degrees in the direction of pelvic rotation during walking with weights.

In these two subjects, it appeared that the normal pattern of rotation, with change of direction at a point in the middle of the thoracic spine, was altered by the damping effect of the addition of weights on arm swing.

Axial Rotation of the Thoracolumbar Spine: Lateral Bending

By means of the miniaturized axial-rotation recorder described above, axial rotation associated with motion in the coronal plane (lateral bending) was studied in three subjects (N. W., J. D., and S. G.).

Subject S. G. had about 12 degrees of rotation between the seventh thoracic vertebra and the sacrum while bending to his right and about 9 degrees of rotation while bending to his left. In subject J. D., about 13 degrees of rotation were measured between the sixth thoracic vertebra and the sacrum while he bent to the left and about 10 degrees while he bent to the right. At the first lumbar vertebra in this subject, about 15 degrees of rotation occurred with bending to the left and about 14 degrees with bending to the right. Subject N. W. had about 5 degrees at the eighth thoracic vertebra while bending to the left and about 6 degrees while bending to the right. At the twelfth thoracic vertebra, there were about 10 degrees of rotation during bending to the left and about 9 degrees during bending to the right. It is interesting to note that at all levels studied, axial rotation was toward the left when the subject bent to his left and toward the right when he bent to the right except at one level (the twelfth thoracic) in N. W., where rotation was opposite to the direction in which the subject was bending. These observations of axial rotation during lateral bending agree with Lovett's studies (9) on cadaver spines and are evidence in support of the concept that axial rotation is an integral motion of the thoracolumbar spine during lateral bending.

SUMMARY

Measurements of axial rotation of the thoracolumbar spine during conditions of standing, sitting, lateral bending, and level walking were made in living subjects; Steinmann pins were inserted in various thoracolumbar spinous processes of seven male subjects, between twenty and twenty-six years old, and direct measurements were made of the angular displacement of the pins during rotation.

The subjects (standing erect, then sitting, with rotation measured relative to the fixed pelvis) turned from side to side as far as possible. In one subject, 9 degrees of rotation occurred between the first and the fifth lumbar vertebrae during standing and 8 degrees during sitting; additional rotation of approximately 10 degrees was observed at the thoracolumbar joint. An average of approximately 6 degrees was measured at each of the remaining thoracic levels. Some individual variation in the amount of axial rotation was observed in the subjects tested.

In one half of a walking cycle during normal level walking on a treadmill, 5 degrees of rotation occurred at the first thoracic vertebra and, in the opposite direction, 6 degrees at the fifth lumbar vertebra. There appeared to be a transition point (displacement node) in the sixth to eighth thoracic vertebral region above which rotation was in the direction opposite to that below.

In an additional study, axial rotation was found to occur with motion of the spine in the coronal plane, an observation that supports the concept that axial rotation is an integral motion of the thoracolumbar spine during lateral bending.

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